NIST NCSTAR 1-4

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Active Fire Protection Systems

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

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U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

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NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

The National Institute of Standards and Technology investigation of active fire protection systems in World Trade Center (WTC) 1, 2, and 7 included the design, installation, capabilities, and performance on September 11, 2001, of the automatic fire sprinkler, standpipe, standpipe preconnected hoses, fire alarm, and smoke management systems. The purpose and normally expected performance of each active fire protection system in the buildings are described, as well as details about the systems installed in WTC 1, 2, and 7. Using fire protection engineering methods, the capabilities of the installed systems to respond to various fire threats from normal office fires up to and including the extraordinary challenge of the fires ignited by the aircraft impacts on September 11, 2001, were assessed. Information from The Fire Department of the City of New York records was used to document the history of significant fire events in WTC 1, 2, and 7. Findings of the investigation are presented with regard to the fire suppression, fire alarm, and smoke management systems installed on the day the buildings collapsed.

Keywords: Fire alarm systems, fire protection engineering, fire protection systems, hydraulic calculations, smoke detection, smoke management, smoke purge, sprinklers, standpipes, voice communication, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

AFA	AFA Protective Services
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BBFAS	Base Building Fire Alarm System
BCNYC	Building Code of the City of New York
BWS	Bureau of Water Supply
BWSO	Bureau of Water Sewer Operations
DEP	Department of Environmental Protection
EMR	elevator machine room
FCA	floor control assembly (sprinkler system)
FCS	Fire Command Station
FDC	fire department connection
FDNY	The Fire Department of the City of New York
FEMA	Federal Emergency Management Agency
FHC	fire hose cabinet
FHV	fire hose value
HAI	Hughes Associates, Inc.
HVAC	heating, ventilation, and air-conditioning
MER	mechanical equipment room
NBFU	National Board of Fire Underwriters
NCC	network command center (fire alarm system)
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NYC	New York City
OCC	Operations Command Center
O&M	Operations and Maintenance
PANYNJ	Port Authority of New York and New Jersey
PSR	Power Supply Remote
RJA	Rolf Jensen and Associates, Inc.

SSB	Salomon Smith Barney
TTB	Terminal Transmission Box
USC	United States Code
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
μm	micrometer
CO_2	carbon dioxide
ft	foot
ft^2	square foot
gal	gallon
gpm	gallons per minute
h	hour
hp	horsepower
in.	inch
in. H_2O	inches of water column (unit of pressure)
L	liter
m	meter
m^3	cubic meters
mi	mile
min	minute
Pa	Pascal (unit of pressure)
psi	pounds per square inch
s	second
t^2	square ton
V	volt

METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01

PRESSURE or STRESS (FORCE DIVIDED BY AREA)

kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) (kip/in.^{2})	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) (kip/in.^{2})	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) (lbf/in.^{2})	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) (lbf/in.^{2})	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) (lbf/in.^{2})	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) (lbf/in.^{2})	kilopascal (kPa)	6.894 757 E+00

TEMPERATURE

degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15

VELOCITY (includes SPEED)

foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01

VOLUME (includes CAPACITY)

cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch (in.^{3})	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

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

The specific objectives were:

1. Determine why and how WTC 1 and WTC 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 current building and fire codes, standards, and practices that warrant revision.

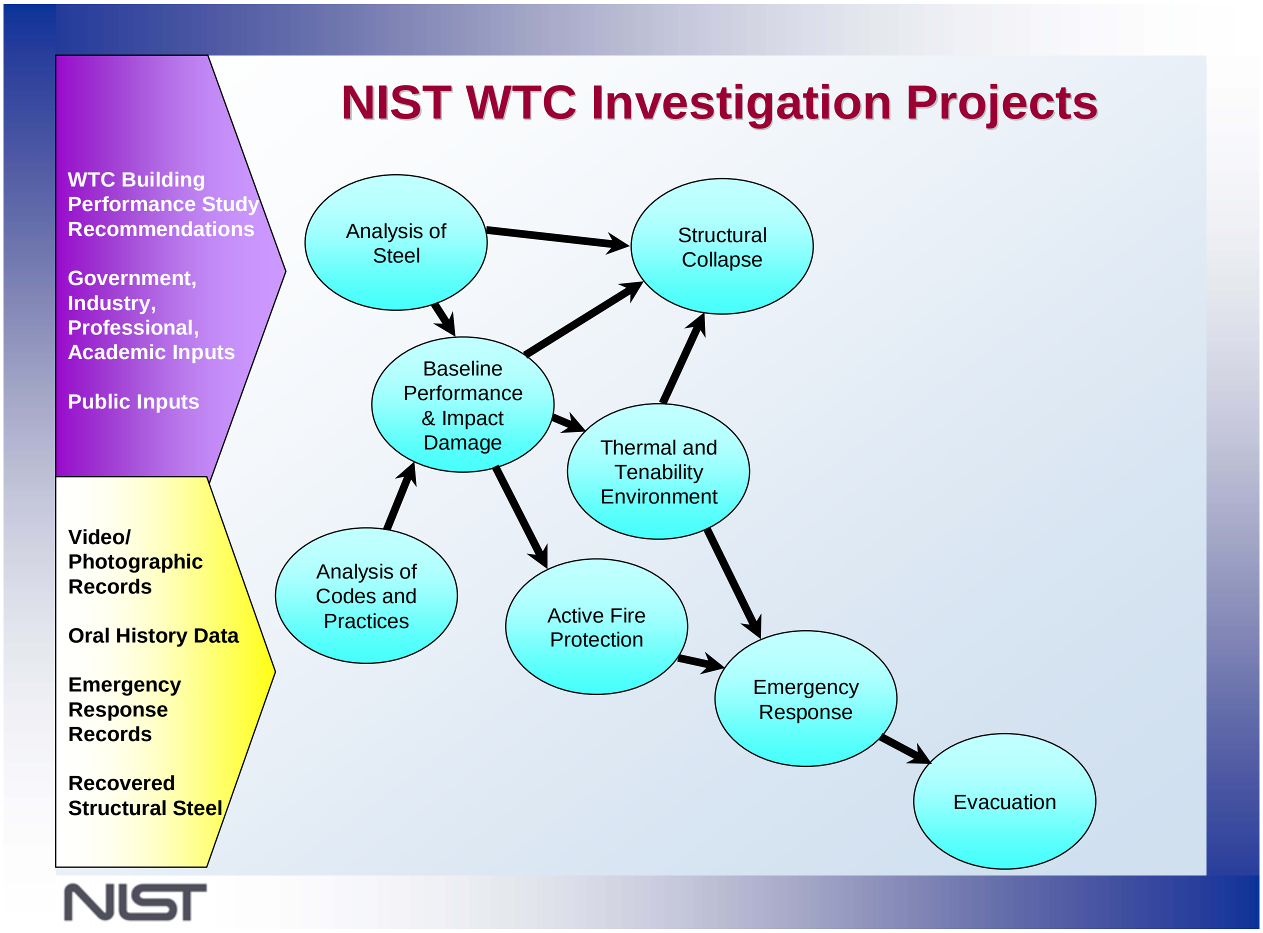
NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze 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 WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze 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; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate 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; Project Leader: Dr. Richard G. Gann	Reconstruct 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; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.



NIST WTC Investigation Projects

WTC Building Performance Study Recommendations

Government, Industry, Professional, Academic Inputs

Public Inputs

Video/ Photographic Records

Oral History Data

Emergency Response Records

Recovered Structural Steel

Analysis of Steel

Structural Collapse

Baseline Performance & Impact Damage

Thermal and Tenability Environment

Analysis of Codes and Practices

Active Fire Protection

Emergency Response

Evacuation

NIST

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

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John Drucker, who previously served as project manager for Siemens Building Technologies - the contractor implementing the upgrades to the fire alarm systems for the World Trade Center (WTC) - deserves special thanks for his assistance in providing background and detailed information on the fire alarm systems within the WTC which would not have been available otherwise. The authors also wish to acknowledge the assistance provided by Steven Hill of the Bureau of Alcohol, Tobacco and Firearms.

As it is important that all readers of this report have a common basis for understanding the results of the investigation, information is provided to orient readers to the basic functioning and intent of active fire protection systems. Chris Jelenewicz, Engineering Programs Manager, Society of Fire Protection Engineers, assisted the authors by providing easily understood introductory and summary materials.

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EXECUTIVE SUMMARY

In the event of a fire in a building, the safety of occupants and first responders is accomplished through the building egress system and a combination of passive and active means. A passive fire protection system is one which is an integral part of the building layout and materials of construction, such as partitions to confine the fire or sprayed fire-resistive material to increase the fire resistance of a load-bearing steel structure. Active fire protection systems are designed to come into play only when a fire is present and require activation through a combination of sensors or mechanical means. The active fire protection systems in World Trade Center (WTC) 1, 2, and 7 consisted of fire sensors and alarms, notification systems, sprinklers, water supplies, and smoke management systems. Active and passive fire protection systems work together to control the spread of the fire and maintain the integrity of the structure; however, the fire department is always relied upon to fully extinguish the fire and rescue occupants who may be immobilized.

The automatic fire sprinkler systems in WTC 1, 2, and 7 were the first line of defense. Water stored in the building from public sources or pumped from fire apparatus was supplied through dedicated piping to the area of the fire. Also present in the buildings were hoses, preconnected to a water supply through standpipes located in the stairwells and other utility shafts. The standpipes provided hose connections at each floor for The Fire Department of the City of New York (FDNY). In addition, standpipe preconnected hoses were installed for trained occupants to manually suppress fires.

The heart of the fire detection system was the automatic fire alarm and emergency notification system. Occupants in the building depended on this system to detect fires and provide information for emergency evacuation. Capabilities were also designed for the ventilation system to operate in a way to purge smoke produced by fires from the building. Smoke purge was intended to be used for post-fire clean-up but could be used during a fire event at the discretion of the FDNY.

This report includes an examination of the design and installation of the active fire protection systems in WTC 1, 2, and 7 and a description of the normal operation of fully functional systems and their potential effect on controlling the fires on September 11, 2001. The applicable building and fire codes and standards, as well as the history of fires in these buildings, are also documented.

E.1 SIGNIFICANT FIRES PRIOR TO SEPTEMBER 11, 2001

Significant fires in WTC 1, 2, and 7 prior to September 11, 2001, were of interest to the investigation, particularly those that activated multiple sprinklers or where hoses were used to suppress the fires. Because the records of fire events in the buildings maintained by The Port Authority of New York and New Jersey (PANYNJ) were destroyed in the fire and collapse of WTC 1, information available for study was limited to that from FDNY fire and investigation reports.

A major fire occurring in WTC 1 in 1975, prior to the installation of sprinklers, and the bombing of the WTC towers in 1993 were the most significant incidents in the history of these buildings. In addition, 47 other fires were identified that were substantial enough to activate a sprinkler or require hoses to suppress the fire. Sixteen fire incidents exercised multiple sprinklers or multiple standpipe connected hoses (with or without the activation of at least one sprinkler). Thirty-one fires involved the use of one standpipe hose or one standpipe hose and discharge of one sprinkler. Only three fires were identified to have occurred in WTC 7 prior to 2001. The FDNY fire reports and fire investigation records obtained by the National Institute of Standards and Technology (NIST) indicate that in areas protected by automatic sprinklers, no fire activated more than three sprinklers.

E.2 SPRINKLERS, STANDPIPES, AND PRECONNECTED HOSE SYSTEMS

The evaluation of the sprinklers, standpipes, and preconnected hose systems was performed by Hughes Associates, Inc., under contract to NIST. The project documented the design, installation, and operation of the fire suppression systems in WTC 1, 2, and 7; evaluated the consistency of the sprinkler and standpipe systems installations with best engineering practices; described the New York City (NYC) water supply system and evaluated the sprinkler system water supply; and estimated sprinkler system performance when challenged with design fire scenarios assumed in standard engineering practice as well as with a fire scenario similar to that which occurred on September 11, 2001.

Major features of the fire suppression systems are documented based on a review of the available information. In addition to describing in detail the sprinkler, standpipe, and preconnected hose systems, special fire suppression systems are briefly discussed. System features documented include riser systems, zone arrangements, water tanks, pumps, fire department connections, control valves, and hose rack arrangements. Additionally, documentation of the sprinkler, standpipe, and preconnected hose system installations was examined for consistency with the applicable installation standards and state-of-the-art engineering practices at the time of system installation.

A description of the NYC water supply, including sizes, locations, and directions of water mains surrounding the WTC complex and distribution system within the buildings is provided to adequately evaluate the primary source of water for the automatic sprinkler and hose systems. Assessment of the adequacy of the sprinkler system water supply was based on a detailed review of the available documentation and estimates of the flow capacity and duration of water supplies. Hydraulic calculations were performed with variations in primary and secondary water supplies, the number of sprinklers flowing, and floor level. The results from the calculations were used to evaluate the expected sprinkler system performance.

Multiple fire scenarios were analyzed in order to more fully understand the potential impact of the suppression systems to provide the flow of water required to control typical office fires within high-rise buildings. The analysis included single fires on different floors in the towers and in WTC 7 with various combinations of sprinklers activated and with primary and secondary water supplies. Additionally, hydraulic calculations based on simultaneous fires on up to a total of nine floors were performed. Estimates of suppression system performance in WTC 1, 2, and 7 on September 11, 2001, were also made.

The following list summarizes the findings of the suppression and water supply study:

- Based upon the documents examined, the fire suppression systems in WTC 1, 2, and 7 appear to have been installed in a manner consistent with accepted engineering practices at the time of their installation, with a few minor exceptions. The installations also appear to comply with current accepted engineering practices, again with a few minor exceptions.

- Sprinkler protection was installed throughout WTC 1, 2, and 7 on September 11, 2001, with the exception of specific rooms and spaces where sprinkler protection was permitted to be omitted by the Building Code of the City of New York (BCNYC).

- Storage tanks, along with direct connections to the NYC water distribution system, supplied water for WTC 1 and WTC 2, and for floors 21 through 47 of WTC 7. Fire suppression systems for floors 1 through 20 in WTC 7 were supplied directly through the NYC water distribution system and an automatic fire pump, with no secondary supply.

- The installation of the supply piping from the storage tanks on the 110th floor in WTC 1 and WTC 2 included a long horizontal length (greater than 100 ft) of 4 in. diameter pipe, which restricted the flow to several floors. The flow capacity was sufficient to supply the suppression systems, but the installation was not consistent with current engineering best practices.

- The suppression systems in WTC 1, 2, and 7 required manual initiation of the electric fire pumps in order to provide supplemental water. An automatic supplemental water supply is required by National Fire Protection Association (NFPA) 14 and represents current best practice. Due to extensive damage to the sprinkler and standpipe systems in WTC 1 and WTC 2 on September 11, 2001, it is doubtful that automatic pumps would have made any difference in performance.

- The supply risers for automatic sprinkler systems in WTC 1, 2, and 7 were configured to provide redundant capabilities. However, the sprinkler floor level controls were installed with one connection to the sprinkler riser. This represented a single point of failure location for the water supply to the sprinklers on that floor.

- The water flow capacities of the sprinkler systems installed in WTC 1, 2, and 7 were designed to provide densities considerably greater than typically provided for high-rise office buildings. Based on hydraulic calculations, it was estimated that the sprinkler systems could have controlled a typical fire at a coverage area up to two to three times the specific design area of 1,500 ft^2. However, a coverage area of 4,500 ft^2 constitutes less than 15 percent of the area of a single floor.

- The standpipe and preconnected hose systems were consistent with the applicable requirements in the Building Code of New York City (BCNYC). They were not consistent with the flow rates and durations specified by NFPA 14.

- The loading berth and fuel oil pump rooms in WTC 7 were protected by dry-pipe sprinkler systems. The first floor room containing the 6,000 gal fuel oil tank was protected by an Inergen clean agent fire suppression system.

- No information was found that indicated that the generator/fuel day-tank enclosures in WTC 7 on floors 5 and 7 were protected by automatic sprinklers or other special hazards protection; however, the generator rooms on the 8th and 9th floors were protected with sprinklers.

- Primary and backup power were provided in all three buildings, but the absence of remote redundancy of the power lines to emergency fire pumps could have affected the operability of the sprinkler and standpipe systems once power was lost.

- Due to the magnitude of the initial fires and the likely aircraft impact-induced damage sustained to the suppression systems infrastructures in WTC 1 and WTC 2, it is not unexpected that the suppression systems present in these buildings failed to control the fires on September 11, 2001.

E.3 FIRE ALARM SYSTEMS

The evaluation of the fire alarm systems, a review of applicable codes and standards, documentation of the normal operation of fully functional fire alarm systems, and their potential performance in WTC 1, 2, and 7 on September 11, 2001, were performed by Rolf Jensen and Associates, Inc., under contract to NIST.

Major features of the fire alarm systems in WTC 1, 2, and 7 are described based on a review of the available documentation. Details on the fire command station, fire alarm system functions, fire alarm system installation criteria, control panel configurations, fire alarm devices, and firefighter telephone system are provided. Additionally, the staff emergency response plan that provided direction for emergency response is outlined. The responsibilities of the fire safety director, deputy fire directors, assistant fire safety coordinator, and floor wardens are described.

For WTC 1 and WTC 2, performance on September 11, 2001, was documented based on brief images of illuminated status lamps on the system’s control panels, which were filmed during the event, and through interviews with people who were in the buildings at the time. The performance of the WTC 7 fire alarm system was assessed on the basis of the printout of the fire alarm system’s remote monitoring system.

The following is a summary of findings based upon the review of the building designs and analysis of the various fire alarm systems:

- Because the design of the WTC 1 and WTC 2 fire alarm system required manual activation of the alarm signal to notify building occupants, the alarm signal was not transmitted until 12 min after impact in WTC 1.

- The fault tolerance performance standards for telephone communication circuits are not as well defined as compared to other types of fire alarm circuits. This limits the survivability characteristics of the telephone communication circuits in comparison to other types of fire alarm circuits.

- Although the fire alarm systems in WTC 1 and WTC 2 used multiple communication path risers, the systems experienced performance degradation, especially in WTC 1 where all fire alarm notification and communication functions appear to have been lost above the floors of impact.

- The fire alarm system installed in WTC 7 sent to the monitoring company only one signal indicating a fire condition in the building on September 11, 2001. This signal did not contain any specific information about the location of the fire within the building.

E.4 SMOKE MANAGEMENT

Hughes Associates, Inc., under contract to NIST, evaluated the design and installation of the smoke management systems in WTC 1, 2, and 7, reviewed applicable codes and standards, and documented the normal operation of the fully functional smoke management systems and their potential effect on smoke conditions in WTC 1 and WTC 2 on September 11, 2001.

The review of building codes and standards determined those that were applicable to WTC 1, 2, and 7. Specifically, the versions of BCNYC that applied and the local laws that were enacted which pertain to smoke management are presented. This review was used as a basis for documenting building designs and evaluating system performance. Descriptions are provided of the basic architecture of each building as it pertains to the establishment of smoke control zones, heating, ventilation and air-conditioning (HVAC) components and layout relevant to smoke management, and sequences of operation of smoke management systems (i.e., activation of fans and positioning of dampers to control airflow during smoke control operations).

Smoke management system performance of WTC 1 and WTC 2 was evaluated based on the understanding of the systems developed during the design reviews. Analysis was performed using industry-accepted software to analyze the interaction between the building and the HVAC systems to determine the extent to which building pressures could be maintained in order to control or prevent the spread of smoke from a zone of fire origin to the rest of the building. The ability of the documented smoke management system to perform under typical design fire scenarios was analyzed along with the ability of the – assumed to be fully functional – system to perform given the damage sustained and the extreme fire/smoke conditions that developed as a result of aircraft impacts on the building.

In order to more fully understand the potential impact of smoke management systems within high-rise buildings, multiple smoke management strategies, design fire scenarios, building configurations and weather conditions were analyzed. In total, a set of 180 simulations were performed, and results were evaluated.

The following are findings from the evaluation of the smoke management systems:

- The smoke management systems in WTC 1 and WTC 2 were not initiated on September 11, 2001.

- Had the smoke purge sequence been initiated in WTC 1 or WTC 2, it is unlikely the system would have functioned as designed, due to damage caused by aircraft impacts.

- WTC 1 and WTC 2 were not required by the 1968 BCNYC, as amended by Local Law 5 and Local Law 86, to have active smoke and heat venting and/or stair pressurization because they contained automatic sprinklers throughout.

- Even if fully operational, none of the potential smoke management systems evaluated would have prevented smoke spread given the damage caused by aircraft impact.

- During the events occurring on September 11, 2001, stair pressurization would have been ineffective in improving conditions for occupants trying to exit the building.

- Installation of combination fire/smoke dampers in HVAC ductwork, which was not required in WTC 1 or WTC 2, may have acted to slow the development of hazardous conditions on the uppermost floors of the building, but would likely not have had a significant effect on the ability of occupants to egress the building due to the impassibility of the exit stairways.

Chapter 1
INTRODUCTION

1.1 BACKGROUND

In the event of a fire in a building, the safety of occupants and first responders and the protection of property is accomplished through a combination of passive and active means. A passive fire protection system is one which is an integral part of the building layout and materials of construction, such as partitions to confine the fire, a stairway to assist rapid evacuation, or sprayed fire-resistive material to increase the fire resistance of a load-bearing steel structure. Active fire protection systems are designed to come into play only when a fire is present and require activation through a combination of sensors or mechanical means. The active fire protection systems in World Trade Center (WTC) buildings 1, 2, and 7 consisted of fire sensors and alarms, notification systems, sprinklers, water supplies, and smoke management systems. Active and passive fire protection systems work together to control the spread of the fire and maintain the integrity of the structure; however, the fire department is always relied upon to fully extinguish the fire and rescue occupants who may be immobilized.

1.1.1 Building and Fire Prevention Codes

The WTC was designed in accordance with the New York City Building and Fire Prevention Codes of 1968 in effect at the time of the building's construction. The objective of the Port Authority of New York and New Jersey (PANYNJ) was to adhere to or exceed local code requirements whenever practical.

During the life of the buildings, in addition to legislated building codes, the PANYNJ relied on nationally recognized fire safety standards published by the American National Standards Institute (ANSI) and the National Fire Protection Association (NFPA), as well as internal protocols established with fire officials in the city. Two noteworthy protocols included the "Protocol for Periodic Joint Port Authority/ Fire Department of New York Inspections of Port Authority New York City Facilities" of 1988 and the "WTC/ FDNY Joint Protocol for Inspectional Activity at the World Trade Center Complex" of 1986. The PANYNJ maintained a positive working relationship with the Fire Department of the City of New York (FDNY) through these protocols that allowed the Fire Department access for inspections and evaluation of life safety and fire protection systems at the complex. The Fire Department was provided with the authority to issue advisory reports resulting from their inspections, which the PANYNJ could consider on a voluntary basis.

This spirit of cooperation also existed with the New York City Department of Buildings and formally acknowledged in a Memorandum of Understanding between the two parties after the explosion at the Towers on November 3, 1993. The most current edition of the New York City Building Code was identified as the design basis for any construction after November 1993.

The applicable building codes document the minimum acceptable level of safety for occupants. The building codes in effect are the primary source for determining what safety features will be installed in the building. The building code includes referenced standards that address how various aspects of the building and systems are to be installed and constructed in order to provide the intended levels of safety. Another regulatory element that comes into play is product safety standards. Building codes and installation standards require the use of products that have been investigated to verify that they perform as intended without causing a safety hazard. Product safety standards and listing agencies provide vehicles for evaluating the performance of products from a safety perspective. Verification and testing of products for public safety ensure that the level of safety established by the building codes for the building design, and implemented per recognized installation standards during the building's construction, will be accomplished through the products' performance.

The active fire protection systems studied in this investigation were the automatic fire sprinklers, preconnected hoses, fire detection and alarms, and smoke purging. The automatic fire sprinkler system was the first line of defense against fires in the WTC buildings. Automatic sprinklers are designed to provide water on and around the area of the fire to control the fire and possibly extinguish it. Water for automatic sprinklers and standpipes stored in the buildings, from public sources, and even pumped from fire apparatus could be supplied through dedicated piping to the area of the fire. Also present in the buildings were hoses preconnected to a water supply through vertical standpipes located in the stairwells and other utility shafts. The standpipes provided hose connections at each floor for The Fire Department of the City of New York (FDNY). In addition, standpipe preconnected hoses were installed for trained occupants to manually suppress fires. The heart of the fire detection system is the automatic fire alarm and emergency notification system. Occupants in the building depended on this system to detect fires and provide information for emergency evacuation. The FDNY used this system to help determine the locations of fires that could not be located visually. Capabilities were also designed for the ventilation system to purge smoke produced by fires from the buildings. Smoke purge was intended to be used for post-fire clean-up but could be used during a fire event at the discretion of the FDNY.

The active fire protection systems installed in WTC 1, 2, and 7 had the potential to reduce the severity of the fires, to provide information for occupants and first responders, and to limit the effects of the fires on the buildings and their occupants. It was the objective of this project to document the major features of the installed systems in WTC 1, 2, and 7, to evaluate their performance on September 11, 2001, and to assess their role in fire control, emergency response, and the fate of occupants and responders.

1.2 APPROACH

Many relevant documents describing the design, operation, and maintenance of the active fire protection systems for WTC 1, 2, and 7 were lost in the collapse of those buildings. With the cooperation of The Port Authority of New York and New Jersey (PANYNJ) and Silverstein Properties Inc., information was obtained from other locations and from contractors, consultants, and operators. As an example, some information was obtained from the engineering offices of PANYNJ in Newark. Other written materials describing the design and operation of active fire protection systems were obtained from files maintained by contractors. Lastly, information from engineers and system operators was helpful in clarifying details of the installation and operation.

National Institute of Standards and Technology (NIST) investigators led three teams of fire protection engineers. Each team specialized in one of the fire protection systems being investigated—fire sprinkler, fire alarm, and smoke management. Guidance was given to the teams to document systems at a level that provided a clear understanding of the design, capabilities, and normal operations. Following this guideline, all the major components of the active fire protection systems were documented, but not every part of the system hardware was addressed in detail. Information in this project report depended heavily on the technical work provided in the three subject reports (NIST NCSTAR 1-4B, NIST NCSTAR 1-4C, NIST NCSTAR 1-4D[1]). Liberal use of text and graphics from those reports has been made in assembling this project report.

Technical assistance to NIST in the investigation of the sprinklers, standpipes, and preconnected hoses was provided by Hughes Associates Inc. (HAI) of Baltimore, Maryland. This group was tasked with:

- Documenting the design and installation of the systems;
- Documenting the design and capacity of the water supply including provisions for redundancy;
- Identifying differences in the designs used in WTC 1, 2, and 7;
- Documenting the normal operation and effect of the fully functional systems for fire control;
- Assessing the probable performance of the systems in WTC 1 and WTC 2 on September 11, 2001; and
- Assessing the documented system installation procedures with respect to present best practices.

Technical assistance to NIST in the investigation of the fire alarm systems was provided by The Rolf Jensen and Associates, Inc., (RJA) of Fairfax, Virginia. This group was tasked with:

- Documenting the design and installation of the system;
- Documenting the normal operation and effect of the fully functional systems, including provisions for redundancy;
- Documenting modifications made to the fire alarm systems in WTC 1 and WTC 2 after the 1993 bombing;
- Assessing the probable performance of the systems in WTC 1 and WTC 2 on September 11, 2001; and
- Assessing the installed systems with respect to present best practices.

Technical assistance to NIST in the investigation of the smoke management systems was provided by Hughes Associates, Inc. (HAI), of Baltimore, Maryland. This group was tasked with:

- Documenting the design and installation of the systems;
- Describing the normal operation in fire emergencies; and

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[1] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

- Assessing the installed systems with respect to present best practices.

1.3 REPORT ORGANIZATION

A review of past fire incidents in WTC 1, 2, and 7 is included in Chapter 2. This provides perspective on the types of fires that may have been anticipated prior to September 11, 2001, and highlights the extraordinary severity of the fire and damage by which the fire protection systems (passive and active) were challenged that day. A full report on the fire history of these buildings is provided in NIST NCSTAR 1-4A.

Chapter 3, based upon the HAI contractor's report (NIST NCSTAR 1-4B), is a description and analysis of the sprinklers, hoses, and standpipe systems in WTC 1, 2, and 7. The analysis includes a thorough assessment of the flow of water that an undamaged system would have delivered to sprinklers on various floors throughout each of the buildings, assuming the designed primary and/or secondary water supplies were intact.

The fire alarm and installed emergency communications systems are described in Chapter 4. NIST NCSTAR 1-4C, written by Rolf Jensen & Associates, Inc., is the primary source for this material.

Chapter 5 is a description and an analysis of the smoke management system. In addition to reviewing the building and fire codes which address smoke management systems, describing the systems, and assessing their likely performance on September 1, 2001, a number of alternative strategies for management of the smoke are presented. A detailed report on the smoke management system is available in the contract report from HAI (NIST NCSTAR 1-4D).

The findings of the WTC Investigation in all areas pertaining to active fire protection are summarized in Chapter 6. These findings provide the basis for the recommendations for improving model standards, codes, and practices regarding the design, installation, and operation of sprinkler, fire alarm, and smoke management systems in all high rise (and selected other) buildings. Refer to NIST NCSTAR 1, for these recommendations.

Chapter 2

SIGNIFICANT FIRES IN WTC 1, 2, AND 7 PRIOR TO SEPTEMBER 11, 2001

Significant fires in World Trade Center (WTC) 1, 2, and 7 prior to September 11, 2001, were of interest to understand, in particular, how the fires were suppressed. Information was sought on all fires that activated multiple sprinklers or where hoses were used to suppress the fires. Because the records of fire events in the buildings maintained by The Port Authority of New York and New Jersey (PANYNJ or Port Authority) were destroyed in the fire and collapse of WTC 1, information available for study was limited to that from The Fire Department of the City of New York (FDNY) fire and investigation reports.

2.1 FDNY RECORDS

Fires occurred in WTC 1, 2, and 7 prior to September 11, 2001. Facts related to the performance of automatic sprinkler, manual suppression, fire detection, and smoke purge systems during significant fires in the buildings after first occupancy were documented.

Extensive records of fire incidents kept in the WTC 1 offices of the PANYNJ were lost in the collapse of the building; however, FDNY maintained records of the responses to all fires. These records consisted of standardized forms on which fire events were described using codes from a predefined list of descriptive phrases and categories. In addition, some records contained supplemental information in the form of written comments about the incident.

The FDNY provided 397 Bureau of Operations Fire Reports and 112 Bureau of Fire Investigation Records (Fire Marshals' Reports) that served as the basis for this summary of the fire history in the WTC 1, 2, and 7. The National Institute of Standards and Technology (NIST) reviewed these reports of fires for the period from 1970 to 2001, and fire investigation records between 1977 and 2001, for WTC 1, 2, and 7.

2.2 SIGNIFICANT FIRES

All of the FDNY Bureau of Operations and Bureau of Fire Investigation records consisted of standardized forms that could be supplemented with other materials. Many were for minor fire events, such as fires that were extinguished by occupants before FDNY arrival. These were not of interest for this investigation. The records of significant fires were identified. NIST defined significant fire incidents as those involving the discharge of multiple sprinklers, use of a standpipe connected hose, or the combination of a single sprinkler discharge and a hose. The majority of fire records for significant fires documented the performance of the fire alarm system detectors and sprinkler systems, but almost all reports lacked information about the performance of the smoke management system.

Table 2–1 contains the categorization of all structural fire incidents contained in the FDNY records for WTC 1, 2, and 7 available to this Investigation. This information was obtained from 345 of the 397 Bureau of Operations Fire Reports that described structural fire incidents. The table contains

Table 2–1. Summary of historical fires in WTC 1, 2, and 7.

Category	Dates	Number	Generalization of Incidents
WTC 1			
No detection, no sprinkler	1980–2001	66	Unattended food/appliances, overheated elevator equipment, discarded material, welding operations, electrical failure and suspicious fires
No detection information and no sprinklers	1970–1979	79	Trash can fires, discarded material, food on stove, electrical failure, overheated equipment
Detection, no sprinklers	1980–2000	57	Unattended food/appliances, overheated elevator equipment, discarded material, welding operations, electrical failure
Detection and sprinklers	1977–1999	18	Suspicious, electrical failure, discarded material
WTC 2			
No detection, no sprinkler	1980–1999	37	Discarded material, welding too close, overheated equipment, suspicious, elevator motor
No detection information and no sprinklers	1975–1979	40	Discarded material, fire in office furniture, trash can fires
Detection, no sprinklers	1981–1999	40	Food on stove, small elevator fire, electrical failure, suspicious, overheated equipment
Detection and sprinklers	1977–2000	5	Mechanical failure, suspicious
WTC 7			
No detection, no sprinkler	2000	1	Trash can fire/discarded material
Detection, no sprinklers	1990	1	Electrical switch on floor — explosion
Detection and sprinklers	1988	1	Suspicious

information on the category of fire incident, the time period over which the fire occurred, the number of records in that category, and a descriptive statement about the category. As Table 2–1 shows, the majority of the 345 Fire Reports refer to fires in WTC 1 and WTC 2, whereas only three reports provided to NIST pertained to WTC 7. The details of these incidents are documented further in NIST NCSTAR 1-4A, which contains copies of the FDNY reports used in the investigation, as well as other information that was not used by the investigation.

To summarize , 16 significant fires occurred in WTC 1, 2, and 7 that exercised multiple sprinklers or multiple standpipe connected hoses, with 12 occurring in WTC 1, three in WTC 2, and one in WTC 7. After reviewing these fires, trends developed relating to the time of day that the fires occurred. Overall, 12 of the 16 fires occurred between the hours of 6 p.m. and 4 a.m. The fires that occurred during office hours (between 7 a.m. and 6 p.m.) included a dumpster fire in the floor 43 elevator lobby (WTC 1), a dumpster fire on floor 106 (WTC 1), a kitchen fire on floor 107 (WTC 2), and a bearing overheating in the fan motor room on floor 108 (WTC 2). Almost all of the incendiary (arson) and suspicious fires (5 out of 6 fires) and unclassified or unlisted fires (4 out of 5 fires) occurred after business hours (before 7 a.m. or after 6 p.m.).

Trends in the cause of the fire, the materials involved in the fire, and the reported damage to the building also can be highlighted. Of the 16 fires and their causes, five were labeled as unlisted or unclassified, six as suspicious or incendiary, two as discarded material, and three as an electrical failure or mechanical failure. For the material involved in the fire, eight reports noted trash, waste, and supplies; two reported not listed or not classified; one reported furniture; three reported electrical equipment; one reported duct work; and one reported shanties were the material involved in the fire. Lastly, the majority of the fires were confined to the area of origin, with only two fires extending to less than 15 percent of the space on the floor.

In addition to the fires discussed above, 31 fires occurred in WTC 1 and WTC 2 that involved the use of one standpipe (with or without the activation of one sprinkler). Of these additional 31 fires, 23 occurred in WTC 1 and eight occurred in WTC 2. Four of the 31 reports describe fires that were extinguished with one sprinkler and one standpipe line. Three of these fires occurred in WTC 1 between 1986 and 1991 and the other in WTC 2 in 1981. In some of the fire reports, the FDNY noted that the sprinkler controlled the fire, and the standpipe was used to actually extinguish the remaining fire. Half of the fires were labeled as incendiary/suspicious, one was an electrical failure, and the last was unknown.

Twenty-seven of the 31 fire reports describe fires that were extinguished using one standpipe line. Twenty of these fires occurred in WTC 1, and the other seven occurred in WTC 2. A majority of these fires (19) are labeled as incendiary/suspicious or unknown, while the other causes of the fires are attributed to short circuits, abandoned material/cigarette, welding close to combustibles, and a mechanical failure. The dates of occurrence for these fires range from 1973–1999, with a majority (23) occurring between 1973 and 1985. These fire incidents did not result in any casualties, but five civilians and one uniformed officer were injured.

Two of the 27 fires involved a 300-person (April 19, 1980) and a 1,500-person (April 17, 1981) evacuation. On April 19, 1980, at 2:06 p.m., the FDNY received reports of an activated smoke detector in the return air duct on floor 106 of WTC 1. The FDNY also received reports of heavy smoke on floor 106, light smoke on floor 109, and heavy odor of smoke in stairways A and B. The report notes that while only one standpipe was used, approximately 300 people were evacuated from the Windows on the World restaurant on floor 107 via stairway C (which was clear of smoke). The fire cause was labeled as abandoned or discarded material and involved plastic material. This fire did not cause any injuries or casualties.

On April 17, 1981, at 9:18 a.m., the FDNY was informed of a fire on floor 7 and a smoke condition on floors 7 through 11 of WTC 1. The FDNY hooked up one standpipe and extinguished the fire located in an air conditioning unit in the mechanical equipment room (MER) room on floor 7. The cause of this fire was labeled as a mechanical failure. The fire report notes that the Port Authority personnel reported an evacuation of approximately 1,500 people from floors 9 through 23. However, no injuries or casualties were reported from this fire.

Two other very major incidents occurred in the WTC towers: an office fire in WTC 1 in 1975 (prior to the installation of sprinklers) and the 1993 bombing incident, which impacted both towers. On February 14, 1975, a fire started on floor 11 of WTC 1. Workers reported the fire to WTC police headquarters. When police reached the fire floor, they reported a serious fire and ordered the heating, ventilating, and air conditioning (HVAC) system be placed into the smoke purge mode. Fire spread through unprotected floor openings in utility closets. Fire damage occurred on floor 10 through floor 19.

Approximately 9,000 ft^2 (800 m^2) of the floor 11 contents were destroyed or damaged. At that time, sprinklers had not been installed in the office spaces. However, fire barriers divided the floor into quadrants. The fire on floor 11 was confined to the southeast quadrant. Fire damage on other floors was confined to the utility closets. The fire was extinguished by the FDNY. More details about this fire incident can be found in Powers (1975) and Lathrop (1975).

The bombing incident occurred at 12:18 p.m. on February 26, 1993. The explosion occurred on the B2 level in the area of the garage under WTC 3 and adjacent to WTC 1. The explosion resulted in a loss of normal electric power in WTC 1 and WTC 2. HVAC systems shut down. Smoke spread throughout WTC 1 and to a lesser extent in WTC 2. More details about this fire can be found in Isner and Klein (1993a, 1993b).

In conclusion, many of the fires that occurred in WTC 1, 2, and 7 were recorded as suspicious or unknown in cause, occurred during off-peak work hours, and involved materials such as trash or paper-based supplies. In cases where sprinklers were activated, the FDNY records indicated that the sprinklers either extinguished the fire completely or aided in controlling the spread.

The FDNY fire reports and fire investigation records indicate that in areas protected by automatic sprinklers, no fire activated more than three sprinklers. The maximum design area for three sprinklers is a floor area of 63 m^2 (675 ft^2) in a light hazard occupancy system of the type installed in the WTC 1, 2, and 7 office spaces and other high-rise office building as specified in the NFPA 13 Standard for the Installation of Sprinkler Systems (NFPA 13 2002). Sprinklers contained fires to a very small fraction of the area of a single floor.

Chapter 3
SPRINKLERS, STANDPIPES, AND PRECONNECTED HOSE SYSTEMS

In the event of fire in World Trade Center (WTC) 1, 2, and 7, there were two primary means to provide water for fire fighting. One was the installed fire sprinkler system. This system of water-charged piping throughout the building provided water spray from sprinklers that were installed in ceilings. In the event of a fire, hot gases would heat the sprinklers in the area of the fire. When the temperature and duration of heating was sufficient, the sprinklers that had reached a predetermined response temperature would activate and release a spray of water. Sprinkler systems were designed to control the spread and growth of expected fires. Manual intervention by fire fighters or others with hand held fire extinguishers or hose lines generally would be required to extinguish all of the burning, especially in areas that were shielded from the sprinkler spray. In some cases, fires may have been extinguished by the automatic fire sprinkler system before the fire department arrived.

In high-rise and other buildings, a network of vertical and horizontal pipes known as the standpipe systems supply water for fire hoses on each floor. On each floor there are connections provided for fire hoses carried into the building by fire fighters. The standpipes may have pre-connected hoses that can be used by building occupants. The safe and effective use of standpipe pre-connected hoses requires training.

The design of the water supply system and sizing of components that would automatically supply water to installed sprinklers and standpipe systems was guided by local building code requirements, widely used and accepted installation standards, and fire protection engineering practice. These systems provided the means for the fire department to supplement the building water supply with water pumped from street fire hydrants and other sources.

The design and installation of the fire sprinkler, standpipe, and preconnected hose systems have been documented in NIST NCSTAR 1-4B prepared for National Institute of Standards and Technology (NIST) by Hughes Associates, Inc. This publication also includes the results from a hydraulic analysis of the systems to determine capabilities for fire suppression water flow throughout the above grade areas of WTC 1, 2, and 7. The reader is referred to Bryan (1990), Cote (2003), National Fire Protection Association (NFPA) 13 (NFPA 2002) and NFPA 14 (NFPA 2003) for comprehensive descriptions and details relied upon by engineers and contractors in the design, installation, commissioning and periodic testing of these systems.

3.1 AUTOMATIC FIRE SPRINKLER SYSTEMS

Automatic fire sprinkler technology is a 19th century invention. Modern systems have evolved over time, and are fundamentally straightforward in their operation. A major innovation in fire sprinkler technology occurred with the introduction of the spray sprinkler in the early 1950s. The spray sprinkler was designed to provide a relatively uniform distribution of the water spray to the area to be protected. This was a significant advancement over previously used sprinkler devices that produced non-uniform sprays that resulted in inefficient use of the water and gaps in the coverage.

In simple terms, an automatic fire sprinkler system consists of a water supply, a series of distribution pipes, and individual sprinkler devices. The basic systems are supported by control valves, pumps, and water flow alarms. The valves and pumps are used to maintain the water supply, both before and during a fire incident. A typical individual sprinkler installed near the ceiling is shown in Fig. 3–1.

Source: Hughes Associates, Inc.

Figure 3–1. Typical sprinkler installed in ceiling.

While there are variations, the basic operating principle involves operation of each sprinkler device, individually, when exposed to a rising temperature condition (i.e., due to the thermal output from a fire). Typically, if a fire becomes large enough, a sprinkler device in the vicinity of the fire will operate, discharging water at a rate determined by the system design. If the fire continues to grow, additional sprinklers operate. This continues until the fire is controlled or extinguished, or until the available water supply is depleted. Only those sprinklers directly exposed to the hot fire gases operate and discharge water.

The design method used for the sprinkler systems in the WTC buildings is referred to in NFPA 13, Standard for Installation of Sprinklers Systems, as the occupancy hazard fire control approach (NFPA 2002). The general premise in the design of these types of sprinkler systems is to define a hazard imposed by the occupancy use of the area served and to design the sprinkler system to limit the fire to the room or area of origin. Based on the specified occupancy hazard(s), a minimum water spray density and a minimum area of sprinkler operation must be determined.

Designs using this type of approach have been around for decades. This approach has been developed based on many years of fire testing and associated analyses. In order to employ this approach, the occupancy hazard(s) for the particular structure must be determined. There are several occupancy classifications, including the following:

- Light Hazard (including offices, data processing facilities, clubs and restaurant seating areas, commercial shops),

- Ordinary Hazard Group 1 (including manufacturing and processing plants, laundries, and restaurant service areas),

- Ordinary Hazard Group 2 (including dry cleaners, library stack areas, post office, and repair garages),
- Extra Hazard Group 1 (including metal extruding and plywood and particleboard manufacturing plants containing little or no flammable and combustible liquids),
- Extra Hazard Group 2 (flammable liquid spray booths, open oil quenching areas containing moderate to substantial amounts of flammable or combustible liquids or having areas where combustibles were shielded from the sprinkler spray).

Predominantly, WTC 1, 2, and 7 contained office spaces that were classified as Light Hazard occupancy. In an area classified as such, the quantity and combustibility of contents is assumed to be low. Fires are expected to burn with low rates of heat release. This definition requires an understanding of burning rates and combustibility and knowledge of fuel loading; examples are provided in the appendix section of NFPA 13 (NFPA 13 2002).

NFPA 13 also specifies the minimum discharge density and minimum area of coverage for the different occupancy classification sprinkler systems. The application or discharge density refers to a water flow rate over a unit area. In practice, densities are described in units of gallons per minute per square foot (gpm/ft^2). Design areas are described in units of square feet. The density is used to specify the minimum flow rate to be discharged from an individual sprinkler, the design area, and the minimum flow rate required for the system. For Light Hazard occupancy sprinkler systems, NFPA 13 minimums are 0.1 gpm/ft^2 density and 1,500 ft^2 design area. This design area represented a small fraction of the area of a single floor in WTC 1, 2, and 7.

3.2 STANDPIPES AND PRECONNECTED HOSES

Standpipe systems are fixed piping systems that provide water to designated areas of a building to support manual fire fighting efforts. Typically, standpipe systems for high-rise buildings consist of vertical pipe risers with fire hose connections at each floor. The systems are supported by control valves and pumps, and have fire department connections (FDC) at the street. These FDCs are used by firefighters to supplement the building system water supply. The fire hose connections may or may not include preconnected hoses, depending on the type of system and the requirements of the local code authority. The number of standpipe risers and connections are dependent on the building configuration, size, and number of exit stairway enclosures. Usually, the systems are pressure or flow monitored to ensure operability.

The basic concept of standpipe systems has not changed appreciably over the last 90 years, although specific requirements have been modified from time to time. The nationally recognized design and installation standard for standpipe systems is NFPA 14, Standard for the Installation of Standpipe and Hose Systems (NFPA 14 2003), which was originally adopted in 1915 (Bryan 1990). While the Building Code of New York City (BCNYC) does not reference NFPA 14 specifically, the recognized types and classifications of standpipe systems, as well as associated requirements in the BCNYC, are similar to those in NFPA 14.

Typically, standpipe systems are installed to support fire department operations, use by building occupants, or both. In NFPA 14, standpipe systems are classified, accordingly, as Class I, Class II or Class III systems. The following is a brief description of each class:

- Class I Systems are designed to provide 2½ in. hose (standpipe) valves, which are used to provide heavy streams for fire department personnel usage in advanced stages of fire. Hose valves are required in all exit stair enclosures and throughout all portions of a story or building section.

- Class II Systems are designed to provide 1½ in. preconnected hose stations, which are used to provide small streams for trained building occupants or fire brigades to fight incipient fires and for mop up efforts. Hoses and nozzles are provided at the hose stations and are spaced similarly to Class I hose valves, except hose stations are required at all areas within 20 ft of a nozzle at the end of a 100 ft hose.

- Class III Systems are a combination of Class I and II systems; Class III systems are the same as Class I systems with added 1½ in. outlets or 1½ in. adapters and hose. Class III systems are designed for use by the fire department, trained building occupants, or a fire brigade.

The standpipe systems in WTC 1, 2, and 7 were similar to Class III systems, but were designed and installed according to the provisions of the 1968 BCNYC.

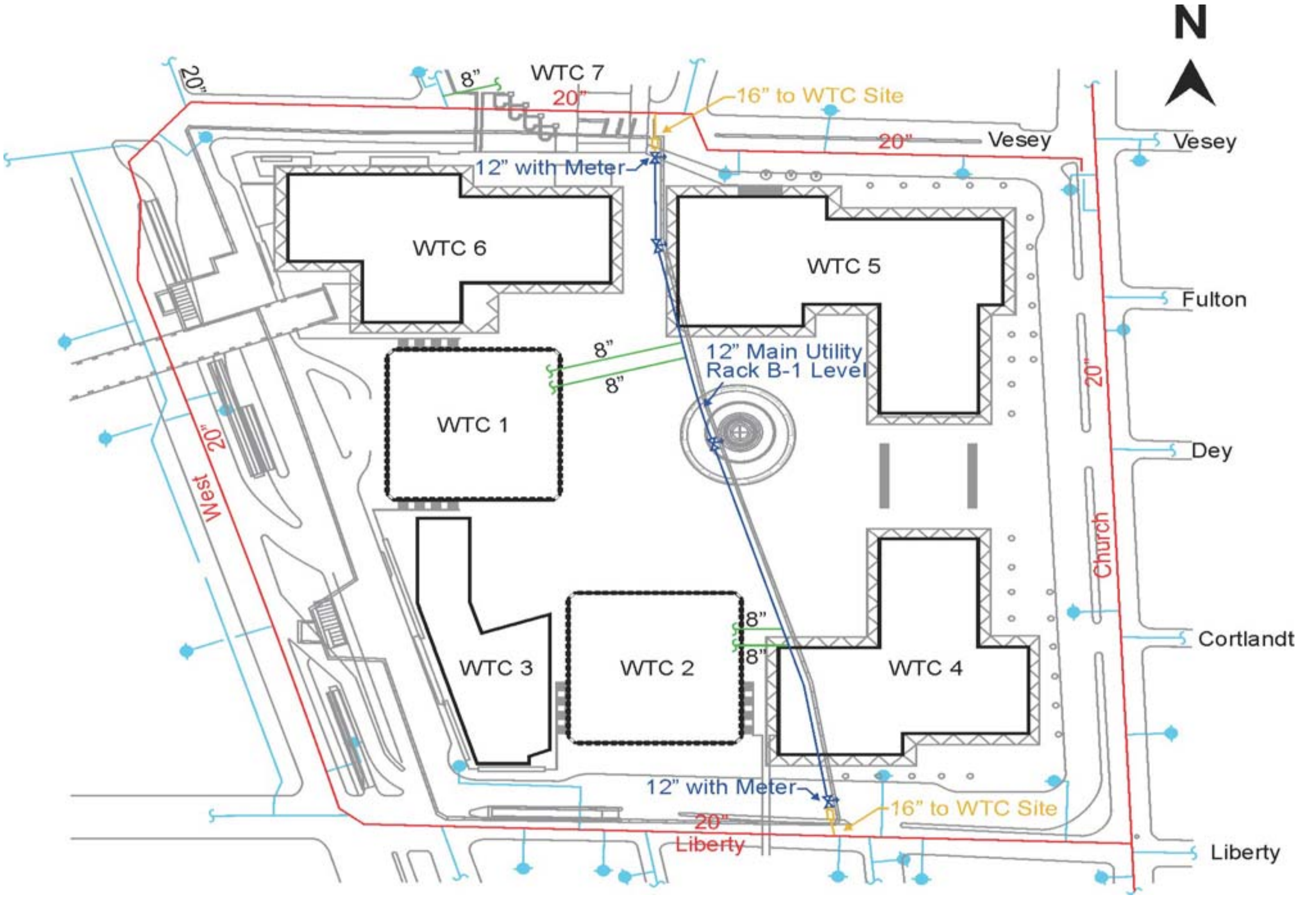
The basis of design for Class I and III standpipe systems specify a performance requirement of 500 gpm at 100 psi to be supplied to the most hydraulically remote standpipe hose connection valve and 250 gpm at 100 psi to be supplied to each additional standpipe up to a maximum of 1,250 gpm. This performance requirement anticipates the use of two 2½ in. hose lines connected to the most hydraulic-remote standpipe and an additional hose line connected to each of the other standpipes. Hydraulic-remote does not refer to physical or spatial remoteness. The most hydraulically remote standpipe is the standpipe that requires the highest initial pressure to provide the specified flow and pressure to the end standpipe hose connection valve. The design of Class II standpipe systems includes 100 gpm for the most hydraulically demanding standpipe at 65 psi.

Performance records are not maintained for standpipe and pre-connected hose systems. Obviously, eliminating the need for extended hose lays from the fire department apparatus to the fire location on an upper floor in a high-rise building would improve manual fire fighting operations. While pre-connected hoses are provided in many buildings, including WTC 1, 2, and 7, concerns over reliance on these hoses and their use by building occupants has been a long standing debate. In some jurisdictions, only Class I or similar standpipe systems are permitted, for use only by the fire department. In addition, standpipe systems are not considered to be an alternative to automatic fire suppression, e.g., automatic sprinklers.

3.3 NYC WATER SUPPLY

The primary source of all water for the fire suppression systems in WTC 1, 2, and 7 was the New York City (NYC) water supply and distribution system. This system was operated by the New York City Department of Environmental Protection (NYC DEP). Two separate divisions (bureaus) of the DEP were responsible for the water supply and distribution system: The Bureau of Water Supply (BWS) and the Bureau of Water and Sewer Operations (BWSO) (LZA Technology 2002).

The NYC water distribution system in lower Manhattan surrounding the WTC complex was composed of a grid network of 20 in. and 12 in. ductile iron mains. Figure 3–2 shows a plan of the system in the area surrounding the WTC complex. A 20 in. loop was located beneath the streets surrounding the main WTC complex where towers WTC 1 and WTC 2 were located. The mains were beneath Vesey Street to the north, Liberty to the south, Church Street to the east, and West Street to the west. These mains were interconnected to a series of 20 in. and 12 in. mains. This permitted water to flow along a large number of paths, minimizing the effects of friction loss while flowing a large volume of water. The large volume of water within the distribution system mains, transmission mains, and at the source (watersheds in upstate New York) allowed for a large capacity of water to be available for fire fighting capabilities. A 20 in. water main was located beneath West Broadway, immediately to the east of WTC 7. This main supplied water to the 20 in. loop around the WTC plaza. A 12 in. main to the west of WTC 7 beneath Washington Street supplied two parallel 8 in. diameter lead-ins (feeder mains) for WTC 7 and connected to a 12 in. main at the north side of WTC 7 beneath Barclay Street and the 20 in. main beneath Vesey Street. The 12 in. main on Barclay Street increased to a 20 in. diameter pipeline near the center of WTC 7 at Greenwich and interconnected to the 20 in. main on West Broadway. A 12 in. and a separate 20 in. parallel main connected to the 20 in. water main on Barclay and continued to the north on Greenwich. This arrangement of the water distribution system provided a near constant pressure for all flows that are normally anticipated for fire protection system demands (typically 500 gpm – 750 gpm), with a residual pressure that was nearly identical to the static pressure.



Source: LZA Technology 2002; Beyler 2002. Reproduced with permission of the Silverstein Properties Group.

Figure 3–2. Plan of water distribution system surrounding the WTC complex.

3.4 WTC 1 AND WTC 2 INSTALLED FIRE SUPPRESSION FEATURES

Through review of available information (PANYNJ 1987, 1972), the major features of the fire suppression systems installed in WTC 1, 2, and 7 on September 11, 2001, were documented. These systems included the water supplies, automatic sprinkler systems, standpipe and pre-connected hose systems and special fire suppression features.

3.4.1 Overview

WTC 1 and WTC 2 were protected by automatic fire sprinkler systems, essentially throughout. The sub-grade areas of the complex were provided with sprinkler systems during the initial construction. The systems were not installed in the towers during construction of the two buildings, but were retrofitted. The retrofit program had been completed prior to September 11, 2001.

In addition to automatic fire sprinkler systems, each building had vertical standpipe systems located in the stairwells. The standpipe systems were configured with four vertical water supply zones and included three standpipe risers in each zone.

The standpipes provided fire suppression water to pre-connected hoses located in the stairwells at each floor. WTC 1 and WTC 2 were equipped with standpipe systems which included Class III pre-connected hose stations in all exit stair enclosures and in certain corridors and tenant spaces. Each hose station was provided with a standpipe hose control valve, a 125 ft long fire hose, and a nozzle for use by a trained fire brigade or The Fire Department of the City of New York (FDNY).

The primary water supply for the standpipe systems was initially gravity fed from reserve water storage tanks located above the standpipe system zone. Also, a series of manually operated fire pumps provided water supplied by the NYC water distribution system. The primary water supply consisted of a fire main that looped the WTC complex. The 12 in. diameter main was supplied directly from the municipal water supply by two redundant 16 in. diameter connections. Operating pressures were maintained by two 750 gpm high-pressure electric pumps that supplied the sub-grade loops and were located beneath the towers on the B1 level of the complex.

Each tower had three 750 gpm manually initiated electrical fire pumps, located on the 7th, 41st, and 75th floors to supplement standpipe pressures. Each pump provided sufficient pressure for the standpipes to skip the next sequential pump above it if any failed to operate. In addition to the pumps, a single 500 gpm automatic fire pump was provided in each tower on the 108th floor for the sprinkler systems located on the 99th through 107th floors and the hose stations in the mechanical rooms on the 108th through 110th floors. Six emergency power generators were located in the basement at the B-6 level. These generators provided back-up power to the fire pumps, as well as to communications equipment, elevators, and emergency lighting.

Each reserve water supply consisted of 5,000 gal storage tanks, filled from the building's domestic water system. Figure 3–3 shows one of the installed tanks. Tanks were located on the 20th, 41st, 75th, and 110th floors in each tower. The tanks supplied the initial water supply to the WTC fire brigade or the FDNY. Without supplemental water supplied by the domestic water system, the tanks provided approximately 10 min for The Port Authority of New York and New Jersey (PANYNJ) maintenance staff to manually start the fire pumps.

Source: Merritt & Harris, Inc. 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–3. Typical 5,000 gal water storage tank, WTC 1 and WTC 2.

Fourteen FDC stations were located at ground level for use by the FDNY to supplement the water supply and pressure to the fire suppression systems in the buildings. Any of the FDC stations could be used to supply the standpipe systems throughout the complex or sprinkler systems in WTC 1 and WTC 2 above the 32nd floor level. Isolation valves were installed between consecutive FDC stations. This provided independent supply and operation of the standpipe systems throughout the WTC complex. Two additional express FDC stations were provided to supply only the sprinkler systems in WTC 1 and WTC 2 above the 32nd floor level, and two separate FDC stations were provided for the sprinkler systems in WTC 1 and WTC 2 at and below the 31st floor level.

Several types of special suppression systems were installed in WTC 1 and WTC 2 on a limited basis to protect specific areas. These systems included:

- Dry chemical and steam smothering systems
- Carbon dioxide (CO_2) systems
- Halon 1301 total flooding systems

These systems were supervised by the fire alarm systems in WTC 1 and WTC 2 and were designed to transmit signals to the FDNY upon activation.

Restaurant cooking appliances were equipped with dry chemical fire suppression systems (PANYNJ 1987). These systems contained dry chemical fire suppression agents (potassium bicarbonate or ammonium phosphate). The dry chemical agents were stored in cylinders and would be released by an actuator that would discharge the agent upon fusing of a thermal link located above the cooking appliance or within the exhaust duct. The dry chemical systems were also provided with manual release mechanisms to allow for the occupants to actuate the systems manually. The Operation and Maintenance

(O&M) manual (PANYNJ 1987) described that these systems were installed in WTC 1 and WTC 2, but again did not identify specific locations.

The use of steam systems for fire suppression preceded the use of CO_2 and dry chemical fire suppression systems (PANYNJ 1987). The exhaust ducts in the large kitchens at the WTC complex were equipped with steam smothering systems. The O&M manual indicated that steam smothering systems were installed in the kitchens at the following locations:

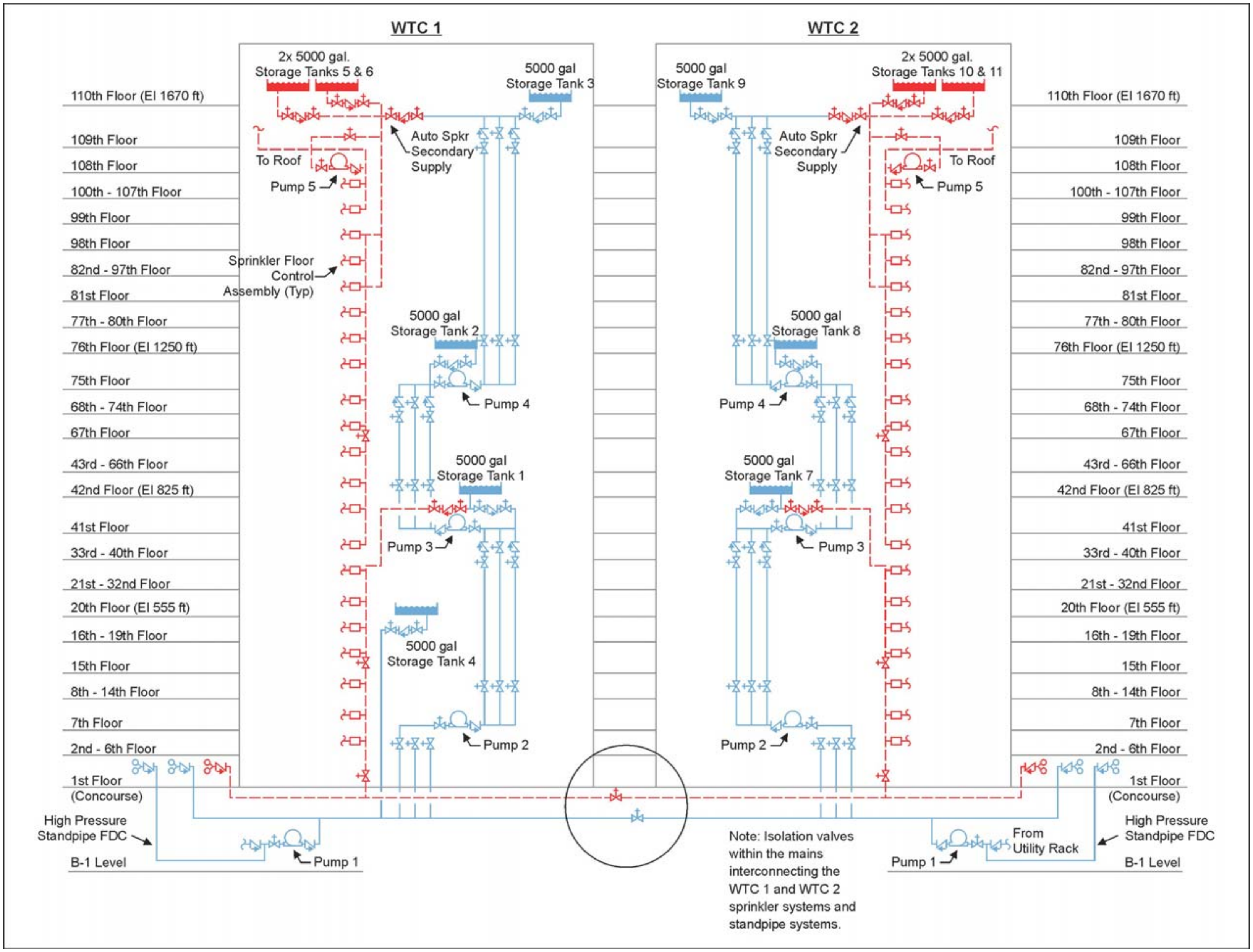
- PANYNJ Cafeteria
- The "Big Kitchen"
- The Sky Dive
- Windows On The World
- The New York State Cafeteria
- The Observation Deck

Carbon dioxide is electrically nonconductive and is commonly used to extinguish fires involving electrical equipment; hence, CO_2 suppression systems were installed in computer rooms in WTC 1 and WTC 2. Smoke and heat detectors were used to actuate the releasing mechanism, causing CO_2 to discharge into the room. In particular, a total flooding CO_2 system was used to protect the under floor space of a large computer room in WTC 2 (PANYNJ 1987). The O&M manual contains a reference to other systems at the WTC complex, but it did not indicate their locations. Local alarm bells were provided to indicate to the occupants that the system had activated and the room should be evacuated.

Halon 1301 total flooding systems were used for the protection of computer rooms in WTC 1 and WTC 2. Halon is stored in holding cylinders, which are actuated upon the response of two cross-zoned smoke detectors. The O&M manual identifies that two separate cross-zoned detection system zones that were installed, and release occurred upon activation of a detector within both zones. The available drawings for WTC 1 show that two Halon 1301 systems were installed for protection of the computer room on the 70th floor. One system was installed for protection of the under floor space and the other for protection of the room (PANYNJ 1987, 1986, 1972).

3.4.2 Details of the Sprinkler and Standpipe Riser System

The sprinkler and standpipe riser system provides water for automatic and manual fire suppression. Figure 3–4 shows the major features and connections of the riser system in WTC 1 and WTC 2. The standpipe system contained four vertical zones and the sprinkler system three zones. Using Fig. 3–4 as a reference, the normal operation of the system in each zone is discussed below.



Source: Hughes Associates, Inc.

Figure 3–4. WTC 1 and WTC 2 sprinkler and standpipe risers.

Tanks and Pumps

Four reserve water storage tanks were provided in WTC 1 to supply the standpipes (PANYNJ 1987, 1972). Each tank had a holding capacity of 5,000 gal for a total of 20,000 gal of water dedicated for manual fire suppression (PANYNJ 1987, 1986, 1972) . These tanks were located on floors 20, 41, 75, and 110 (PANYNJ 1987, 1986, 1972) . The tanks were designated FSP storage tank No. 20A, FSP storage tank No. 1A, FSP storage tank No. 75A, and FSP storage tank No. 110A, respectively (PANYNJ 1987).

Three reserve water storage tanks were provided in WTC 2 to supply the standpipes. These tanks were located on floors 42, 76, and 110 (PANYNJ 1987, 1972). The tanks were designated FSP storage tank No. 41B, FSP storage tank No. 75B, and FSP storage tank No. 110B, respectively (PANYNJ 1987). Similar to WTC 1, each of the tanks had a holding capacity of 5,000 gal of water. The total holding capacity of the tanks in WTC 2 was 15,000 gal.

Two parallel 5,000 gal water storage tanks were provided on the 110th floor in each of the towers (PANYNJ 1987, 1986, 1972). These tanks provided a dedicated water supply of 10,000 gal for the high and mid-level zone sprinkler systems. The 5,000 gal standpipe reserve water storage tank on the 110th floor level also served as secondary automatic water supply for the high and mid-level automatic fire sprinkler systems.

The 5,000 gal water storage tanks located in the 41st floor level mechanical rooms were arranged to provide the primary water supply for the low zone sprinkler systems and the standpipe system zone serving floors 8 through 31. Therefore, a minimum of 5,000 gal was provided for the standpipe and sprinkler systems in each tower. Since each tank was also equipped with a 2 in. diameter automatic fill line supplied by the domestic water system, the volume of water in the tank would be partially replenished as the water was depleted from the tank.

The WTC complex was provided with 12 fire pumps and a single vertical turbine jockey pump (PANYNJ 1987, 1986, 1972). These pumps provided means to move water vertically in the building using the standpipe and sprinkler system risers. The primary water supply for most pumps were the water mains. Fire department engines could pump water from hydrants into the buildings through FDCs. The WTC complex was provided with 14 separate FDC stations, with a total of 32 FDCs (PANYNJ 1987, 1972).

The standpipe system reserve storage tanks located in the 75th and 41st floor level mechanical rooms were configured to serve as secondary manual water supplies for the high and mid-level zone automatic sprinkler systems (PANYNJ 1987, 1972). The use of these storage tanks required the manual starting of the fire pumps to lift the water to the 110th floor level (PANYNJ 1987, 1972). Any two manual fire pumps operating in series were capable of providing adequate capacity and pressure to supply the fire protection (suppression) systems within the high or mid-level sprinkler or standpipe systems (PANYNJ 1987, 1986, 1972).

A single fire (booster) pump was provided in each tower at the 108th floor level for the high zone sprinkler systems, and the hose racks were located on the 110th floor level (PANYNJ 1987, 1972). The suction line for each of the fire pumps received water from the sprinkler and standpipe reserve water storage tanks located in the mechanical rooms on the 110th floor. The 15,000 gal combined water capacity within those tanks was capable of supplying water to the booster pump at a flow rate of 500 gpm (the 100 percent capacity of the fire pump) for a minimum duration of 30 min without any supplemental water being supplied by the domestic water system. This duration would be reduced to 20 min if the pump was operating at 750 gpm (the 150 percent capacity of the fire pump) which is the maximum permissible design flow rate for a 500 gpm pump.

Automatic Fire Sprinkler and Standpipe Systems

Each tower contained three separate standpipe risers to supply water to the hose stations located on floors 1 through 110. One standpipe riser was provided in each exit stair enclosure. Table 3–1 provides a summary of the standpipe designations and locations. Standpipe risers FS-F1, FS-F2, and FS-F3 were located within and supplied water to pre-connected hose racks located in each respective stair enclosure (PANYNJ 1972, 2000). Figure 3–5 shows a typical hose rack arrangement with a typical intermediate isolation valve. Standpipe riser FS-F1 also supplied water to auxiliary hose cabinets located in the corridors and tenant areas of both buildings (PANYNJ 1972, 2000).

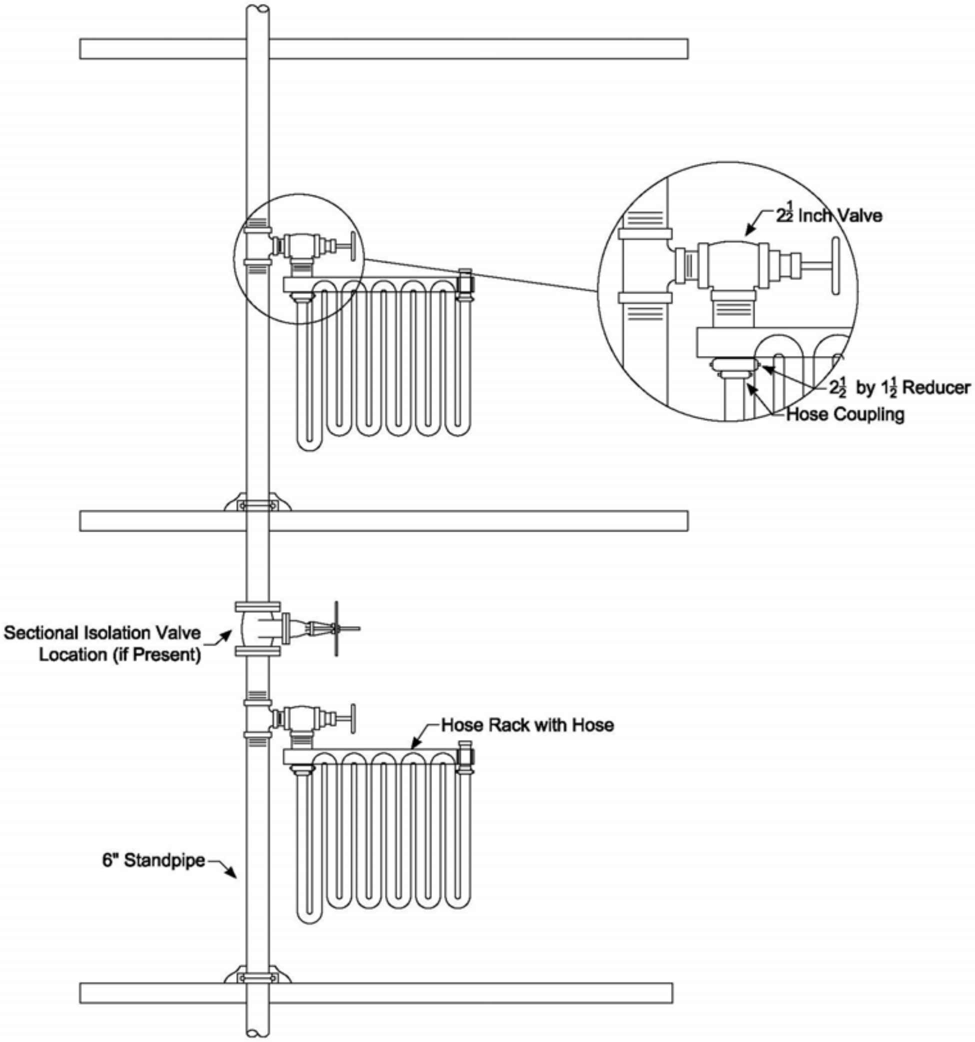
Table 3–1. Standpipe designations and locations, WTC 1 and WTC 2.

Tower	Stair Enclosure	Standpipe Riser Designations	Location of Stair Enclosure
WTC 1 (A)	Stairway B (3)	FS-F1	South
	Stairway C (2)	FS-F2	Northwest
	Stairway A (1)	FS-F3	Northeast
WTC 2 (B)	Stairway B (3)	FS-F1	East
	Stairway C (2)	FS-F2	Southwest
	Stairway A (1)	FS-F3	Northwest

The standpipe systems within each tower were installed with four vertical water supply zones (PANYNJ 1987, 1986, 1972):

1. High or upper
2. Upper mid-level
3. Lower mid-level
4. Low

Table 3–2 identifies the zones. In the initial operating mode with water supplied from the water storage tanks only, each of these standpipe system zones functioned separately from the other zones. A series of check valves were installed between zones that prevented water from flowing downward from one zone to the next (PANYNJ 1987, 1986, 1972). In other operating modes, water was permitted to flow upward from one zone to the next. The manual fire pumps were used to supply water from the NYC water distribution system to all floors within either tower (PANYNJ 1987, 1972). The FDCs were also used by the FDNY to supply water to the standpipe systems from the ground level. Further information on the operation of the standpipe system in each vertical zone is presented in the subject report (NIST NCSTAR 1-4B).



Source: Hughes Associates, Inc.

Figure 3–5. Typical hose rack arrangement.

Table 3–2. Standpipe system zones, WTC 1 and WTC 2.

	Zone	Description	Lower Floor	Upper Floor	Notes
WTC 1 (A)	1	High	77	110	Floor 75 was occupied by a 2-story MER
	2	High mid-level	42	76	Hose rack on FS-F1 only
	3	Low mid-level	9	41	Floor 41 was occupied by a 2-story MER
	4	Low	1	8	Floor 7 was occupied by a 2-story MER
WTC 2 (B)	1	High	77	110	Floor 75 was occupied by a 2-story MER
	2	High mid-level	42	76	Hose rack on FS-F1 only
	3	Low mid-level	9	41	Floor 41 was occupied by a 2-story MER
	4	Low	1	8	Floor 7 was occupied by a 2-story MER

The sprinkler systems for the towers were configured such that each floor level was provided with an independent sprinkler system (PANYNJ 1972). These sprinkler systems were supplied with water from a single shared sprinkler riser within the vertical water supply zones (PANYNJ 1972). The primary "automatic" water supply for each zone was provided from a series of gravity supplied water storage tanks dedicated to the automatic sprinkler systems or combined with the standpipe systems (PANYNJ 1987, 1986, 1972).

Separate sprinkler and standpipe risers were provided, even though the two systems shared the standpipe system infrastructure to provide water in addition to the initial reserve water supply stored in the gravity tanks (PANYNJ 1972). These systems were unlike most typical "combined systems" that have both sprinkler system floor control valve assemblies and standpipe hose valves directly connected to the same risers. In this case, the standpipe systems served as the secondary or tertiary water supplies for the sprinkler systems, depending on the riser (PANYNJ 1987, 1972). Both the FDCs and manual pumps could be used simultaneously to supply water to the standpipes and automatic fire sprinkler systems (PANYNJ 1987, 1986, 1972).

Existing documentation refers to the sprinkler systems as having two separate vertical zones with three risers (PANYNJ 1987, 1986, 1972). The zones are identified as the high zone and the low zone. However, the high zone was separated into two sub-sections using two separate risers. Therefore, the buildings were actually separated into three vertical water supply zones. These zones are referred to as the high, mid-level, and low zones in this report. Each zone was provided with a separate sprinkler system riser as identified in Table 3–3. Figure 3–4 illustrates the configuration of the risers within WTC 1 and WTC 2. In all cases, the primary direction of water flow was downward from the top of the riser to the sprinkler systems. However, the low zone risers were arranged to allow water to flow upward while using a secondary water supply.

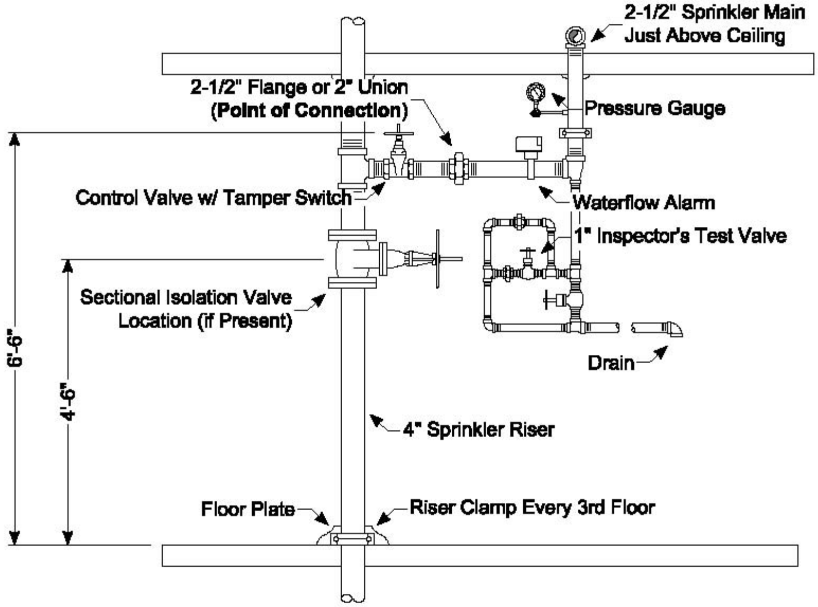
Table 3–3. WTC 1 and WTC 2 sprinkler system risers.

Zone	Riser	Lower Floor	Upper Floor
High	A	99	107
Mid-level	B	98	33
Low	C	32	1

Each sprinkler riser was supplied with water through a single connection to the standpipe system. Risers A and B in both towers were connected to the water storage tanks and standpipe system on the 109th floor (PANYNJ 1987, 1986, 1972). Riser A in each tower is referred to in this report as the high zone. Similarly riser B is referred to as the mid-level zone. Riser C was connected to the combined standpipe and sprinkler system tank on the 41st floor level and supplied water to the low zone in each tower. The A risers were different from the other gravity supply risers, since these risers were equipped with small booster pumps located on the 108th floor level. Additionally, the A risers supplied standpipe hose stations on the 110th floor.

Sectional isolation valves were provided at floor levels 1 and 15 for riser C of WTC 1 (PANYNJ 1987, 1986, 1972). A single sectional isolation valve was provided at floor level 67 in riser B of WTC 1. Sectional isolation valves were also provided at floor levels 1 and 15 for riser C of WTC 2. However, a single sectional isolation valve was provided at floor level 77 in riser B of WTC 2. Neither of the high zone (A) risers was provided with an intermediate sectional isolation valve.

Each of the individual floor level sprinkler systems were connected to the shared riser and water supply within each respective zone. Each system contained a floor control valve assembly separating it from the shared infrastructure. Figure 3–6 shows the configuration of a typical floor control valve assembly. In general, automatic fire sprinkler protection was provided throughout the WTC 1 and WTC 2 buildings, with the exception of the mechanical equipment room (MER) floor levels.



Source: Hughes Associates, Inc.

Figure 3–6. Typical floor control valve assembly.

Documentation indicated that pendent sprinklers with chrome cover plates were installed in all finished areas (PANYNJ 1987, 1986, 2000). Figure 3–7 is a photograph of a typical concealed sprinkler cover plate. Exposed upright or pendent type sprinklers were installed in areas without finished ceilings. Sprinklers with an operating temperature rating of 165 °F were specified throughout most areas (PANYNJ 1987, 1986, 2000). Higher temperature rated sprinklers were specified in areas with normal ambient ceiling temperatures above 100 °F (PANYNJ 1987, 1986, 2000). Protective guards or shields would have been installed in areas where sprinklers were potentially subject to mechanical damage (PANYNJ 1987, 1986, 2000). Documentation indicated that ½ in. orifice sprinklers with a k-factor of 5.6 gpm/psi$^{1/2}$ were installed throughout WTC 1 and WTC 2 (PANYNJ 1987, 1986, 2000). (The flow rate of water from a sprinkler is directly proportional to the water pressure to the half-power. K-factor is the proportionality constant in that relationship and is used in the design of sprinkler systems).

Source: Hughes Associates, Inc.

Figure 3–7. Typical concealed pendent sprinkler.

3.5 WTC 7 INSTALLED FIRE SUPPRESSION FEATURES

3.5.1 Overview

Available documentation and drawings indicated that automatic fire sprinkler systems were installed in most areas of WTC 7; however, they were not installed in the electrical equipment spaces including switchgear, networking, and switchboard rooms. Also, they were not installed in the generator rooms or bathrooms throughout the building. A majority of the fifth floor was not protected by sprinkler systems, with exception of the mechanical space to the east and the office area along the north side of the building (Syska & Hennessy 1984). Specifically, based on review of architectural drawings (Syska & Hennessy 1984) and O&M documents, no evidence was found to indicate that sprinklers were present in enclosures on the 5th, 7th, and 8th floors, which housed electrical generators and day tanks. Lack of sprinklers in these areas is likely the case since BCNYC allowed exclusion of automatic sprinkler protection in generator spaces.

A standpipe system was installed in each stairwell. Pre-connected hoses were located in the stairwells at each floor, connected to the standpipe. In addition, a supplemental pre-connected hose cabinet was located on the east side of each floor. Additional hose cabinets were installed in different locations on different floors in order to achieve the required reach for the hose lines. Three vertical zones are identified based on the water source and flow path.

The primary water supply for WTC 7 was provided by the 12 in. water main beneath Washington Street. FDCs were located on the south, east, and west sides of the building. A 750 gpm manual fire pump that served the entire building was located on the ground floor. A 500 gpm automatic fire pump, located on the ground floor, supplied the sprinkler and standpipe systems through the 20th floor. The 21st floor through 39th floor sprinkler systems and 21st floor through 44th floor standpipe systems were supplied from two gravity fed water storage tanks on the 47th floor. Each tank had a holding capacity of 17,500 gal and a fire reserve capacity of 7,500 gal. The 40th floor through 47th floor sprinkler systems and the 45th floor through 47th floor standpipe systems were supplied from the storage tanks on the 47th floor via a 500 gpm booster pump on the 46th floor.

Emergency power generators were located on several floors to provide back-up power to emergency systems in the building, including the fire pumps. The loading berth and fuel oil pump rooms in WTC 7 were protected by dry-pipe sprinkler systems. The first floor room containing the 6,000 gal fuel oil tank was protected by an Inergen clean agent fire suppression system. The televator storage area beneath the tank was protected by a wet pipe sprinkler system.

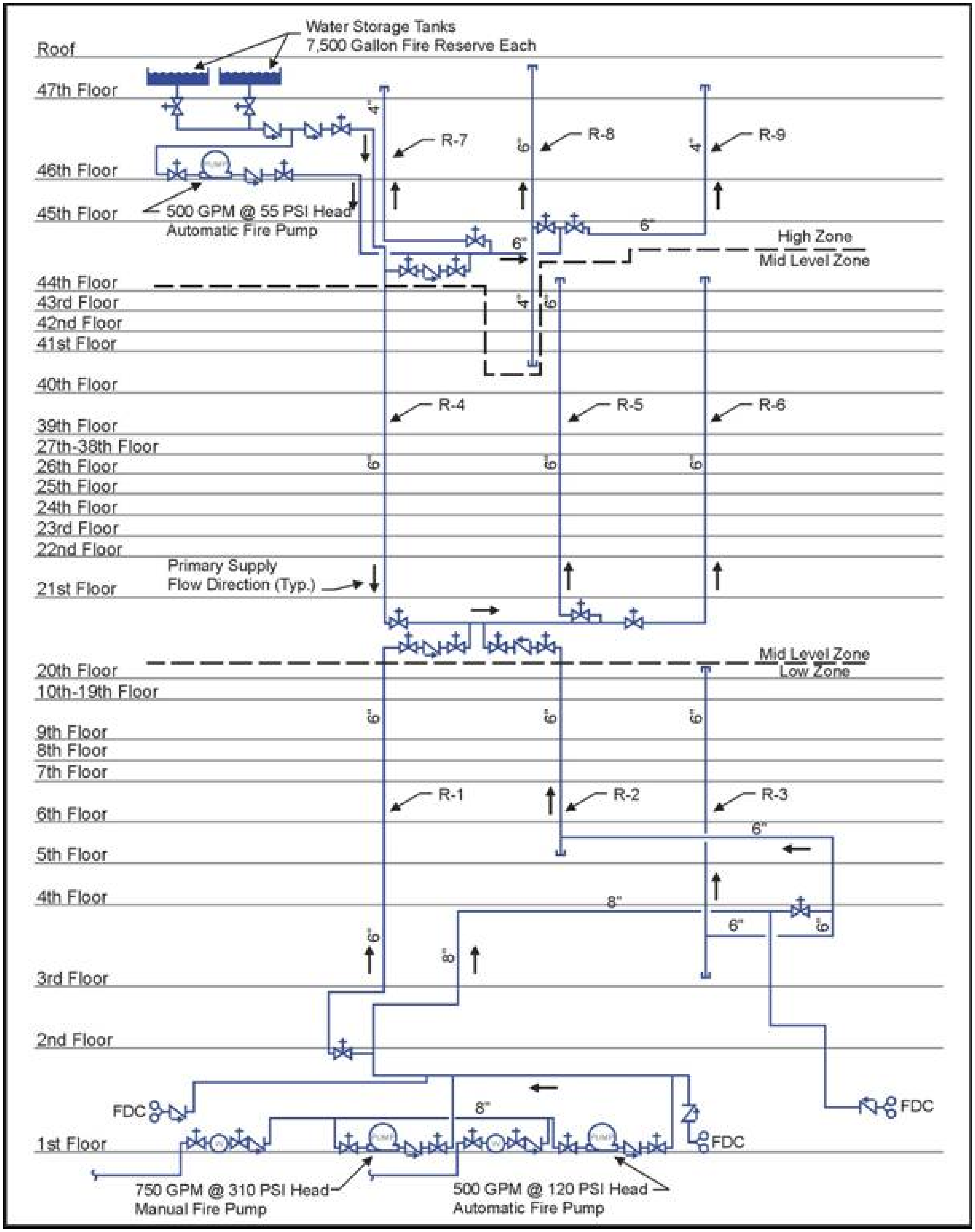
3.5.2 Details of the Standpipe and Sprinkler Riser Systems

Figure 3–8 shows a schematic diagram of the three zone WTC 7 water riser system. Check valves were located at the top of the low and mid-level zones for isolation. The check valves were oriented such that water from the automatic booster pump on the 46th floor could only supply the high zone, and the water storage tanks on the 46th floor could only supply the mid-level zone (Gensler and Associates 1995).

Tanks and Pumps

The combination system for the mid-level zone was primarily supplied with water from two 17,500 gal storage tanks. The water storage tanks were located on the 46th floor and extended up to the 47th floor level. The tanks were used as a domestic water storage system. However, each tank had a fire suppression system reserve capacity of 7,500 gal.

The make-up water to fill each tank was supplied by three 435 gpm capacity booster pumps via an 8 in. domestic express supply riser from the second floor. Each pump was provided with two float switches in each tank. A single pump operated when the water level dropped to a set point established by the electrode control unit. The pumps operated individually but would operate simultaneously if the load exceeded the capacity of one pump (Syska & Hennessy 1984). The tanks were combination domestic and fire water storage tanks. Therefore, the pumps would turn on at a certain drop in water level, due to domestic usage or fire water usage.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–8. WTC 7 water riser schematic.

Both domestic water storage tanks on the 46th floor were joined at the base by a connecting 8 in. pipe. A control valve was in place below each tank on the discharge piping, such that the tanks could be isolated from the system. The 8 in. pipe supplied the automatic booster pump on the 46th floor and the risers (R-4, R-5, and R-6) in the mid-level zone. The elevation of the storage tanks was approximately 600 ft above the first floor. The tanks provided a gravity fed supply to the base of risers R-5 and R-6 on the 20th floor (approximate elevation 255 ft) via standpipe riser R-4. Figure 3–8 illustrates the arrangement. The control valve at the base of riser R-4 would isolate the tank water supply from risers R-5 and R-6 if closed. Common practice would require valves to be provided to allow isolation of a standpipe without interrupting the supply to other standpipes for the same source of supply (NFPA 14).

The automatic booster pump on the 46th floor supplied the combination system risers in the high zone. The pump was a single stage pump rated for 55 psi at 500 gpm (Syska & Hennessy 1984). The water supply for the booster pump came directly from the water storage tanks.

An automatic fire pump on the first floor supplied the combination system risers, hose connections, and sprinkler control valve assemblies in the low zone. The water supply for the fire pump came directly from two separate 8 in. connections to the 12 in. main on Washington Street. The connections to the 12 in. main were separated using an isolation valve (Gensler and Associates 1995).

The pump was a single stage horizontal split case pump rated for 120 psi at 500 gpm. The pump was equipped with a 50 hp, 460 V, three-phase electric driver. The pump was provided with an emergency power source via an automatic transfer switch (Syska & Hennessy 1984).

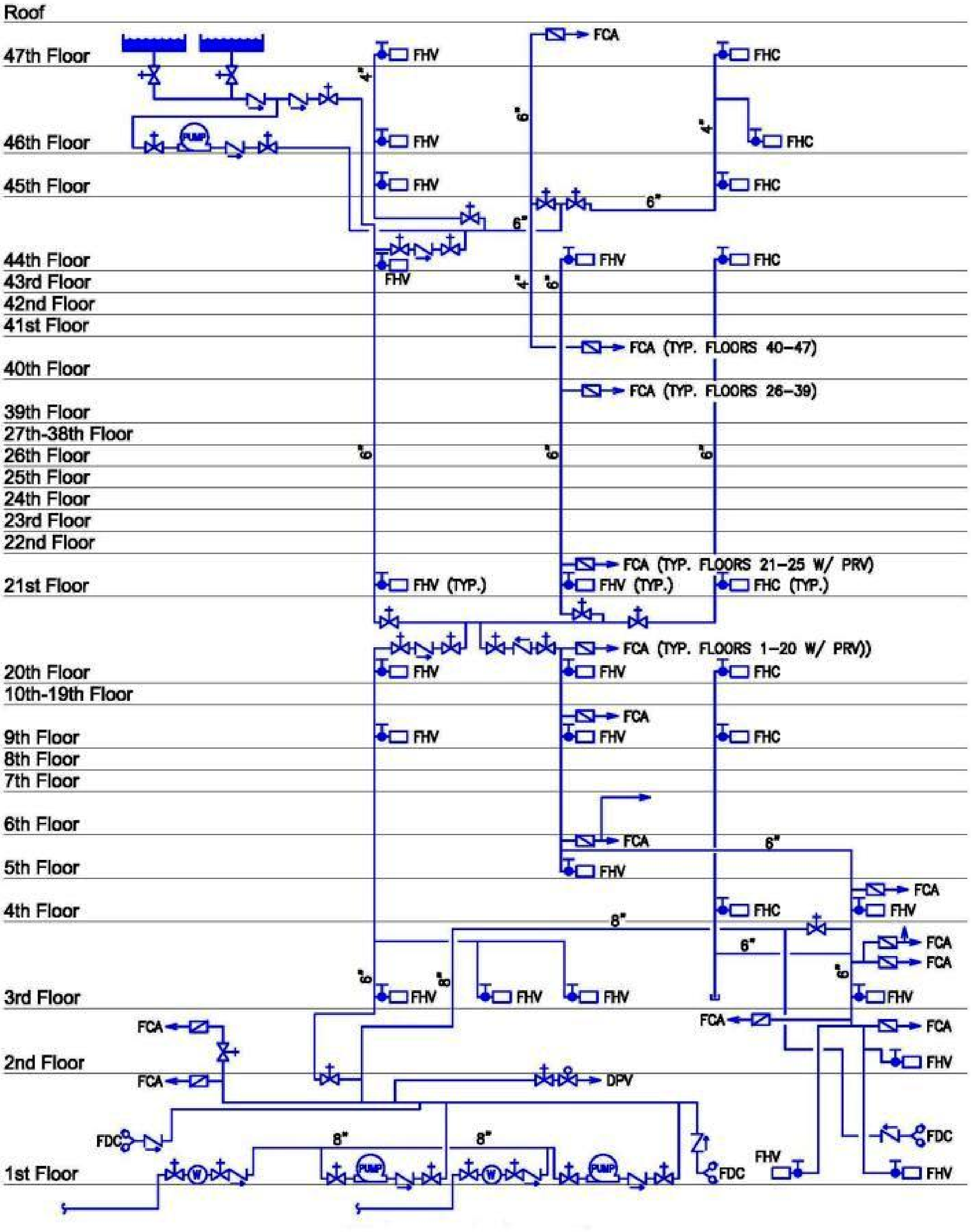
A manual-start electrical fire pump was connected in parallel with the automatic fire pump on the first floor as illustrated in Fig. 3–8. The manual fire pump served as a secondary water supply for the entire combined system throughout the building (Gensler and Associates 1995).

Combination Automatic Fire Sprinkler and Standpipe Systems

WTC 7 had combined automatic sprinkler and standpipe systems, consisting of nine vertical risers in three zones. Each zone consisted of three risers, one combination sprinkler/standpipe riser and two standpipes for manual fire fighting. Therefore, the water supply for a particular zone was common for sprinkler piping and standpipes within that zone. The type, arrangement, and interconnection of the water supplies to the sprinkler systems and hose connections, including standpipe and sprinkler riser locations and zones of influence and isolation valves, are addressed in this section. System components such as valve type, pipe type, and valve locations are also described. Refer to Fig. 3–9 for the water supply riser configuration, valving arrangements, and vertical zones.

High Zone

The high zone included two standpipes and one combination riser that were supplied by an automatic booster pump on the 46th floor. The standpipes are identified as riser 7 (R-7) and riser 9 (R-9). The combination riser is identified as riser 8 (R-8). A cross connection main located on the 44th floor connected each riser. Each riser could be individually isolated from the cross connection main supplying each riser. Note the direction of flow in Fig. 3–8. The water discharged from the tank on the 46th floor, flowing down to the cross connection on the 44th floor where it fed each riser.



Source: Hughes Associates, Inc.

Figure 3–9. Floor control valve and fire hose valve/cabinet locations, WTC 7.

Check valves were located at the top of riser 4 (R-4) of the mid-level zone at the connection with the high zone cross connection main. The check valve was oriented so that water could not flow from the high zone down to lower zones. However, the high zone could be served from lower zones through the check valve by the manual fire pump, which served as a secondary supply.

Figure 3–9 illustrates the vertical orientation of each riser in relation to the fire hose valves (FHV), fire hose cabinets (FHC) and floor control assemblies (FCA) on each floor. Riser 7 (R-7) was a 6 in. standpipe used for manual fire suppression activities. The standpipe was located in stair 1 on the west side of the building and extended from the isolation valve on the 44th floor through to the roof level. Riser 7 supplied FHVs on the 45th, 46th, and 47th floors and a 3 in. by 2½ in. manifold roof hydrant.

Riser 8 (R-8) was a combination sprinkler/standpipe riser located in stair 2 in the center of the building between the 40th floor through the 47th floor. Riser 8 was a 6 in. combination riser supplying the FCAs and FHVs between the 45th and 47th floors. It then was reduced to a 4 in. riser between the 40th and 44th floor where it only supplied the FCAs. Refer to Fig. 3–9. Riser 9 (R-9) was a 6 in. riser located in the utility shaft on the east side of the building. This riser extended from the isolation valve on the 44th floor to the FHC on the 47th floor and supplied FHCs on the 45th, 46th, and 47th floors.

Mid-Level Zone

The mid-level zone also included two standpipes and one combination automatic sprinkler/standpipe riser identified as riser 4 (R-4), riser 6 (R-6), and riser 5 (R-5), respectively. The gravity tanks on the 47th floor were the primary supplies for the mid-level zone.

A cross connection main located on the 20th floor connected the risers to each other. The isolation valves located at the base of risers 5 and 6 could be closed to isolate each riser, respectively. Riser 4 also had a riser isolation valve located at its base. However, the gravity tanks supplied riser 5 and 6 via riser 4 (Fig. 3–8). Therefore, closing the riser isolation valve at the base of riser 4 would also isolate risers 5 and 6 from their primary supply. Risers 5 and 6 were not connected at the top. Typical industry practice in this type of arrangement involving a tank supply would include standpipe interconnections at the top, as well as at the bottom, consistent with NFPA 14 Section 5-5 (2000 edition). Check valves would be installed at the bases of the standpipes in such a case to prevent circulation.

Check valves were located at the top of riser 1 (R-1) and riser 2 (R-2) of the low zone at the connection with the mid-level zone cross connection main. The check valves were oriented so that water could not flow from the mid-level zone down to the low zone. However, the mid-level zone could be served from the low zone through the check valves by the manual fire pump (which served as a secondary supply) or from excess pressure served by the city supply and automatic fire pump serving the low zone.

The following is a description of each mid-level zone riser and the systems that they served. Figure 3–9 illustrates the vertical orientation of each riser in relation to the FHVs, FHCs, and FCAs on each floor.

Riser 4 (R-4) was a 6 in. standpipe used for manual fire suppression activities in addition to serving as the primary supply for risers 5 and 6. Riser 4 was located in stair 1 on the west side of the building. Riser 4 supplied FHVs on the west side of the building from the 21st through the 44th floors.

Riser 5 (R-5) was a 6 in. combination sprinkler/standpipe riser. Riser 5 extended from the cross connection main on the 20th floor through the 44th floor. The riser was located in stair 2 through the 23rd floor. Riser 5 remained in stair 2 through the 44th floor, however, stair 2 shifted approximately 20 ft toward the west from the 24th through the 46th floors. Riser 5 supplied the FCAs and FHVs on each floor from the 21st through the 39th floors. Riser 5 only supplied the FHVs on the 40th through the 44th floors. Each FCA on the 21st through the 25th floors contained a pressure-reducing valve. The pressure-reducing valve regulated the high supply pressure produced by the manual fire pump to within the listed rating of 175 psi for the sprinkler piping components. Riser 6 (R-6) was a 6 in. standpipe that supplied FHCs. This riser was located in the utility shaft below riser 9. It extended from the 21st through the 44th floors. The primary supply for riser 6 was from the water storage tanks on the 47th floor level via riser 4 and the cross connection main on the 20th floor.

Low Zone

The low zone included two standpipes and one combination sprinkler/standpipe riser. Additionally, sprinkler system FCAs and FHVs were located off of the infrastructure piping on the first through fourth floors. Refer to Fig. 3–9 for piping and valving arrangements. The standpipes and combination riser are identified as riser 1 (R-1), riser 3 (R-3), and riser 2 (R-2), respectively. The automatic fire pump located on the first floor was the primary supply for the low zone.

Riser 1 was connected to the discharge side of the pump manifold. The isolation valve for riser 1 was located in the first floor pump room. An 8 in. cross connection main extended from the first floor fire pump room, on the west side of the building, up to the third floor via stair 1. The cross connection extended to the east side of the building to an isolation valve in stair 2. Figure 3–8 illustrates that both risers 2 and 3 were controlled from a single isolation valve (Gensler and Associates 1995).

The following is a description of each low zone riser and the systems that it served. Figure 3–9 illustrates the vertical orientation of each riser in relation to the FHVs, FHCs, and FCAs on each floor.

Riser 1 (R-1) was a 6 in. standpipe feeding FHVs only. Riser 1 was located in stair 1 on the west side of the building. It extended from the 1st floor fire pump room through the 20th floor. On the fifth floor, riser 1 shifted further toward the center of the building with stair 1. Note the valving orientation at the top of riser 1. Water could feed the mid-level zone from riser 1 by flowing through the check valve. The mid-level and high zones could also be isolated from the system infrastructure by closing the isolation valves at the top of risers 1 and 2.

Riser 2 (R-2) was a 6 in. combination sprinkler/standpipe riser. Riser 2 was located in stair 2, which was located in the west side of the building through the fourth floor. Stair 2 then shifted to the center of the building on the fifth floor. Therefore, riser 2 also shifted to the center of the building on the fifth floor. Riser 2 supplied the FCAs and FHVs at the stair landings on the 5th through 20th floors. The top of riser 2 was equipped with a valving arrangement similar to that of riser 1, allowing isolation or flow to the mid-level cross connection. Also, each FCA on riser 2 was equipped with a pressure-reducing valve to regulate the pressure produced by the manual fire pump down to within the rated working pressure of the sprinkler piping.

Riser 3 (R-3) was a 6 in. standpipe that fed FHCs. Riser 3 was located in a utility shaft on the east side of the building below riser 6. It extended from the 3rd to the 20th floors. Riser 3 was only used to supply the FHCs on each floor; it was not connected to the mid-level cross connection as were risers 1 and 2.

3.6 CONSISTENCY WITH ENGINEERING BEST PRACTICES

An evaluation of the consistency of the documented sprinkler and standpipe system installations with applicable codes and standards provisions and state-of-the-art engineering "best practices" during the time of construction of the buildings was performed for WTC 1, 2, and 7. The intent of this evaluation was to determine if the installed suppression system infrastructure (excluding tenant space fit-outs that were not investigated) in these three buildings were designed and installed in a manner consistent with performance expectations associated with applicable codes and standards, as well as those related to recommended best practices at the time of the design and construction of the buildings. The results of this evaluation indicated that, according to the documents examined, the fire suppression systems in WTC 1, 2, and 7 were installed in a manner consistent with best practices in existence at the time of their installation, with few exceptions. In recent years, there have been advances in sprinkler technology, such as faster responding sprinklers. Use of faster responding sprinklers available today would not have materially affected the design of the water supply, standpipe, and sprinkler riser systems that are the focus of this investigation.

3.7 WTC 1, 2, AND 7 SUPPRESSION SYSTEM INSTALLATION DIFFERENCES

WTC 1 and WTC 2 were constructed in the 1970s. Some of the fire suppression infrastructure was installed at that time. However, the automatic sprinkler systems were installed later, in the 1980s and 1990s. Construction of WTC 7 was completed in 1986, and all of the fire suppression features for WTC 7 were installed as part of the initial construction of the building.

The primary water source for all three buildings originated from the NYC water distribution system (PANYNJ 1972, 1987, 1986; Beyler 2002). The towers were supplied from the sub-grade loops on the north and south sides of the complex at two remote locations. The two mains provided redundant supplies and had isolation valves to allow for independent operation of either main without impairing the fire suppression systems in the WTC complex. Two mains located within 12 ft of each other supplied WTC 7 from the same NYC water distribution system main. The standpipe systems in all three buildings were similar in design to NFPA 14 Class III type standpipes. The primary difference between the sprinkler and standpipe systems in WTC 7 and those in the towers was that the sprinkler and standpipe systems in WTC 1 and WTC 2 were supplied by separate risers, and the sprinkler and standpipe systems in WTC 7 were combined. Both arrangements were permitted according to NFPA 14.

Multiple water supply zones were provided in each building. The standpipe systems in WTC 1 and WTC 2 included four vertical zones. The sprinkler system infrastructures in WTC 1 and WTC 2 included three vertical zones. The combined sprinkler and standpipe systems in WTC 7 had three vertical zones.

Water storage tanks were used as the primary water supplies for all sprinkler and standpipe system zones in WTC 1, 2, and 7, except for the low zones of WTC 7 which were supplied by the NYC water distribution system through a 500 gpm automatic fire pump. A single 750 gpm manual-start fire pump was used as the secondary water supply for the combined sprinkler and standpipe systems in WTC 7. A series of four vertical 750 gpm manual-start fire pumps were used in each tower.

Sprinklers were provided essentially throughout all areas of WTC 1, 2, and 7. Sprinklers were omitted from the MERs in WTC 1 and WTC 2. The electrical, data/telephone, and generator rooms that were part of the core areas in WTC 7 were not protected by the wet pipe sprinkler systems. The sprinkler systems in all three of the buildings were designed and installed with looped mains and were capable of delivering robust discharge densities exceeding the code required minimum densities. Pressure reducing valves were used in all three buildings. Although the configurations were different, it is doubtful there were any significant advantages or disadvantages in the systems on September 11, 2001.

The types of special hazard fire suppression systems in each building were different, but no information was found that indicated these systems played a significant role in fire control or the loss of fire control on September 11, 2001. While limited information was available regarding the actual performance of the installed fire suppression systems on September 11, several design features were identified that could be improved upon in future installations. For example, in WTC 1 and WTC 2, the supply from the primary water storage tanks on the 110th floor to the sprinkler systems included a long horizontal length (greater than 100 ft) of 4 in. diameter pipe on the floor directly under the tanks that led to the vertical riser. Due to the associated friction loss in this long run of pipe, the flow was unnecessarily limited on the upper floors.

In WTC 7, the automatic sprinkler systems on floors 1 through 20 were supplied directly from the city distribution system through an automatic fire pump located on the 1st floor (PANYNJ 1987a). Either a loss of power to the fire pump or significant damage to the underground city main in the vicinity of the building could interrupt the water supply to these sprinkler systems. A simple means of backing up the primary water supply for floors 1 through 20 would have been to provide secondary access to the stored water on the upper floors of the building. There is not enough information about the initiating fires to determine if access to the stored water in the low zone of the building would have had a significant impact on the spread of the fires or on the FDNY decision not to fight the fires.

3.8 WATER SUPPLY CAPACITIES FOR WTC 1, 2, AND 7 SPRINKLER SYSTEMS

Hydraulic calculations were performed to evaluate the expected sprinkler system performance based on the configuration of the water supply (NIST NCSTAR 1-4B). The objective of the analysis was to determine any variations in the performance of the sprinkler systems in each building and within each water supply zone. The initial water supplies for the systems were primarily gravity fed from stored water tanks. A group of sprinkler systems from each building was selected for analysis. Sprinkler systems near the top and the bottom of each water supply zone were selected to bound the effects of elevation on the performance of these sprinkler systems. In some cases, intermediate systems were also selected for evaluation because the arrangements of the systems varied as a result of using outside screw and yoke or pressure reducing type control valves. A commercial computer program, Hydraulic Analyzer of Sprinkler Systems, Version 7.5 was used to perform the calculations (HRS Systems 2004).

Several factors were examined as part of this analysis. Supply calculations were used as a means to compare the flow rate of water delivered from the primary and secondary supplies to the sprinkler systems. Calculations were also performed with variations in the number of sprinklers flowing water for the highest and lowest floor level sprinkler systems to observe the effects on the discharge density of the sprinkler systems and water supply duration (i.e., how long the flow could be maintained). The intent of this analysis was to provide sufficient information to characterize the capabilities of the water supplies.

The automatic sprinkler systems were provided with both primary and secondary water supplies. In most cases the supply piping was configured to provide redundant supply paths to the water supply zones in the buildings. This arrangement would have allow for continued sprinkler operability in the event that one of the supply paths was interrupted.

The results of the hydraulic calculations for the Light Hazard occupancy sprinkler systems in WTC 1 and WTC 2 (see Table 3–4) indicated that the expected water densities and duration of the water supplies exceeded the baseline levels customarily provided for fire hazards represented by high-rise office building occupancies (0.10 gpm/ft^2), with supply densities ranging from 0.10 to 0.27 gpm/ft^2 with up to 16 open sprinklers. The associated flow rate could be maintained from the primary water supply source for approximately 10 to 89 min, depending on the location and number of open sprinklers.

Table 3–4. Results of hydraulic calculations.

Building	Occupancy Hazard	Number of Open Sprinklers	NFPA 13 Delivered Density (gpm/ft^2)	Calculated Delivered Density (gpm/ft^2)	Calculated Duration (min)
WTC 1 and WTC 2	light	4	0.10	0.14 – 0.27	33 – 89
WTC 1 and WTC 2	light	8	0.10	0.13 – 0.18	18 – 39
WTC 1 and WTC 2	light	16	0.10	0.10 – 0.15	10 – 33
WTC 1 and WTC 2	ordinary	4	0.15	0.33 – 0.56	18 – 61
WTC 1 and WTC 2	ordinary	15	0.15	0.22 – 0.38	8 – 27
WTC 1 and WTC 2	ordinary	25	0.15	0.15 – 0.22	9 – 26
WTC 7	light	4	0.10	0.17 – 0.38	87 – 133[a]
WTC 7	light	9	0.10	0.16 – 0.22	45 – 61[a]
WTC 7	light	18	0.10	0.11 – 0.16	31 – 45[a]

a. Duration for low zone is controlled by the availability of the NYC water supplied.

Similarly, the results of the calculations for Ordinary Hazard Group 1 sprinkler systems in WTC 1 and WTC 2 indicated that a density ranging from 0.15 to 0.56 gpm/ft^2 could be provided for up to 25 open sprinklers for 9 to 61 min. The delivered density specified in the NFPA 13 standard for Ordinary Hazard occupancies is 0.15 gpm/ft^2.

The results of the calculations using the Light Hazard criteria for the sprinkler systems in WTC 7 indicate that the available water density ranging from 0.17 to 0.38 gpm/ft^2 could be maintained for four open sprinklers for 87 to 133 min. A density of 0.16 to 0.22 gpm/ft^2 could be provided to nine open sprinklers for 45 to 61 min. And a density of 0.11 to 0.16 gpm/ft^2 could be provided to 18 open sprinklers for 31 to 45 min. The durations do not apply to the low zone sprinkler systems because water was supplied from an automatic fire pump drawing suction directly from the NYC distribution. Therefore, the supply would be continuously provided as long as the water distribution and electrical systems were intact and operational.

Details of the hydraulic calculations can be found in the subject report (NIST NCSTAR 1-4B).

3.9 SUPPRESSION SYSTEM PERFORMANCE UNDER SELECTED FIRE SCENARIOS

As a baseline for further understanding of the performance of the installed fire suppression systems, and specifically understanding the limitations with respect to the fires on September 11, 2001, the expected performance of the automatic sprinkler systems and the standpipe/pre-connected hose systems in WTC 1, 2, and 7 was analyzed for selected fire scenarios. A lack of performance criteria and history for standpipe systems limited the evaluation of the pre-connected hoses.

Hydraulic analyses relied on the minimum delivered density and pressure requirements in NFPA 13 as the basic criteria for evaluating the fire control capacity of the sprinkler systems. It is important to recognize that in NFPA 13 the required densities and pressures are based on the assumption that an installed fire sprinkler system is designed to control a single fire. In addition, in the analyses performed here, small fires were assumed to be approximately the size of the area covered by a four-sprinkler array (i.e., approximately 750 ft^2). In fact, available performance history indicates that typical fires in high-rise office buildings are controlled or suppressed by less than four sprinklers, lending additional conservatism to the estimates of system capacity presented here. Finally, the calculations were based on availability of the primary water supplies only, without any consideration for fire department actions to provide a secondary water supply.

In NYC such action is routine, and the secondary water supply is considered infinite in duration, with equivalent or higher capacity to the primary water supply. At the same time, due to the normal availability of a reliable, high capacity secondary water supply, duration of water supply was not included in this analysis.

While it is difficult to assess the performance capabilities of the standpipe pre-connected hoses, hydraulic calculations indicated that the size of the standpipes and the capacity and number of fire pumps were consistent with the requirements for pressure and flow in the BCNYC for both WTC 1 and WTC 2. However, the booster pump on the 46th floor was undersized, and could not provide the higher minimum flow and pressure required in NFPA 14.

3.9.1 Scenarios

Hydraulic calculations using the supply calculation approach were used to analyze the capacity of the water supply to the sprinkler systems in WTC 1, 2, and 7 (NIST NCSTAR 1-4B). For a supply calculation, the water supply and sprinkler system configuration are given. The water flow from the supply is relayed forward through the system, overcoming the pressure losses due to friction and elevation, until the water discharges from the designated sprinklers. Supply calculations are used to show the actual or maximum discharge density that the water supply is capable of delivering to the sprinkler system.

It was considered impractical to perform hydraulic calculations for every floor and every subsystem. Therefore, representative system configurations were selected to represent conditions within each water supply zone. Configurations were chosen to provide bounding results (in terms of available pressure, flow and duration) for each vertical hydraulic zone in the buildings.

This approach limited the number of cases to a manageable level and at the same time provided representative results applicable to any location in the buildings. The results also provided the baseline information needed to evaluate the performance capabilities of the sprinkler systems. The calculations were based on the following bounding conditions for each vertical zone:

Water Supply

- Primary–water storage tanks and/or automatic fire pumps
- Secondary–manual fire pumps or water storage tanks

Number of Operating (Opened) Sprinklers

- Four sprinklers–smaller than the required design area
- Eight to 15 sprinklers–design area for light or Ordinary Hazard Occupancy
- Eighteen to 25 sprinklers–larger than the required design area

Floor Level within the Vertical Zone

- WTC 1 and WTC 2
    - 107th floor (highest floor system in high water supply zone)
    - 99th floor (lowest floor system in high water supply zone)
    - 98th floor (highest floor system in mid-level water supply zone)
    - 87th floor (lowest floor system in mid-level water supply zone without a PRV)
    - 86th floor (highest floor system in mid-level water supply zone with a PRV)
    - 32nd floor (lowest floor system in mid-level water supply zone with a PRV)
    - 31st floor (highest floor system in low water supply zone)
    - 9th floor (lowest floor system in low water supply zone without a PRV)
    - 7th floor (highest floor system in low water supply zone with a PRV)
    - 2nd floor (lowest floor system in low water supply zone with a PRV)

- WTC 7
    - 47th floor (highest floor system in high water supply zone)
    - 40th floor (lowest floor system in high water supply zone)
    - 39th floor (highest floor system in mid-level water supply zone)
    - 21st floor (lowest floor system in mid-level water supply zone)
    - 20th floor (highest floor system in low water supply zone)
    - 1st floor (lowest floor system in low water supply zone)

Each combination of the conditions listed above was used to develop supply calculations. The supply calculations provided estimates of the actual water flow rate and pressure that would be expected based on typical sprinkler system arrangements. The duration was determined by dividing the storage capacity by the calculated flow rate. The calculations did not account for the supplemental make-up supplies from the automatic refill lines supplied by the domestic water supply systems. The results of these calculations were intended to approximate the actual delivered discharge densities based on representative sprinkler system layouts provided from the available documentation of the systems. The results are considered to more accurately represent the actual performance as compared to using the minimum required flow rates determined by multiplying the density times the design area specified by NFPA 13 for the applicable hazard.

Calculations for the sprinkler systems in WTC 1 and WTC 2 were performed for several different coverage areas based on the available documentation for the systems. The calculations for Light Hazard areas in WTC 7 used a coverage area of 168 ft^2. The calculations for all systems used k=5.6 $\text{gpm/psi}^{1/2}$, ½ in. orifice sprinklers.

3.9.2 Results

Simultaneous fires on different floors were examined as a challenging scenario to aid in understanding the performance limits of the sprinkler systems. The results presented here apply to the sprinkler systems in the high- and mid-level zones of WTC 1 and WTC 2, and involved fires equivalent in size to the design area of the sprinkler systems. (Refer to NCSTAR 1-4B for additional scenarios and for a similar analysis of the sprinkler system in WTC 7.)

The first set of scenarios involved multiple fires on the 102nd through 106th floors, representing the high zone. Each case included eight sprinklers per system starting with the 106th floor system and adding eight sprinklers on the subsequent floor below until the water supply could not support any additional sprinklers and maintain the limiting delivered density of 0.1 gpm/ft^2. Table 3-5 summarizes the results from the cases evaluated.

Table 3–5. High zone average delivered density per floor vs. number of floors flowing (eight sprinklers/floor), WTC 1 and WTC 2.

Floor	106	105 & 106	104–106	103–106	102–106
106	0.1386	0.1268	0.1101	0.0913	0.0753
105	-	0.1314	0.1149	0.0964	0.0803
104	-	-	0.1200	0.1018	0.0858
103	-	-	-	0.1074	0.0920
102	-	-	-	-	0.0983

The results indicate that the water supply could have supported eight sprinklers on three consecutive floor levels and provided a minimum average density greater than 0.1 gpm/ft^2. The results also indicated that the water supply and supply piping could have supported a maximum of five sprinkler systems, although the delivered densities and end-sprinkler pressures could have dropped slightly below 0.1 gpm/ft^2 and 7 psi, respectively.

Calculations were performed to evaluate a second set of scenarios involving multiple fires on the 98th and 97th floor, in the mid-level zone. Table 3-6 provides a summary of the results of these calculations.

Table 3–6. Mid-level zone average delivered density per floor vs. number of floors flowing (eight sprinklers/floor), WTC 1 and WTC 2.

Floor	98	97 & 98
98	0.1288	0.1200
97	-	0.2346

The results involving the sprinkler systems in this mid-level zone indicate that the riser and water supply would have been expected to control or extinguish two fires equal to the size of the design area. The supply riser size limited the water flow to 440 gpm, which was a limiting factor for the system capabilities.

These results indicate that a fire approximately three times the size of the design area (or about 4,500 ft^2) located in the upper water supply zone would have been controlled by the sprinkler system, based on the performance criteria used in this analysis. The maximum fire size was approximately two times the design area for the mid-level locations.

The estimates of the maximum fire size coincided with the maximum sprinkler coverage area that could deliver the minimum spray density of 0.1 gpm/ft^2 at pressures greater than or equal to 7 psi throughout the coverage area. These fire sizes (3,000 to 4,500 ft^2) represent a relatively small part of the total occupied floor area of approximately 31,000 ft^2. However, automatic sprinkler systems are designed to control or suppress fires that are initially considerably smaller than the 1,500 ft^2 design area, which are the types of fires normally encountered in high-rise office buildings.

The calculations identified limits of performance, but the estimated performance was significantly greater than that required in NFPA 13. The available densities and pressures indicated that the installed systems generally exceeded the minimum requirements in NFPA 13 by significant margins. These systems would have been expected to control multiple small fires or single large fires up to two or three times the sprinkler system design area, and would have been considered robust installations with considerable excess capacity. At the same time, if large fires were to open all of the sprinklers in an area equivalent to two to three times the design area of the sprinkler systems, the hydraulic capabilities of the system(s) would degrade, and although these fire areas would be considered relatively large (i.e., 3,000 to 4,500 ft^2), they represented roughly 8 to 15 percent of the area of a single occupied floor in WTC 1, 2, and 7.

Flow restrictions existed in the mid-level water supply zones in WTC 1 and WTC 2, but the limits of available water flow were still considerably higher than those required in NFPA 13 for control of typical Light Hazard fires.

3.10 ESTIMATES OF SUPPRESSION SYSTEMS PERFORMANCE ON SEPTEMBER 11, 2001

The likely performance of the automatic fire sprinkler and standpipe systems in WTC 1, 2, and 7 on September 11, 2001, was analyzed (NIST NCSTAR 1-4B). A sequence of the five major events was used to structure this evaluation. These events included the separate aircraft impacts into WTC 1 and WTC 2, the collapse of WTC 2, the collapse of WTC 1, and the collapse of WTC 7.

The analysis attempted to answer four key questions in order to assess the performance of the systems on September 11, 2001.

1. What happened to the systems as a result of each major event?
2. What actions may have helped to maintain the systems operability?
3. How was the performance of the systems impacted by each event?
4. At what point in the sequence of events were the systems lost?

The damage to WTC 1 as a result of the aircraft strike was concentrated on floors 94 through 97. Based on best estimate analysis of impact damage (NIST NCSTAR 1-2B), the survival of sprinkler and standpipe risers in stairwells was estimated from the level of damage to surrounding structural and wall board enclosures. Table 3–7 provides stairwell damage estimates from the NIST best estimate analysis.

Table 3–7. Damage estimates to WTC 1 from aircraft impact.

Floor	Stairwell Damage (Stairwell Position Relative to Core)		
	Stair A (1) (Northeast Quadrant)	**Stair C (2) (Northwest Quadrant)**	**Stair B (3) (Southeast Quadrant)**
94	Wallboard Destroyed	Structural Damage	Wallboard Destroyed
95	Wallboard Destroyed	Structural Damage	Wallboard Destroyed
96	Wallboard Destroyed	Wallboard Destroyed	Wallboard Destroyed
97	Wallboard Intact	Wallboard Destroyed	Wallboard Intact

Assuming that all risers were lost in stairwells suffering damage to adjacent structural members (Structural Damage) or debris damage to the stairwell enclosure (Wallboard Destroyed) the following effects were likely to have occurred:

- Loss of standpipe riser FS-F1.
- Loss of standpipe riser FS-F2.
- Possible loss of standpipe riser FS-F3.
- Loss of standpipe system water supply after a limited amount of time as a result of the damage to the standpipe risers.
- Loss of sprinkler systems on the 94th through 96th floors.
- The effectiveness of the sprinkler systems in the high and mid level zones was reduced, however, the systems were capable of containing small fires on multiple floors.
- Possible loss of the sprinkler systems on other floors immediately above the 96th floor and below the 94th floor.
- Loss of sprinkler system water supply after a limited amount of time as a result of the damage to the standpipe risers.

It is not likely that the WTC 1 aircraft strike damaged the sprinkler and standpipe systems and associated water supplies in WTC 2 or WTC 7. Therefore, it is likely that these systems remained intact and operational.

Assuming the damage listed above, it would have been physically possible to partially restore the fire protection systems in WTC 1. The standpipe risers contained isolation valves on the 88th and 99th floors. The standpipe reserve water storage on the 110th floor could have been used to supply water to the hose stations above the 99th floor. The manual fire pumps and FDCs could have been used to supply water to the hose stations below the 88th floor. However, the status of these systems was unknown and communications from above and below the impact zone were sporadic, making it unlikely that partial restoration would have been practical even if the procedure were documented ahead of time.

The initial damage to the sprinkler systems was localized to the 94th through 96th floors. It is possible, but unlikely, that the floor control valves for these systems could have been used to isolate these systems to allow the riser to supply the sprinkler systems on other floors without any reduction in effectiveness. This would have to have been accomplished immediately after the initial impact, before the loss of fire resistive construction required for fire confinement to that part of the building.

The damage to WTC 2 as a result of the aircraft strike was concentrated on floors 78 through 81. Based on best estimate analysis of impact damage (NIST NCSTAR 1-2B), the survival of sprinkler and standpipe risers in stairwells was estimated from the level of damage to surrounding structural and wall board enclosures. Table 3–8 provides stairwell damage estimates from the NIST best estimate analysis.

Table 3–8. Damage estimates to WTC 2 from aircraft impact.

	Stairwell Damage (Position of Stairwell on Floor or in Core)		
Floor	**Stair A (1) (Northwest Quadrant)**	**Stair C (2) (Southwest Quadrant)**	**Stair B (3) (Northeast Quadrant)**
78	Wallboard Intact	Wallboard Intact	Wallboard Destroyed
79	Wallboard Intact	Wallboard Destroyed or Intact	Wallboard Destroyed
80	Wallboard Intact	Wallboard Intact	Wallboard Destroyed
81	Wallboard Intact	Wallboard Intact	Wallboard Intact

Assuming that all risers were lost in stairwells suffering damage to adjacent structural members (Structural Damage) the following effects were likely to have occurred:

- Loss of sprinkler riser B (located in the northeast quadrant).
- Loss of sprinkler and standpipe system water supplies after a limited amount of time as a result of the damage to sprinkler riser B.
- Loss of the sprinkler systems on the 78th through 81st floors.
- Loss of water supply to the sprinkler systems on floors 32 through 78.
- The effectiveness of the sprinkler systems above the 79th floor was significantly reduced as a result of the loss of riser B.
- Possible loss of the sprinkler systems on other floors immediately above the 96th floor and below the 94th floor.

Loss of the standpipe system risers was not foreseen, and manual fire pumps and FDCs were still likely to have been operable. No information was found that indicated that the sprinkler and standpipe systems and associated water supplies in WTC 7 were damaged as a result of the WTC 2 aircraft strike. It is also unlikely that further damage to the sprinkler and standpipe systems in WTC 1 occurred as a result of the WTC 2 aircraft strike.

The collapse of WTC 2 likely impacted the fire protection systems in WTC 1 as a result of the damage incurred to the sub-grade sprinkler and standpipe loops and damage caused by vibration and pressure waves. It is also likely that the collapse of WTC 2 damaged the NYC water distribution system near WTC 2. The configuration of the system would have minimized any impact to the fire protection systems in WTC 1 and WTC 7.

It is likely that the collapse of WTC 1 caused significant damage to the water distribution system. It was reported that burning debris caused fires in WTC 7 as a result of the collapse of WTC 1 (NIST 2004). However, no evidence was found that the integrity of the sprinkler and standpipe riser systems was affected. No fire department actions were taken to suppress fires in WTC 7 once the building was evacuated. An eyewitness account indicated that at some point there was no water to the standpipes. The cause of this is unknown, but could have resulted from a loss of power to the fire pumps, diversion of the water from the standpipes for other fire department operations, and/or the inability of the fire department to supplement the water supply to WTC 7 using the FDCs. A decision was made to not initiate fire fighting activities in WTC 7. It was reported that hose lines connected to the standpipe system in WTC 7 were used to fight fires in other buildings of the WTC complex prior to the collapse of any of the buildings. WTC 7 stood for nearly seven hours after WTC 1 collapsed before succumbing to the fire. The actual effectiveness of the sprinkler systems in WTC 7 would have degraded considerably over that period of time. If the city water supply to the building was interrupted, the sprinkler systems on the lower 20 floors would not have had adequate water to operate properly.

3.11 SUMMARY OF FINDINGS

The following list summarizes the key findings from the review of the building designs and analysis of the water supplies, sprinklers, and standpipe systems (NIST NCSTAR 1-4B):

- In general, the water supplies, automatic sprinklers, and standpipe/pre-connected hose systems in WTC 1, 2, and 7 were determined to be robust, and exceeded the minimum applicable code requirements as well as associated engineering best practices.

- Sprinkler protection was installed throughout WTC 1, 2, and 7 on September 11, 2001, with the exception of specific rooms and spaces where sprinkler protection was permitted to be omitted by the Building Code of the City of New York (BCNYC).

- The water supplies for WTC 1 and WTC 2 and floors 21 through 47 of WTC 7 included large capacity storage tanks and direct connections to the NYC water distribution system. These supplies provided redundant sources of water for the standpipe and sprinkler system infrastructures. The storage tanks provided adequate duration of supply for normally expected fire exposures to allow the fire department to respond and supplement the demand.

- The lower floors (1 through 20) in WTC 7 were supplied directly from the NYC water distribution system through two service lines from the street main on Washington Street. An automatic fire pump was used to supply the water to the combined sprinkler and standpipe risers. The water supply tanks located in the upper part of the building did not service the lower floors. A manual fire pump and secondary connection to the NYC water system were provided for the lower floors rather than using water supply tanks. Therefore, there wasn't a secondary source of water in the event the NYC system became inoperable.

- The installation of the supply piping from the storage tanks on the 110th floor in WTC 1 and WTC 2 included a long horizontal length (greater than 100 ft) of 4 in. diameter pipe, which restricted the flow to several floors. The flow capacity was sufficient to supply the suppression systems, but the installation was not consistent with current engineering best practices.

- The suppression systems in WTC 1, 2, and 7 required manual operation of the electric fire pumps in order to provide secondary water. An automatic supplemental water supply is required by NFPA 14 and represents current best practice. Whether or not the building maintenance staff performed this task on September 11, 2001, could not be confirmed. Due to the extensive damage to the sprinkler and standpipe systems in WTC 1 and WTC 2, however, it is doubtful that automatic pumps would have made any difference in performance.

- The supply risers and related infrastructure for the automatic sprinkler systems in WTC 1, 2, and 7 were configured to provide redundant capabilities. However, the typical floor level sprinkler system was installed with one connection to the sprinkler riser, providing a single point of failure of the water supply to the floor level sprinklers.

- Based upon the documents examined, the sprinkler systems installed in WTC 1, 2, and 7 were appropriately designed, with calculated water spray densities considerably greater than typically provided for high-rise office buildings. The sprinkler systems met or exceeded the applicable installation requirements in the BCNYC and NFPA 13. There were several design features that were considered inconsistent with current engineering best practices, but no evidence was found to indicate that these features affected the events that occurred on September 11, 2001.

- Based on hydraulic analyses it was estimated that the sprinkler systems could have provided fire control at coverage areas up to two or three times the specified design area of 1,500 ft^2. However, while this capability would be considered very robust, a coverage area of 3,000 to 4,500 ft^2 constituted less than 15 percent of the floor area of a single floor in these buildings. Estimates of the intensity and extent of the initial fires in WTC 1 and WTC 2 on September 11, 2001, were considerably greater than two to three times the specified design areas, and involved multiple floors. While there was no way to confirm the extent of the initial fires, it is likely that a large number of sprinklers would have been opened on multiple floors. Additionally, the aircraft impact damaged the sprinkler system infrastructure, reducing effectiveness. Once the number of open sprinklers or the extent of system damage area exceeded an area equivalent to two or three times the design areas the system's ability to control the fire would have been reduced, and the duration of the primary water supply would have rapidly degraded.

- Documentation indicated that the standpipe preconnected hose system installations were consistent with the applicable requirements in the BCNYC. They were not consistent with the flow rates and durations required in NFPA 14.

- No information was found that indicated that the generator/fuel day-tank enclosures in WTC 7 on floors 5 and 7 were protected by automatic sprinklers or other special hazards protection;

however, the generator rooms on the 8th and 9th floors were protected with sprinklers and, a 6,000 gal fuel oil storage tank on the first floor was protected with an Inergen clean agent system.

- Primary and backup power was provided in all three buildings, but the absence of remote redundancy of the power transmission lines to emergency fire pumps could have affected the operability of the sprinkler and standpipe systems once power was lost.

- The roles of the special fire suppression systems that were installed in WTC 1, 2, and 7 on September 11, 2001, could not be determined due to the absence of any information regarding their performance.

- Due to the magnitude of the fires and the likely damage sustained to the suppression systems infrastructures in WTC 1 and WTC 2, it is not unexpected that the suppression systems present in these buildings failed to control the fires on September 11, 2001. Although the installed sprinkler systems were determined to be appropriately designed, the initial sizes of the fires likely overwhelmed the sprinkler systems, and even if the systems had been designed to protect much higher hazard levels (i.e., Ordinary Group II or Extra Hazard), the magnitude of these fires would have resulted in the fires not being controlled.

Chapter 4

FIRE ALARM SYSTEMS

The purpose of a building fire alarm system is to detect fires, notify occupants, summon emergency responders, and provide information to help manage the response. The applicable local building and fire codes establish basic requirements for the fire alarm system. The fire alarm system layout and interaction with other building systems are established by the designers as part of the fire protection plan for a facility. For World Trade Center (WTC) 1, 2, and 7, the primary monitoring and control of the fire alarm system was performed from the Fire Command Station (FCS) within each building. This station and its redundant sites received signals from fire detection devices installed throughout the towers. In response to this automatic fire detection, voice announcements or tone notification could be sent to selected floors or throughout the entire building. The FCS provided means for two-way telephone communications for fire fighters, floor fire wardens, and operators in the mechanical and air handling control rooms. The Fire Department of the City of New York (FDNY) could be notified manually from the FCS. Upon arrival, fire fighters commanded the response from the FCS, using the information and communications provided to understand conditions in the building and aid in the response.

The design and installation of the fire alarm systems in WTC 1, 2, and 7, including the capabilities for emergency communications, have been documented in National Institute of Standards and Technology (NIST) NCSTAR 1-4C prepared for NIST by Rolf Jensen & Associates, Inc. Based on information collected in the investigation and early damage estimates for WTC 1 and WTC 2, the performance capabilities of the systems on September 11, 2001, were estimated. Statements from survivors, video, and voice recordings available later in the investigation were used to assess and improve earlier predictions.

All resources used in the investigation of the fire alarm systems in WTC 1, 2, and 7 are documented in NIST NCSTAR 1-4C. In addition, the fire alarm record for WTC 7 was obtained from AFA Protective Systems, Inc. AFA Protective Systems, Inc provided central station monitoring services for the fire alarm system from an off-site location.

Even though the on-site documentation for the fire alarm systems in WTC 1, 2, and 7 were lost, the investigation gathered documents from alternate sources to help piece together the specifications, design, installation, and maintenance of these systems. Much more information was available to the investigation for WTC 1 and WTC 2 than for WTC 7. In particular, information about the replacement of the WTC 1 and WTC 2 fire alarm systems installed after the bombing in 1993 was valuable in this investigation.

4.1 WTC 1 AND WTC 2 FIRE ALARM SYSTEMS

4.1.1 History

The fire alarm system protecting WTC 1 and WTC 2 on September 11, 2001, was a total replacement for the original system that was damaged by the bombing on February 26, 1993. Details about the originally installed fire alarm system (PANYNJ 1986) are provided in NIST NCSTAR 1-4C. The bomb that exploded on the B-2 level of the underground parking garage totally destroyed the original WTC 1 and WTC 2 fire alarm signaling and communication wiring entering the Operations Control Center (OCC) on the B-1 level. That event effectively made the fire alarm system at the time nonfunctional. Although electricians restored the operability of the fire alarm, public address, and manual station system within two weeks, The Port Authority of New York and New Jersey (PANYNJ or Port Authority) questioned the WTC's existing fire alarm system's capability to provide reliable life safety support functions. In particular, the existing system, which was developed and supplied exclusively for the WTC by the American Multiplex System Company, was no longer manufactured, and the software was not supported. In addition, the 1993 bombing proved the system infrastructure to be vulnerable to a single point of failure. Based upon the inability to obtain spare parts, lack of system support, and the vulnerability of the system, on March 17, 1993, the Port Authority authorized the purchase of a new, state-of-the-art addressable fire alarm system for the WTC complex (including buildings 1, 2, 4, and 5, which were also monitored by the OCC) (PANYNJ 1993). New fire alarm drawings were developed for WTC 1, 2, 4, and 5, which were issued for bid on March 25, 1993. On April 5, 1993, the fire alarm installation project was awarded for construction. On March 26, 1997, PANYNJ issued another purchase order for fire alarm equipment to complete the fire alarm project.

The replacement fire alarm system supported a decentralized infrastructure that consisted of six independent fire alarm systems protecting WTC 1, WTC 2, WTC 4, WTC 5, Concourse Level, and the Sub-Grade Levels. The four buildings had a master monitoring and control Network Command Center (NCC) located at the building's FCS. Building 4 was also provided with a redundant remote NCC that monitored Building 5, and Building 5 was provided with a redundant remote that monitored Building 4. The Concourse and Sub-Grade master NCCs were installed in WTC 2, and remote NCCs for the Concourse and Sub-Grade were installed in WTC 1 along with a remote NCC for WTC 2. A redundant remote NCC for monitoring and control of all six systems was installed in the Operations Command Center (Drucker 2004).

The installation of the WTC 1 and WTC 2 fire detection and alarm systems was separated into three phases to address the constructability of the new systems, while enhancing fire protection capabilities in the quickest manner possible and to ensure fire protection continuity during the switchover to the new fire alarm system. Phase I installed the backbone of the new system, including the master fire alarm panel, remote panels, cabinets on each floor for wiring the new system, and interface modules to provide monitoring and control functions between the old and the new systems during transition. In Phase II, both the new and old systems operated concurrently while making the transition of monitoring and control from the old to the new system. New core area speakers, warden phones, and pull stations were connected to the new fire alarm system. Phase III included the replacement of all existing fire detection devices and expanding the new speaker and strobe capabilities into all tenant and mechanical spaces.

The installation of a new fire alarm system, while maintaining protection for WTC 1 and WTC 2, was an enormous undertaking, requiring years to complete. On September 11, 2001, the replacement of some original system components was still underway. On September 11, 2001, the new installations in WTC 1 and WTC 2 were 85 percent and 80 percent complete, respectively (PACO 2002). The same source estimated that 25 percent of the old fire alarm system was still in use at the time of the attack.

Even though some parts of the original fire alarm system were still operational in WTC 1 and WTC 2, no documentation was found that identified what parts or what areas were protected by the old system. Even though some parts of the system were operating with old system hardware, the entire fire alarm system was managed through the new fire alarm control and monitoring equipment.

4.1.2 FCS and Alarm System Installation and Functions

The overall performance of the fire alarm system is dependent upon the standards covering the design and performance of the fire alarm system, the testing and quality assurance activities associated with ensuring compliance with those standards, and the degree to which the installation is in accordance with those standards, manufacturer's direction and applicable codes. The major equipment installation requirements for the WTC as they related to equipment performance included:

- speakers located to ensure their operation would be heard clearly above ambient noise level
- the voice loudspeaker system required to ensure 50 percent of the system remains operable throughout the building in the event 50 percent became inoperable
- visual alarm devices in common use spaces
- automatic smoke detectors in the mechanical rooms, electrical switchgear rooms, electric and telephone closets
- automatic smoke detectors installed at the return air ducts serving each floor required to shut down corresponding air handling unit upon the detector’s activation
- automatic smoke detectors at each elevator landing for recalling elevators upon detector activation
- at least one manual fire alarm station installed in each story in the path of escape -- No point on a floor could be more than 200 ft from the nearest station.
- floor warden telephone stations located between required stairways
- standpipe telephones near the main standpipe in the stairway on each floor, and within the sprinkler water tank and fire pump rooms
- FCS located in the lobby of the building
- the fire alarm wire with a minimum size, and type that would not support flame
- a terminal connection box for the wiring serving a maximum of five floors above and five floors below the terminal box
- riser cable and its branches not required to be installed in conduits or raceways if not exposed to public view

The fire alarm system within the WTC offered multiple functions to enhance the overall life safety features within the buildings. The primary monitoring and control of the fire alarm system was performed at the FCS within each building. The life safety functions performed by the FCSs were (PANYNJ 1999a; PANYNJ 1999; Drucker 2001; Drucker 2004):

- an audible alarm signal upon an alarm condition or system malfunction
- manual control of the emergency voice and alarm communication capability—voice or alarm notification could be selected by the individual floor, group of floors, or throughout the complete building
- a means to silence the audible alarm signals when the loud speakers were in use and for activating the audible alarm system automatically when use of the loud speakers was terminated
- manual acknowledgment of the alarm or system fault condition through an alpha/numeric display and keyboard
- a two-way telephone system for the firefighters with the capability to make announcements over the emergency voice and alarm communication system
- a two-way telephone system for the floor warden stations, mechanical control center, and air-handling control rooms
- a means to manually transmit a fire alarm signal to the fire department
- means for testing the display, alarms, and connection to the fire department

The detection and notification functions were performed throughout the building by the fire alarm system. The life safety functions performed by the fire alarm system were(PANYNJ 1999a; NCSTAR 1-1H):

- emergency voice and alarm speakers for audible notification and communication in all areas within the building
- strobes to provide visual alarm indications for the hearing impaired
- two-way standpipe telephone communication system
- two-way Floor Warden telephone communication system
- two-way Maintenance telephone communication located at the remote fire alarm panel locations
- automatic smoke detection that would provide an alarm signal at the FCS upon activation
- monitor the fire sprinkler system for water flow or disabled performance conditions that would alarm at the FCS upon activation
- manual stations for occupant activation that would alarm at the FCS upon activation

- monitoring of independent fire alarm systems installed by individual tenants that would annunciate their alarm condition at the FCS
- automatic notification of the fire department upon fire alarm activation

4.1.3 Fire Alarm System Design

The magnitude of the fire alarm system for the WTC towers was reflective of the protected building's size and the large number of people that occupied the building on any given day. To control a project of this size, specific design criteria were developed based upon the system’s performance objectives and fire protection goals. The design criteria designated type, models, location, and performance of the fire alarm control and monitoring equipment, supporting hardware, and fire alarm devices. Procedures were also developed to monitor and track the project’s progress. The phased project approach and its criteria allowed the original system’s fundamental monitoring, controls, and communication capabilities to be transferred to the replacement system during the first phase of the project, and allowed new or revised fire alarm devices to be put into service as soon as they were functional during succeeding phases.

The WTC 1 and WTC 2 fire alarm system consisted of multiple control panels of various capabilities distributed within each tower and interconnected for redundancy (PANYNJ 1986). The distributed panels shared intelligence, information, and control through a system of signal communication paths. The system also provided the capability and controls for emergency communication of voice messages within the buildings. Figure 4–1 shows several alarm and control panels at the lobby FCS in WTC 1. Details of the installed equipment and function are provided in NIST NCSTAR 1-4C.

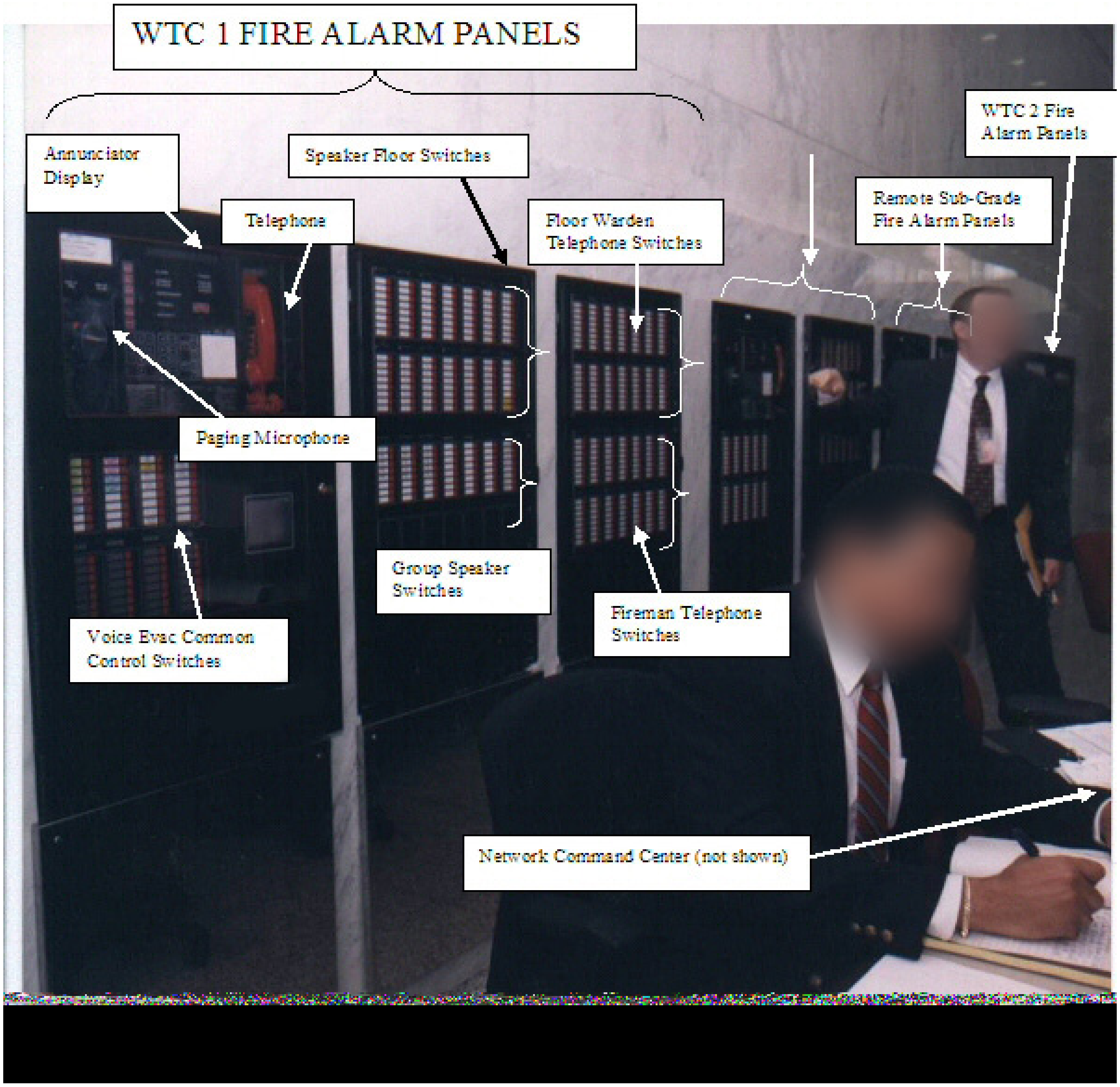


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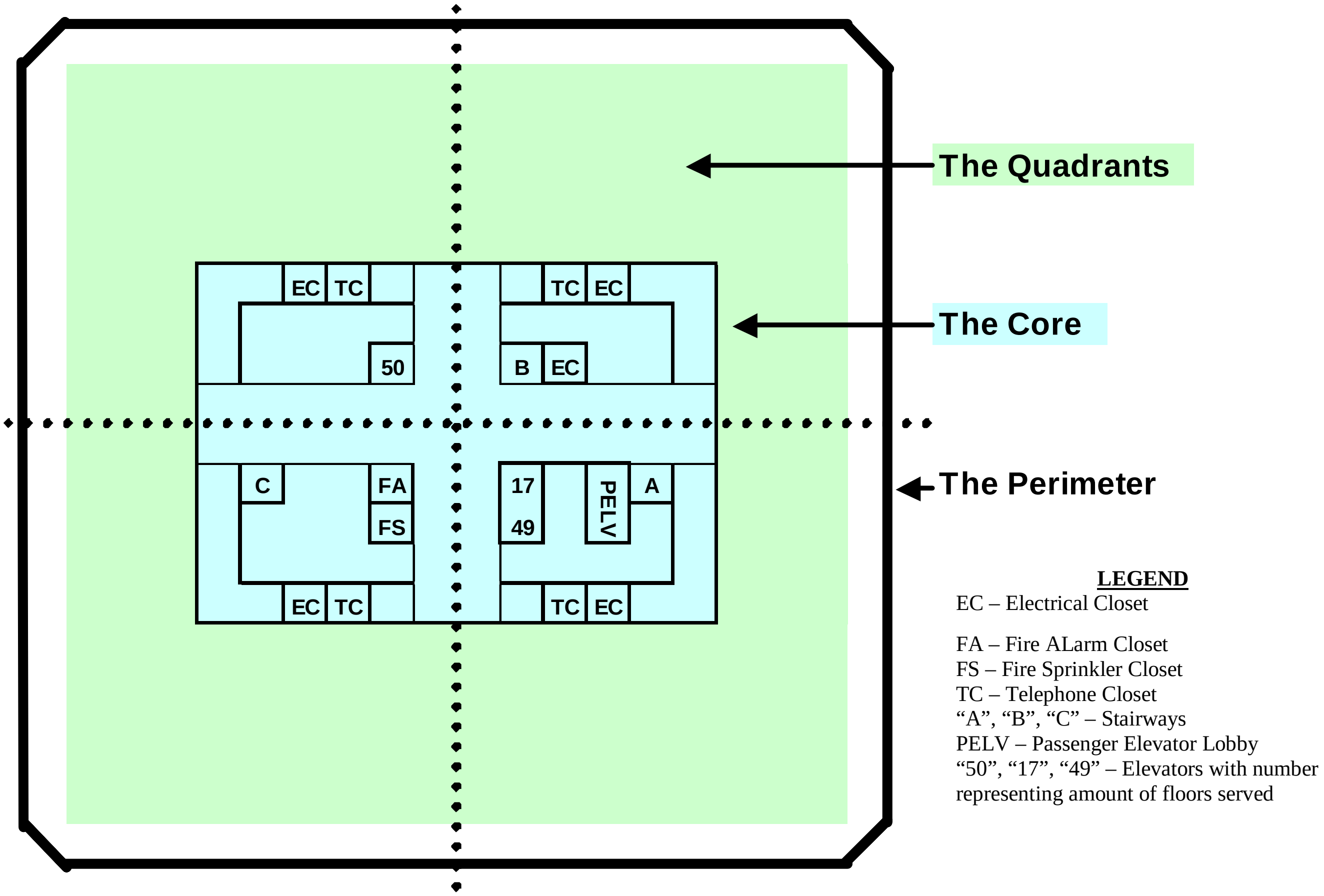
Figure 4–1. WTC 1 FCS with functions of the alarm and control panels labeled.

A standardized approach for the design and installation of WTC 1 and WTC 2 fire alarm equipment and devices was developed by subdividing a typical floor plate into a core and quadrants (See Fig. 4–2.). The intent was to set quality control standards with typical requirements and locations for common equipment, devices, and circuits within an assigned area.

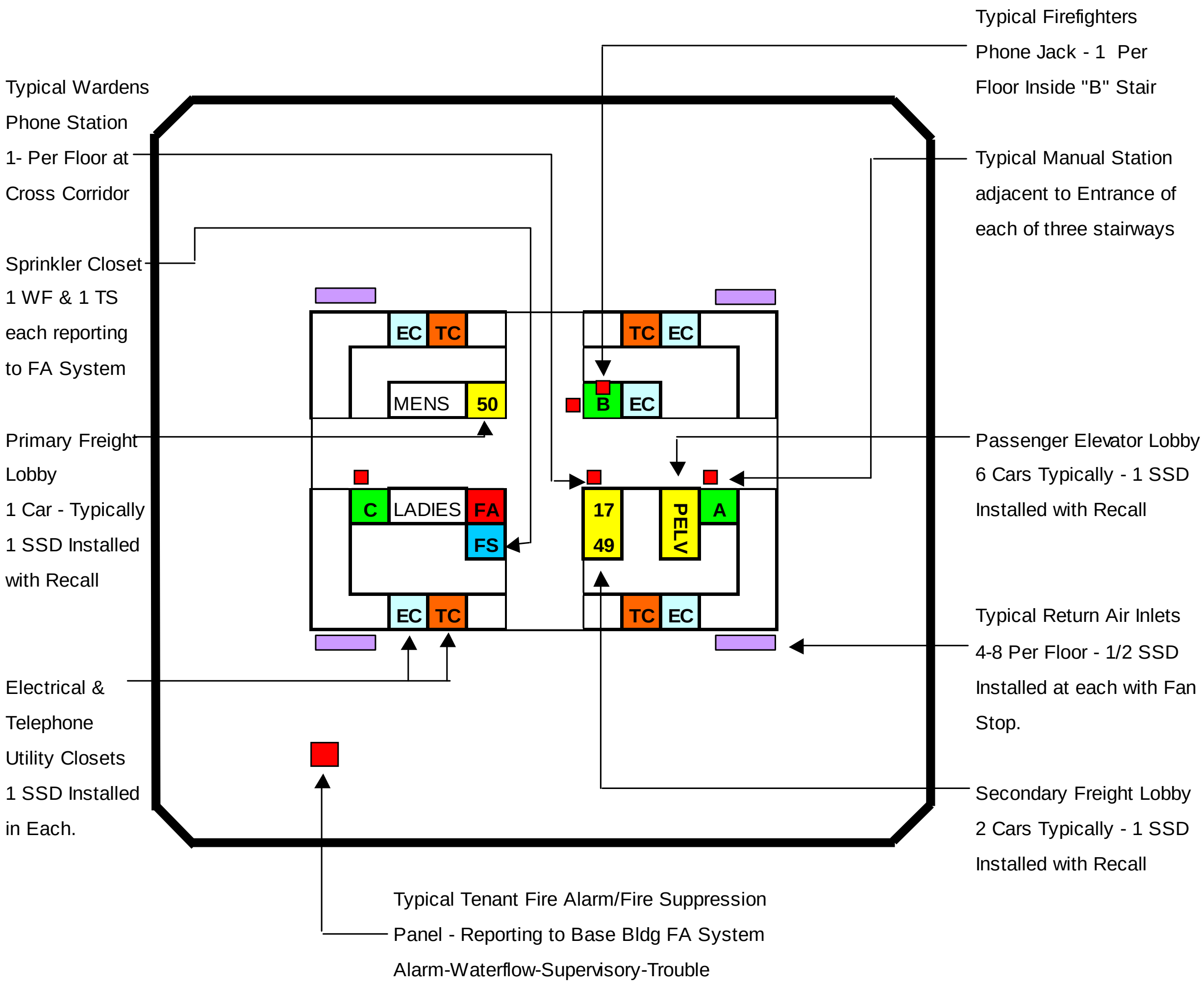


Source: Drucker 2001a, 2001b.

Figure 4–2. Typical WTC 1 and WTC 2 core and quadrants.

Specific areas within the typical floor template were designated for the fire alarm control equipment, initiating devices, and communication equipment, as shown in Fig. 4–3. Drawings were developed to provide a submittal format for architects, engineers, and contractors. The drawings provided a guideline for the design and installation of the fire alarm equipment and devices. The intent was to set a standard on what information was required for approval and what was required from the installation contractor to ensure the performance and survivability requirements for the system.

The fire alarm system chosen for WTC 1 and WTC 2 was the Ceberus Pyrotronics MXL-V, and a backbone was developed and designated as the "Base Building Fire Alarm System" (BBFAS). The BBFAS provided the basic support structure and interface components for the fire alarm system throughout each building. An improved network configuration was developed for the system that enhanced survivability and overall signal processing time through the introduction of a distributed intelligence network.



Source: Drucker 2001a, 2001b.

Figure 4–3. Standard fire alarm equipment and device locations.

The final system architecture consisted of the main head-end MXL-V fire alarm panel located at the FCS; distributed MXL-VR remote control panels which were located within both Towers on levels B6, 7, 41, 75, and 108; and Power Supply Remote (PSR) slave panels that were monitored and controlled by the remote panels. The remote panels provided localized intelligence and acted as the master over the slave panels. Each remote panel would monitor and control up to eight slave panels, which were located every third floor (typically) and contained system transponders, amplifiers, terminal cabinets, and interface points that provided access to the BBFAS platform. Each slave panel would provide the central monitoring and control point for fire alarm cabinets located on each floor.

The interconnection of the distributed panels within each tower was accomplished through multiple vertical system network transmission paths commonly referred to as risers. A fire alarm riser may contain numerous transmission paths for multiple functions associated with the system. The WTC 1 and WTC 2 system risers controlled functional capabilities that included:

- Fire detection
- Life safety system monitoring
- Life safety system control
- Occupant notification
- Floor warden and firefighter telephone communication capability
- System display and control of the fire alarm system

The risers within the buildings contained four types of communication paths that performed separate fire alarm functions. One of the communication paths connected the head-end fire alarm panel to all of the remote panels. The second and third communication paths connected the head-end panel to the slave panels. The fourth communication path connected the separate remote panels to their slave panels.

The single communication path from the head-end panel to the remote panels consisted of a Signaling Line Circuit, referred to by the manufacturer’s term XNET (Fig. 4–4). The XNET provided a global communication path for the head-end fire alarm system in the FCS and OCC to monitor the fire alarm detection and supervisory devices and control the interfaced fire alarm and life safety systems connected to the remote and slave systems. The two separate communication paths from the head-end panel to the slave panels consisted of a Notification Appliance Circuit (Fig. 4–5), which provided the alarm signal and voice messages for the buildings loudspeakers and the Warden/Standpipe telephone circuit (Fig. 4–6). The fourth communication path originated from and was connected to its remote fire alarm panels. The path was a separate Signaling Line Circuit, referred to by the manufacturer’s term MNET (Fig. 4–7). The MNET was a local communication path that was dedicated to each remote fire alarm panel and its slave panels. The MNET provided a local communication path to monitor the slave systems’ fire alarm detection and supervisory devices and control the interfaced fire alarm and life safety systems connected to the slave systems.

The XNET and MNET design and installation provided enhanced network integrity and reliability through a loop wiring topology configuration that provided separate network communication path risers (primary and secondary) installed in three different locations (fire alarm closet and stairways “A” and “C”).

The final circuit was the warden/standpipe telephone system. The single pair of telephone wires did not have the enhanced survivability characteristics associated with the Class A, Style 7 Signaling Line Circuit or Class A, Style Z Notification Appliance Circuit. The telephone circuit performance allowed a single open (cut wire) or wire-to-wire short to disrupt service between the head-end panel and beyond where the wire fault occurred. The disparity of performance between the different types of circuits may have played a role in the variability in performance of the fire alarms after impact.

The communication path risers were separated into three locations to enhance survivability, as seen in Figs. 4–8 and 4–9. The PANYNJ's intent was to limit degradation of the fire alarm system's performance if a riser was damaged. The incorporation of multiple risers was in response to the 1993 bombing, where the blast disabled all fire alarm functions within WTC 1 and WTC 2 when the single fire alarm riser was severed.

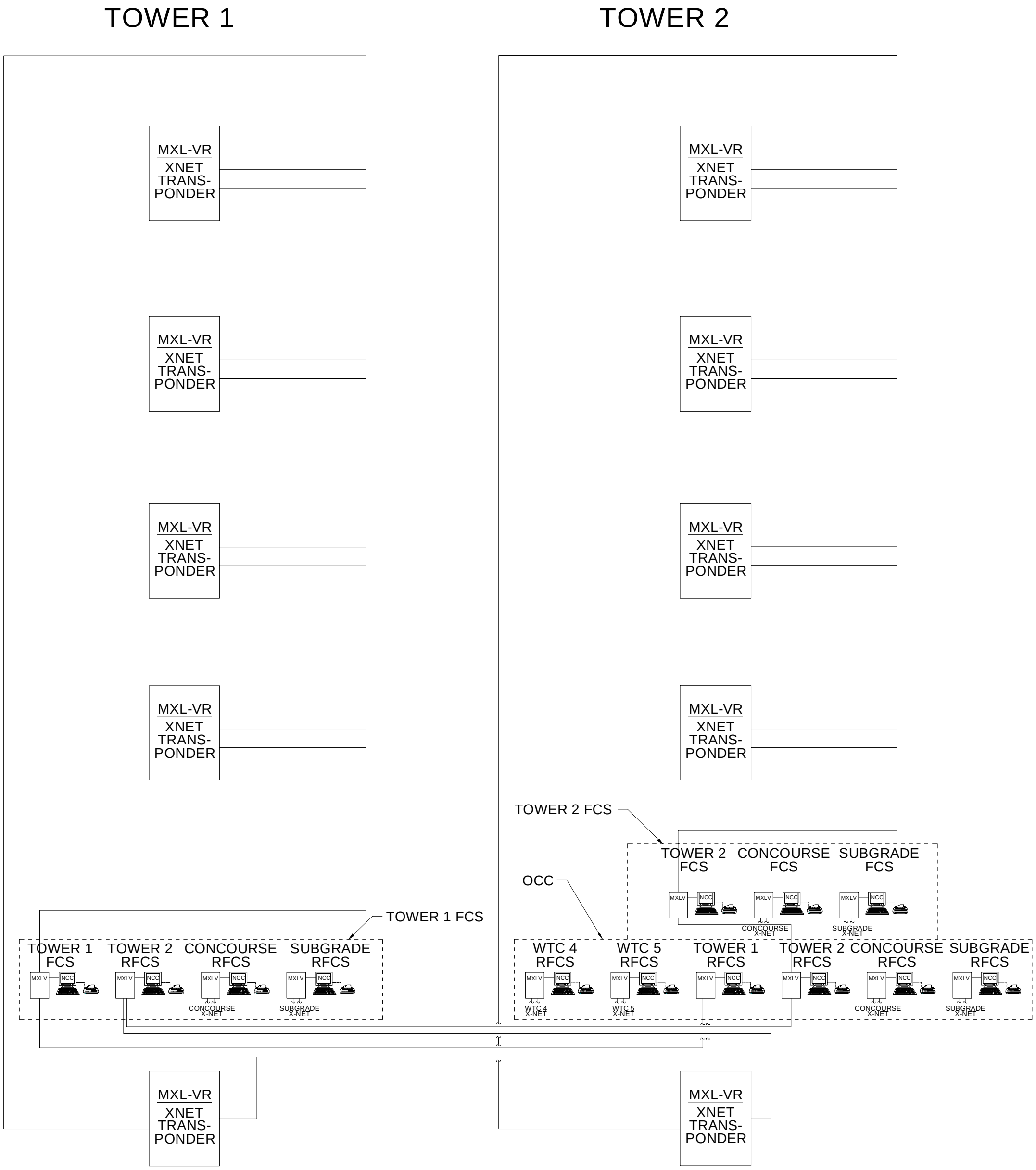


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Figure 4–4. XNET network configuration single-line schematic.

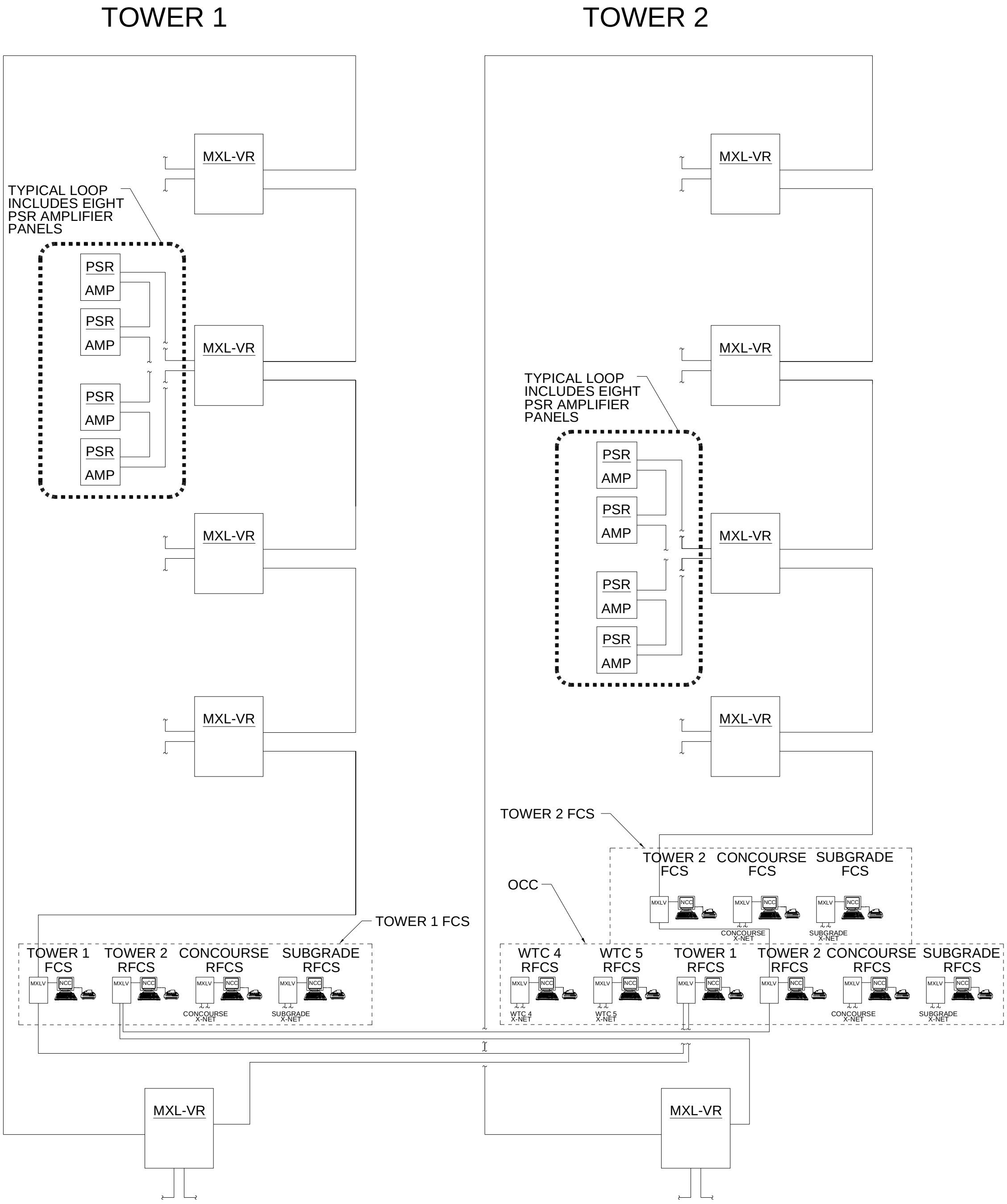

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Figure 4–5. Notification appliance network single-line schematic.

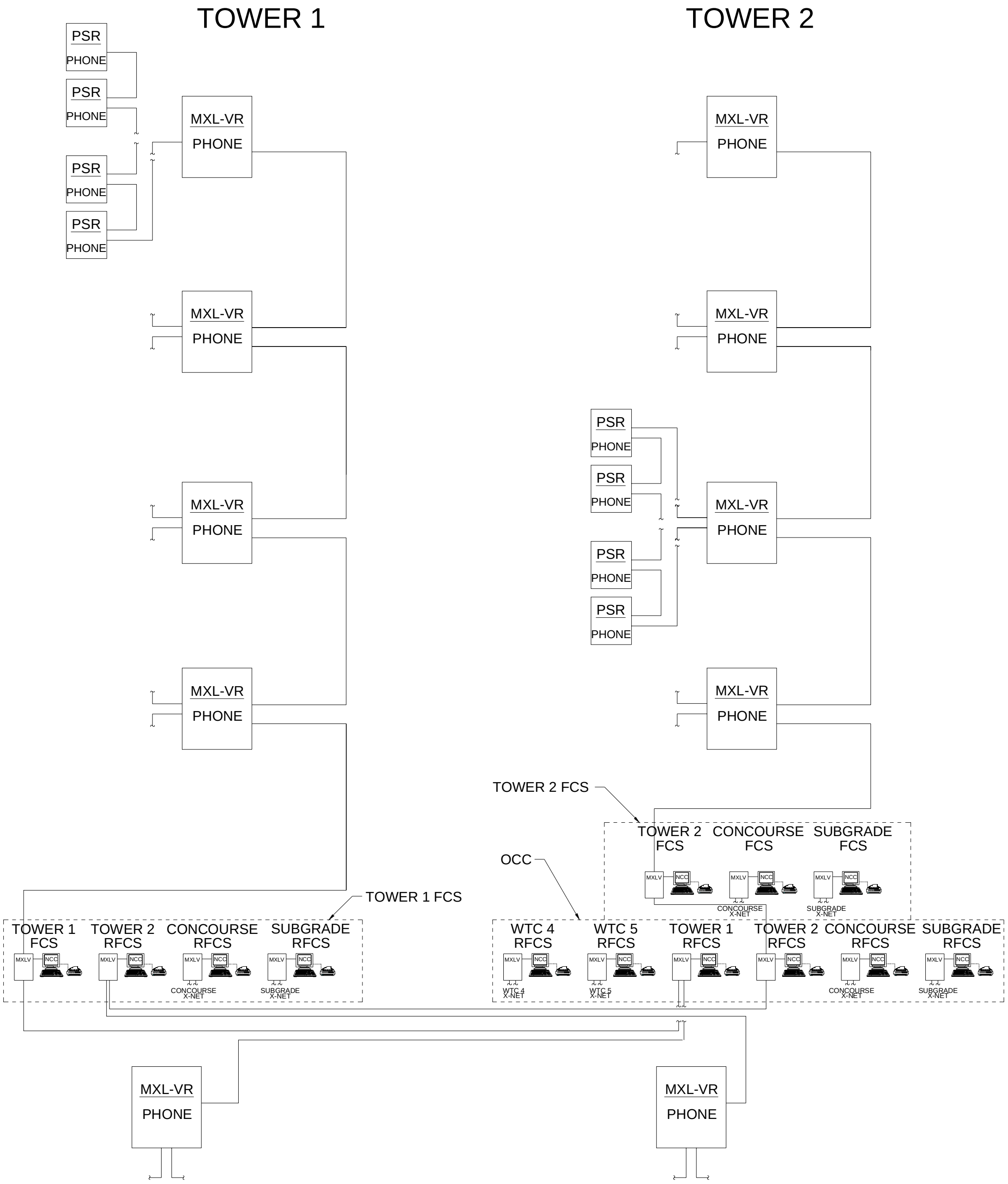

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Figure 4–6. Floor warden and firefighter telephone single-line schematic.

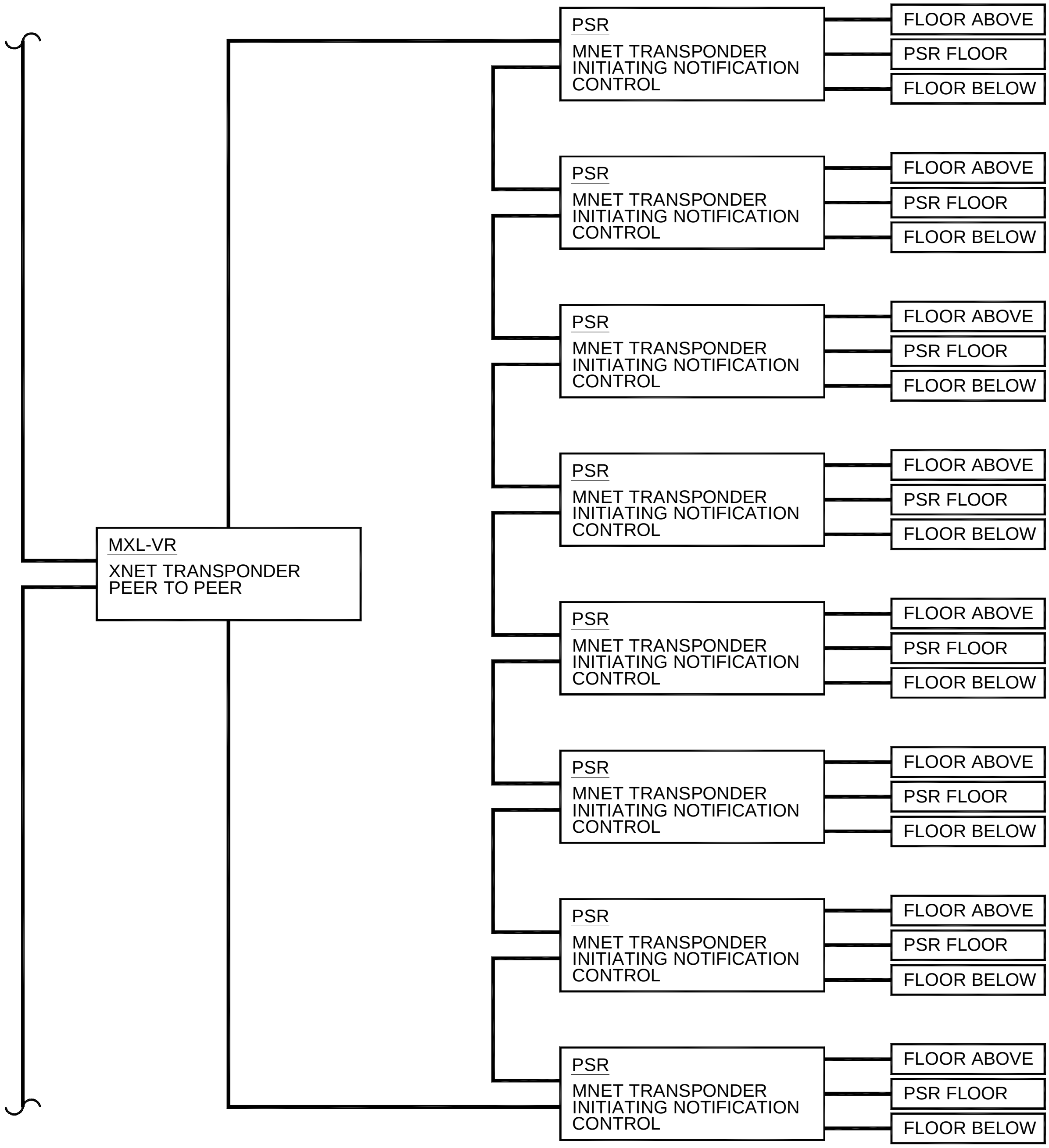

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Figure 4–7. MNET network configuration single-line schematic.

Figure 4–8. Typical WTC 1 riser locations on impact floors.

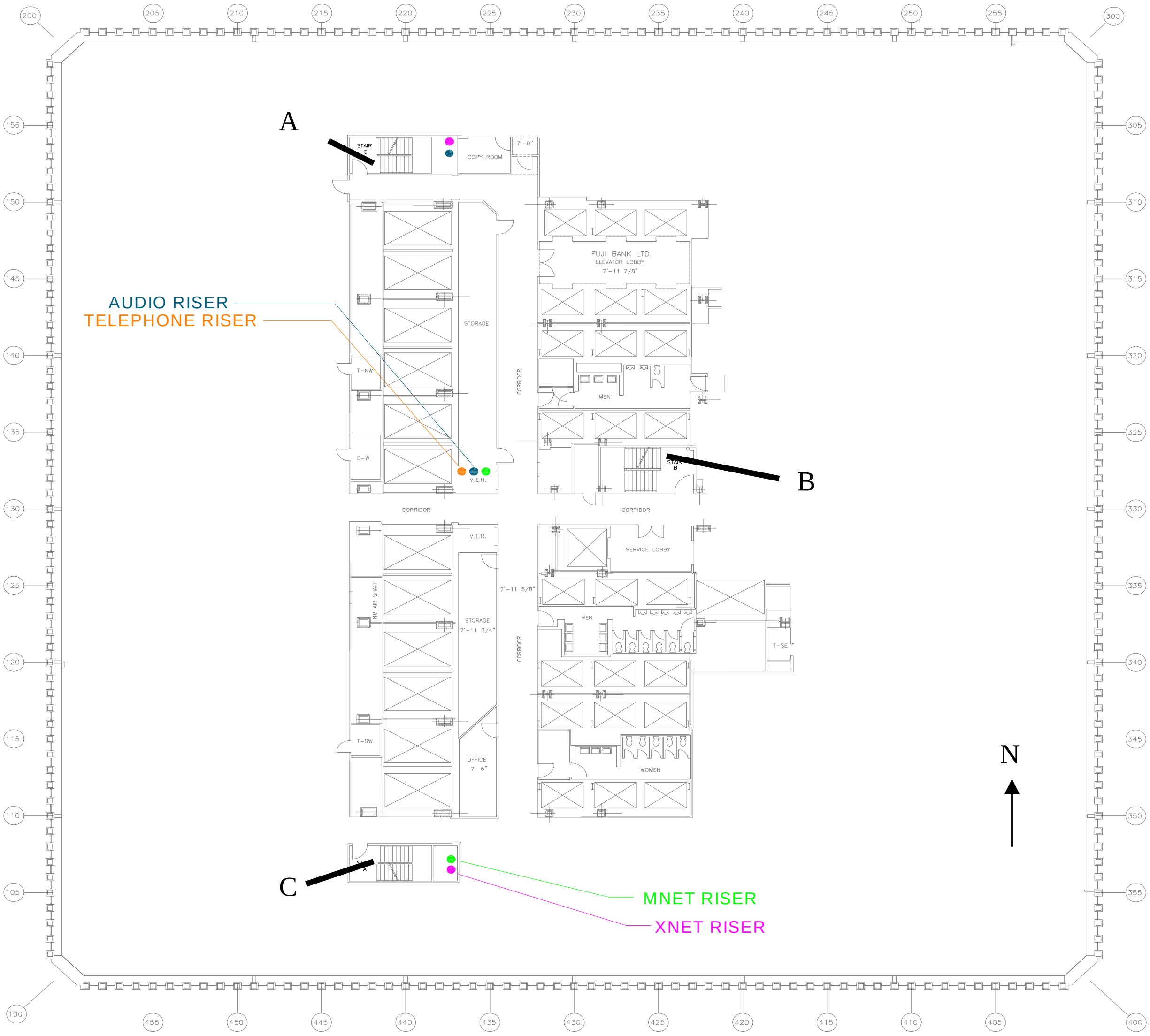

Figure 4–9. Typical WTC 2 riser locations on impact floors.

4.2 WTC 7 FIRE ALARM SYSTEM

4.2.1 History

WTC 7 was built in 1985 across Vesey Street from the main WTC compound. It was a steel building with forty-seven stories, built above a Consolidated Edison substation. WTC 7 collapsed following a long burning fire, seven hours after WTC 1 collapsed.

The fire alarm system for WTC 7 was the original system installed during the initial construction (Syska 1984). Modifications were performed as needed to accommodate renovations and tenant fit-outs. Project development documentation found and analyzed was limited in this investigation to design criteria, specifications, riser diagrams, and a limited number of tenant fit-out drawings that included fire alarm work.

The Basic Design Criteria, labeled as Revised November 5, 1984, was prepared by Syska & Hennessy, and it referenced the applicable local building codes at the time of construction. The only performance criteria in the design that exceeded the minimum requirements of the applicable codes was the statement requiring that "All monitoring, communication and control for the fire alarm system shall be on a separate multiplex channel with its own processor" (Syska & Hennessy 1984).

Fire alarm system specifications dated October 24, 1984, prepared by Tishman Construction Corporation of New York, were reviewed. The specifications provided additional information about the performance requirements of the fire alarm system and provided criteria for its installation.

Based on the information reviewed, the overall design and installation met the applicable code requirements, and inspection, testing and maintenance of the fire alarm system for WTC 7 was provided on a regular basis.

4.2.2 System Arrangement

The baseline for defining the fire alarm system's performance is derived from the specifications, which referred to the applicable local building codes. The basic system was required to contain the following components to monitor and annunciate the status of its devices and initiate an appropriate response (Syska 1984):

- FCS located in the lobby of the building on the entrance floor
- remote alarm display panels in the Mechanical Control Center and Fire Safety Director's location
- manual fire alarm stations provided in each story along the path of escape with additional stations installed so that the maximum travel distance between stations would not exceed 200 ft
- speakers located on all floors and stairways that can be operated in the FCS—the elevator intercommunication system was provided separately
- visual alarm devices (strobes) in public common use areas
- floor warden stations on each floor that provided two-way communication with the FCS
- standpipe firefighter telephone system with communication stations provided at FCS, each floor near the standpipe riser, gravity tank rooms, and fire pump rooms
- fire sprinkler water flow alarm and malfunction monitoring
- tenant fire alarm panels monitoring for alarm and system fault conditions
- fan shutdown and restart system for smoke control
- elevator recall upon its smoke detector activation

- fire stair door releases
- smoke and heat detection

4.2.3 System Architecture and Operation

The fire alarm system chosen for WTC 7 was the Firecom 8500 (Syska 1984). The main user interface was at the Fire Command Station, where the head-end fire alarm panel provided central monitoring and control through a monitor with keyboard, illuminated displays, microphone, and control switches. The Class B Signaling Line Circuit riser from the head-end panel went to a Terminal Transmission Box (TTB) on each floor, which was the data gathering panel for the detection, notification and control devices for each floor. The TTB provided Class B conventional Initiating Device Circuits and Notification Appliance Circuits for the manual pull stations, smoke detectors, and speakers. The TTB also provided the circuit interfaces to control the door releases and air handling units. Bulk amplification for all loudspeakers associated with the emergency voice alarm communication system was generated from the fifth floor.

The specifications provided a sequence of operation during alarm conditions for the different types of devices found on the fire alarm system.

1. Activation of a manual pull station, smoke detector, heat detector, duct detector, or sprinkler waterflow switch would:
    a. Automatically sound all loudspeakers on the floor of alarm and the floor above.
    b. Automatically transmit the fire alarm signal to the fire department via a central monitoring office.
    c. Unlock the doors in the fire stairs.
    d. Sound a fire alarm signal and provide location identification at the FCS, Mechanical Control Center, and Fire Safety Director’s location.
2. In addition to #1 above, the duct detectors would:
    a. Stop air supply and air return from the floor of alarm activation by automatically shutting down air supply and return fans serving these floors.
    b. Open smoke exhaust dampers of smoke shafts on the floor of alarm activation, start associated smoke exhaust fans, and energize fan of stair pressurization system.
3. In addition to #1 above, the elevator lobby detectors and sprinkler water flow switches would cause elevators serving the floor of alarm activation to return non-stop to street floor or to the lowest landing above street floor when the lowest landing of the elevator bank was above street floor. If the lowest landing was the floor of alarm activation, the elevator would return to a landing two floors above.

4.2.4 Design and Installation

Documentation found consisted of modified riser as-built diagrams and floor plans with fire alarm device locations (Syska 1984). Comprehensive as-built drawings for the system were not located.

The modified riser diagrams were conceptual in nature and provided the installation contractor with the number of devices to be installed on each floor, type of fire alarm equipment on each floor, and the number and type of wire interconnecting the devices and equipment. The modified riser diagram had areas crossed-off, which was an indication that the area had undergone renovation. Additional renovation drawings provided a section of the riser with its modifications. The final drawings consisted of the partially modified riser diagrams with areas crossed-out, separate drawings containing a revised section of the riser, and floor plans with the locations of the devices on the designated floor.

It appears that the contractor was responsible for determining the final circuit configurations for the devices and equipment based upon the drawings found. Limited information was found on the specific location of the fire alarm control equipment, initiating devices, and communication equipment.

The third floor lobby was designated as the FCS. On a typical floor, manual pull stations were located at each stair entrance, and smoke detectors were provided in electrical/telephone closets and in elevator lobbies. Sprinkler water flow switches and valve supervisory switches in each stairwell were monitored by fire alarm interface devices. Duct smoke detector locations were not identified, but the criteria required detectors to be installed in heating, ventilation and air-conditioning (HVAC) systems over 2,000 cfm. Fire warden stations were typically installed on the north wall outside the elevator lobby.

A mechanical room was located in the core area of each floor. The south wall of the Mechanical Room was the designated location for fire alarm data gathering panels, which supported and distributed the system’s monitoring, control, and communication circuits. The initiation device circuits, speaker circuits, and the notification appliance circuits serving that floor were terminated at the terminal cabinet at this location. Documentation was not located that provided a standard for the equipment or device connections.

Drawings were not located that provided guidance on the installation of the fire alarm devices to meet tolerances required by code and the manufacturer. The riser diagrams indicated that the smoke detector, manual pull station, speaker and strobe circuits were configured to be a Class B type. The use of a Class B circuit was consistent with the minimum requirements for performance, but a Class B circuit does not have the higher level of survivability associated with a Class A circuit.

Drawings also were not located showing the number of wires required to run between each device, and between the device and equipment, nor were fire alarm power calculations located that would document the capability of the fire alarm equipment to power the number and type of devices connected to the equipment. No quality control documentation was found for the installation, and no testing and commissioning procedures were located.

4.2.5 Inspection, Testing, and Maintenance

Inspection, testing, and maintenance were mandated by the applicable building codes after a fire alarm system was installed and in operation. The building owner was responsible for inspection, testing, and maintenance of the systems. The inspection, testing and inspection was permitted to be done by qualified and experienced personnel employed by the owner, or the work could be performed under contract. For WTC 7, the inspection, testing, and maintenance was conducted by a contractor, and, based upon the information reviewed for 2000 and 2001, was adequately documented.

4.3 COMPARISON OF WTC 7 FIRE ALARM SYSTEM TO WTC 1 AND WTC 2 FIRE ALARM SYSTEM

The fire alarm systems installed in WTC 1, 2, and 7 was consistent with the performance criteria as adopted by New York City, but there were significant differences in the approach in meeting these requirements. The development and implementation of the WTC 1 and WTC 2 fire alarm systems was approached in a methodical way to meet specific goals and objectives adopted by the PANYNJ that exceeded the minimum New York City requirements. This was accomplished through the identification of the overall fire alarm goals and the development of systematic steps for system design and installation. In comparison, documents available on the WTC 7 fire alarm system indicated that the design development for the system did not follow the methodical approach used for WTC 1 and WTC 2. The WTC 7 fire alarm design documents consisted of basic working documents used by construction personnel for the equipment layout, which allowed the installation contractor more leeway in determining what materials were used, where devices and equipment were located, and how the system would ultimately perform within the guidelines of the specification. This approach does not indicate that the system design or product was substandard, it only shows that the design, hardware, and equipment layout did not follow the strict development requirements set forth by the PANYNJ for WTC 1 and WTC 2. No documents were found that would indicate that the WTC 7 fire alarm system did not meet the performance standards required for the building.

Additional differences were apparent in the emphasis on survivability as a major goal for the WTC 1 and WTC 2 fire alarm systems, which was not apparent in the WTC 7 system. The survivability enhancements present in the WTC 1 and WTC 2 included distributed fire alarm intelligence, monitoring, and controls on seven different levels. The WTC 7 fire alarm system did not use distributed intelligence and all of the monitoring and control functions resided in the head-end panel on the third floor. Also, the WTC 7 system used bulk amplification with all loudspeaker circuits originating from the fifth floor. Additional WTC 1 and WTC 2 fire alarm survivability enhancements were incorporated into the three fire alarm riser circuits that were installed in three separate locations and within rigid conduit for additional physical protection. The WTC 7 fire alarm single-riser architecture closely mimicked the pre-1993 fire alarm system riser architecture in WTC 1 and WTC 2 that was severed in the bomb blast that disabled all functions of the system. The addition of the survivability enhancements to the post-1993 WTC 1 and WTC 2 fire alarm systems allowed for the continuing functions, albeit degraded, of the systems after the plane impacts.

Another significant difference between the systems was the design development. Whereas the WTC 1 and WTC 2 systems had “Mandated Fire Alarm Guidelines” (WTC 1999) as the basis for the installation of new equipment, there was no documentation available that indicated the same controls were developed for the WTC 7 system. The advantages gained from the use of adopted guidelines are increased reliability and known performance through design and installation controls. This is especially true for large systems that undergo frequent renovations, maintenance, and repairs.

The final major differences were in the commissioning and acceptance procedures. The WTC 1 and WTC 2 fire alarm systems had comprehensive quality assurance procedures to maintain established performance levels for the fire alarm systems. The procedures included specific design, installation, and maintenance requirements. An example of the controls is the verification of the voice loudspeaker system capability to ensure fifty percent of the system remained operable on a floor if there was a loudspeaker circuit failure. The WTC 1 and WTC 2 design criteria provided typical circuit diagrams, design documentation, and quality assurance procedures to make sure this requirement was met. These strict quality controls were implemented because it is extremely difficult without disabling the voice circuit to verify this capability after the system is installed. The WTC 7 documentation does not indicate this level of quality assurance was performed. The maintenance of the records for these processes provided a baseline for determining performance levels at the time of acceptance in comparison to any future date. This baseline was a major factor in maintaining system performance and availability.

The approach taken for the design, installation, and acceptance of the fire alarm system in WTC 7 was an approach that is commonly taken for commercial high rise construction. The absence of design, installation, and commissioning controls mentioned above does not indicate that common practices were not used in the development and installation of the fire alarm system. The comparison suggests that the enhanced measures that the WTC 1 and WTC 2 fire alarm system installations were subjected to during their life-cycle enhanced performance and may have increased survivability.

4.4 FIRE EMERGENCY RESPONSE

WTC 1, 2, and 7 had a fire safety plan that provided direction for fire emergency response and was organized around a hierarchy of staff associated with its implementation. At the top of this hierarchy was the fire safety director. The fire safety director oversaw fire emergency response until the arrival of the FDNY and was responsible for gathering all necessary information for the FDNY, which he/she relayed to the Chief upon arrival.

Subordinate to the fire safety director in WTC 1 and WTC 2 was the assistant fire safety coordinator, who was responsible for the availability and state of readiness of the fire brigade and the entire emergency response team. (Members of the WTC Division of the Port Authority Police, who received firefighting training, staffed the World Trade Center fire brigade.) Similar duties were performed by the fire safety director and his/her deputy at WTC 7. WTC 7 also had a fire brigade that the fire director was responsible for organizing and training.

In addition to the WTC 1 and WTC 2 assistant fire safety coordinator, the facility had an emergency response team consisting of the deputy fire safety directors, lobby deputy fire safety directors, floor wardens, and deputy floor wardens. Deputy fire safety directors were responsible for performing the duties of the assistant fire safety coordinator in his/ her absence and staffing the FCS for the purposes of executing the fire safety plan. At the end of the hierarchical chain for WTC 1, 2, and 7 were floor wardens and deputy floor wardens, who were responsible for assessing conditions and assisting in evacuation of floor occupants on their respective floors upon direction from the fire brigade and/ or FCS. Floor wardens, deputy floor wardens, and their alternates were appointed tenant employees or Port Authority employees.

4.5 SYSTEM PERFORMANCE ON SEPTEMBER 11, 2001

Documenting the actual performance of the WTC 1 and WTC 2 fire alarm systems was hampered significantly by the loss of all historic documentation stored within the buildings, and the loss of electronic files that were generated by the fire alarm system during the events of September 11, 2001. The analysis of the fire alarm's performance was helped significantly by chance video recording of brief images of illuminated status lamps on the fire alarm system's panels located in the WTC 1 FCS, by the crew filming for the Naudet documentary. Additional information was provided by NIST interviews of individuals in the buildings, or in contact with people in the buildings during the event. The former project manager for the fire alarm installation in WTC 1 and WTC 2 was instrumental in clarifying system architecture nuances.

WTC 7 system performance was recorded by the offsite monitoring company. The record from the company provided typical information from monitoring services.

4.5.1 WTC 1 and WTC 2 Observations

The overall impression of the WTC 1 and WTC 2 fire alarm system's performance was that the system did work, but not all functions performed as intended. The performance depended upon which building experienced the alarm condition and the location of the fire alarm function in relation to the impact damage.

The first plane impacted WTC 1 at 8:46 a.m., and floors 93 through 99 experienced extensive and immediate damage. The second plane impacted WTC 2 at 9:03 a.m., and floors 77 through 85 experienced extensive and immediate damage. The following discussion of fire alarm system performance is based upon the interviews and film documentation.

WTC 1 Interviews—The WTC 1 interviews led to the following observations regarding the fire alarm functions:

- There was no confirmation that audible fire alarms were broadcast above the floors of impact.
- There was no confirmation that the emergency voice communication system functioned on any floor within WTC 1 after the impact.
- Confirmation was provided that alarm tones (not voice messages) were heard on the floors below impact. The interviews provided a time of 8:58 a.m. as the time the alarm tones were broadcast, which was 12 min after impact.[2]
- There was no confirmation that the floor warden or firefighter telephone system functioned after impact.

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[2] NIST Interview data set 2004 and New York City 911 Emergency Call Recording, 2001.

WTC 2 911 Call Recordings – 911 calls from WTC 2 provided the following observations on the fire alarm functions:

- Confirmation was provided that voice messages and alarm tones were broadcast before and after the impact and were heard above the impact floors.[3]

Video Observations–The Goldfish Pictures video (Fig. 4–10) provided brief images of the fire alarm visual status indicators, along with a timeline to reference the observations. Although the images were limited, the following provides a timeline of the observations:

- 8:59 a.m. – The WTC 1 Fire alarm panel general alarm visual indication and system fault visual indications were illuminated. Speaker zones 84 and 89 also indicated that they were in a fault condition. The majority of speaker zone lamps on the WTC 1 fire alarm panel were illuminated solid red, which indicated that those speaker zones were in use. Floors 1 through 84 appeared to have their zones illuminated, which indicated activated speakers.[4] The exact floors may not have been correct because the observation was based on the personal memory of the fire alarm project manager, and was inconsistent with as-built documentation (Drucker 2004). It is not known if a voice command, or if the alarm tone was broadcast over the activated speaker zones. It is not known if any speaker zones were activated, but the interview transcripts do not include evidence of alarm tones nor voice messages were heard above the 92nd floor of WTC 1.[5]

- 9:06 a.m. – The alarm slow whoop tone was heard in the lobby.[3]

- 9:58 a.m. – The visual indicators on the Concourse and Sub-Grade fire alarm panels indicated that they were in alarm and their notification appliances had been silenced.[3]

- 9:58 a.m. – The WTC 2 fire alarm panel redundant displays in WTC 1 indicated that the telephones on floors 64, 71, 73, 93, and 99 of WTC 2 were in use. Zones 76 through 84 on the speaker zones, warden telephone zones, and fireman telephones indicated that they were in a fault condition.[3]

- 9:59 a.m. – WTC 2 collapsed, and all video of the fire alarm panels ceased.

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[3] New York City 911 Emergency Call Recordings, 2001.

[4] Video from Goldfish Pictures inside WTC 1 showing fire command station and fire alarm system displays, provided to NIST, 2001.

[5] NIST NCSTAR 1-7, Figure 6–1.

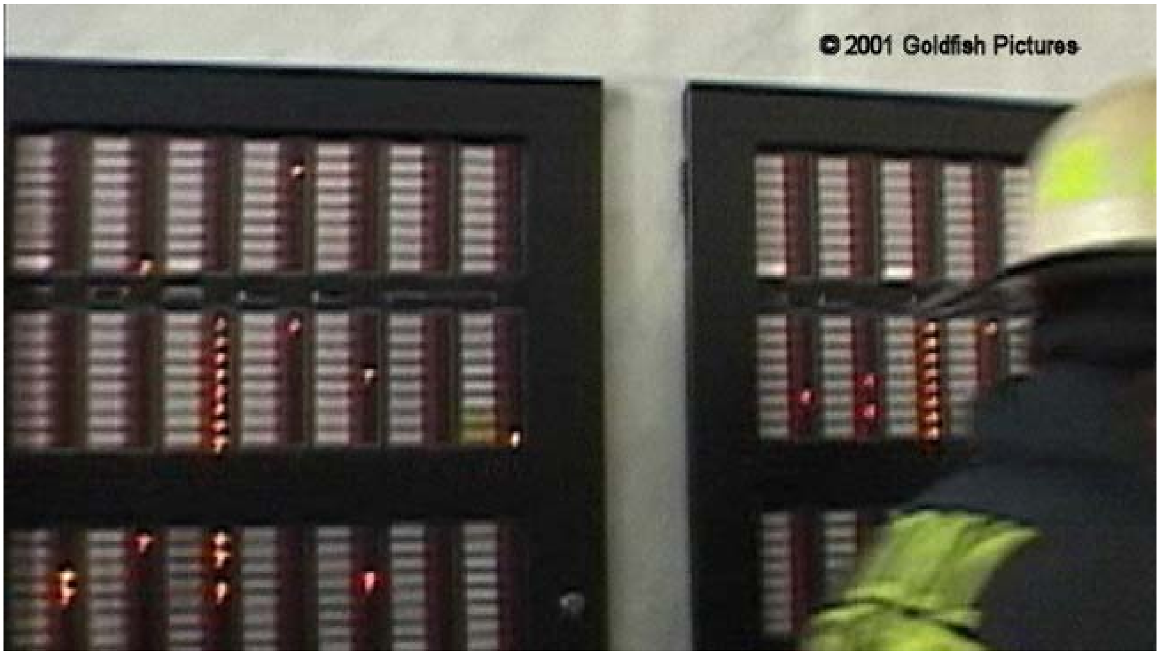

Figure 4–10. Fire alarm system displays at the FCS in WTC 1 showing conditions speaker and telephone circuit faults existing in WTC 2.

Other images of the fire alarm panels for both buildings did not indicate fault conditions on the impact floors or the floors above.[3] This absence of numerous visual indicators may have been due to the loss of the communication paths to the remote MXL-VR panels, or PSR panels, or the loss of the panels themselves. The fact that the WTC 2 fire alarm system was able to continue to provide voice communication capability and floor warden telephones after the impact is probably due to Stair C remaining partially intact after the impact, which was where a portion of the audible riser was located, and the survival of the riser in the core area where the telephone riser was located. Of further interest is the visual indication on the FCS fire alarm panel that indicated that the WTC 2 fire alarm system lost communication to a group of PSR panels. Why the PSR panels lost communication is not known, but it would be reasonable to expect physical damage to the circuits. If the MNET circuits were damaged beyond use, survival of the audible circuits is difficult to explain. The facts verify that the audible circuit did survive, and the fact that the system was able to maintain voice communication can only be attributed to the strict criteria required by the PANYNJ to use survivable circuits protected by robust hardware. The performance of other system functions and components within the system were not verifiable without the recovery of records lost with the buildings.

Standpipe telephone handsets were distributed to firefighters dispatched up into WTC 1 and possibly WTC 2. Some firefighters that received standpipe telephone system handsets at the command post in the lobby at WTC 1 were interviewed as part of the investigation. Every one of the firefighters interviewed indicated that they did not use the standpipe telephone communication system on September 11, 2001.[6] Due to the loss of firefighters in WTC 2, there is no information about the use of the system in WTC 2.

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[6] FDNY Interviews, winter 2004 – summer 2004.

4.5.2 WTC 7 Observations

Information on the performance of the WTC 7 fire alarm system was limited to the record of the offsite system monitoring company on September 11, 2001. The printout shown in Fig. 4–11 indicates the system registered an alarm at 10:00:52 am. This is just after the time for collapse of WTC 2. Even though a fire alarm is indicated, this could be the result of dust entering smoke detectors. Although the entire alarm history record was obtained from AFA Protective Services (AFA), the system monitoring company, the amount of information it shows is typical of system monitoring operations and is meager.

```
09/11/01   14:48:22   DYJ     4612    **** FULL CLEAR ****
09/11/01   14:47:22   LATE   3923   SYSTEM TEST OVER
09/11/01   14:47:22   COMMENT:    TEST: ALL
09/11/01   14:47:21   COMMENT:    LAST SET: 091101   64742
09/11/01   10:00:52   1510    CO  TO CLASS E      AREA:1          *T
09/11/01   06;47:43   COMMENT:    RIC: WILLIAMS
09/11/01   06:47:03   RIC     4210    PLACE ON TEST               CAT:11
09/11/01   06:47:03   COMMENT:    091101  647  091101  1447
09/11/01   06:47:02   COMMENT:    TEST: ALL
09/11/01   06:05:01   RP              20 TIMER TEST
```

Figure 4–11. Monitoring station history tape record for the WTC 7 fire alarm system on September 11, 2001.

The fire alarm history tape record is read from the bottom to the top. Some entries occur as the result of normal operations, and others are the result of actions taken by operators. The bottom line of the record shows that at 6:05:01 a.m. on September 11, 2001, the fire alarm system completed a normal communications check with the central monitoring station. This check was made every day.

At 6:47:02 a.m., AFA placed WTC 7 in a “TEST: ALL” condition. This was normally done in response to a request from the building manager. Ordinarily, it was requested when maintenance or other testing was being performed on the system, so that any alarms that are received from the system are considered the result of the maintenance or testing and are ignored. NIST was told by AFA that for systems placed in the TEST condition, alarm signals are not shown on the operator’s display, but records of the alarm are recorded into the history file.[7]

At 6:47:03 a.m., the record includes an explanation of the request to put the system in the TEST condition. Continuing to read from bottom to top, the date and time the system was placed in TEST is recorded. In this case it is 091101   647 (6:47 a.m., September 11, 2001), and the system will automatically go back to normal monitoring after 8 hr, a system default value, at 091101 1447 (2:47 p.m., September 11, 2001). On the next line above, “RIC” identifies the AFA operator; 4210 is a code number for the “PLACE ON TEST” message. CAT:11 indicates the authority of the person requesting the action.

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[7] Letter from Richard Kleinman, President, AFA Protective Systems, dated July 16, 2003, based on a request by NIST.

On the next line above, the comment entered by RIC identifies that the person who requested that the system be placed on TEST was Williams. This action appears to be common for the building alarm system. Records show that the system was placed on test condition every morning for the seven days preceding September 11, 2001.

At 10:00:52 a.m., a fire condition [1510 CO TO CLASS E] was indicated in WTC 7 by sensing performed by the fire alarm system. The *T at the right end of that record indicates that the system was in TEST at the time. The alarm record also shows that the fire condition is in AREA 1. NIST has been told by AFA that AREA 1 is not a specific area within the building, but a reference to a zone consisting of the entire building.[6] That is to say, fires detected in any fire alarm zone in the building by the fire alarm system would result in the same AREA 1 identification at the monitoring station. The time 10:00:52 a.m. is shortly after the collapse of WTC 2. It is unknown if this fire alarm was triggered by smoke from a fire or dust entering smoke detectors.

At 2:47:21 p.m. and 2:47:22 p.m. (14:47:21 hr and 14:47:22 hr), at the time the 8 hour "TEST: ALL" condition was set to expire, additional actions were recorded that end in an operator (DYJ) entry to "FULL CLEAR."

A much greater amount of information would have been collected and recorded by the fire alarm equipment within WTC 7. None of that information was recovered from the building systems. Although a great amount of information is normally collected and stored by any fire alarm system from fire detectors installed throughout a building, typically, and in the case of WTC 7, specific fire information beyond the fact that a fire condition has been detected is rarely sent to the monitoring site.

4.6 SUMMARY OF FINDINGS

The following is a summary of findings based upon the review of the building designs and analysis of the various fire alarm systems as documented in the full report (NIST NCSTAR 1-4C):

- Remote monitoring of the fire alarm systems only provide a time and date of the alarm condition.
- The design of the WTC 1 and WTC 2 fire alarm system required manual activation of the alarm signal to notify building occupants. This was not accomplished until 12 min after impact in WTC 1.
- A disparity in performance requirements was found for the different type of circuits common to the fire alarm systems installed in the WTC (although it should be noted that the highest levels of circuit performance were provided consistent with NFPA 72). As an example, if an event were to cause a short on both circuits, then the Signaling Line Circuit would be able to turn on Notification Appliance Circuits serving the loudspeakers, but the Notification Appliance Circuits providing the voice message or alarm tone to the speakers would not perform.
- The fault tolerance performance standards for telephone communication circuits are not as well defined as compared to other types of fire alarm circuits. This limits the survivability characteristics of the telephone communication circuits in comparison to other types of fire alarm circuits. The result could be a Signaling Line Circuit with robust survivability performance controlling the operation of a telephone circuit, which has minimal survivability performance.

- Although there is evidence that the floor warden telephones were distributed, the interviews of the firefighters conducted by NIST did not confirm that there were any attempts to use the firefighter telephone system. This is not uncommon since the firefighters are trained to use their radios as the preferred means of communication. The firefighter standpipe telephone systems may have been used if active fire fighting operations had been established.

- Although the fire alarm systems in WTC 1 and WTC 2 used multiple communication path risers, the performance of the respective systems degraded as each building was hit by an airplane. This was especially evident in WTC 1 where all fire alarm notification and communication functions appear to have been lost above the floors of impact.

- The fire alarm system installed in WTC 7 sent to the monitoring company only one signal indicating a fire condition in the building on September 11, 2001. This signal did not contain any specific information about the location of the fire within the building. From the alarm system monitor service view, the building had only one zone, “AREA 1.”

Chapter 5
SMOKE MANAGEMENT SYSTEMS

In the event of fire in World Trade Center (WTC) 1, 2, and 7 there were two primary means to control smoke movement throughout the building. The first means was the construction of smoke barriers which were typically integrated into the architecture of the building, as well as into the ductwork through which heating, ventilation, and air-conditioning (HVAC) air flowed. The use of smoke barriers is referred to as compartmentation, and walls and smoke dampers are used to form these compartments. The second means was through the use of air movement equipment, either dedicated for smoke management or used to provide HVAC air to the building. The design of the smoke management systems is guided by local building code requirements, widely used and accepted installation standards, and fire protection engineering practice.

The design and installation of the smoke management systems have been documented in National Institute of Standards and Technology (NIST) NCSTAR 1-4D prepared for NIST by Hughes Associates, Inc. That publication also includes the results from an analysis of the systems to determine capabilities for various smoke management approaches to WTC 1 and WTC 2. This chapter provides an overview of the work performed by Hughes Associates, Inc. and draws heavily from NIST NCSTAR 1-4D.

5.1 INTRODUCTION TO SMOKE MANAGEMENT

5.1.1 Smoke Management Methods

The movement of smoke can be affected by its temperature (buoyancy), air flow, and barriers it encounters. “Smoke management” is a term used to define the use of active or passive means to minimize or control smoke movement within a building in the event of a fire. Active smoke management generally involves the use of building ventilation systems to control the movement of smoke. Passive smoke management generally involves the use of smoke barriers, such as walls, floors and ceilings and smoke dampers, to provide compartmentation within a building to minimize smoke spread between pre-defined areas of a building typically referred to as smoke zones. Several approaches to active smoke management are presented in the full report (NIST NCSTAR 1-4D); a brief overview of pressurization methods will be presented here as this is the type of system by which the WTC systems could be categorized.

For highly compartmented buildings with predominantly low-ceiling spaces, such as high-rise office buildings (including open-plan office buildings, which are compartmented at the core and floor to floor), the pressurization method is a commonly used smoke management approach. The pressurization method involves the use of mechanical ventilation systems (HVAC systems) to induce a pressure differential across a smoke barrier between the zone of fire origin and adjacent spaces, in order to contain the smoke within the zone of fire origin.

There are two general types of pressurization smoke management systems: positive pressure systems, and negative pressure systems. These two types of systems are depicted in Fig. 5–1. Positive pressurization systems supply air to the zones adjacent to the zone of fire origin to create a positive pressure in the adjacent zones with respect to the fire zone. Negative pressurization systems typically exhaust the zone of fire origin, either alone or in combination with supply in adjacent zones, to achieve the desired pressure differential. The simplest approach is to shut down ventilation airflow to adjacent zones and exhaust air from the zone of fire origin. The benefit of this type of system is that smoke is directly removed from the building, improving conditions within the zone of fire origin and within the building as a whole.

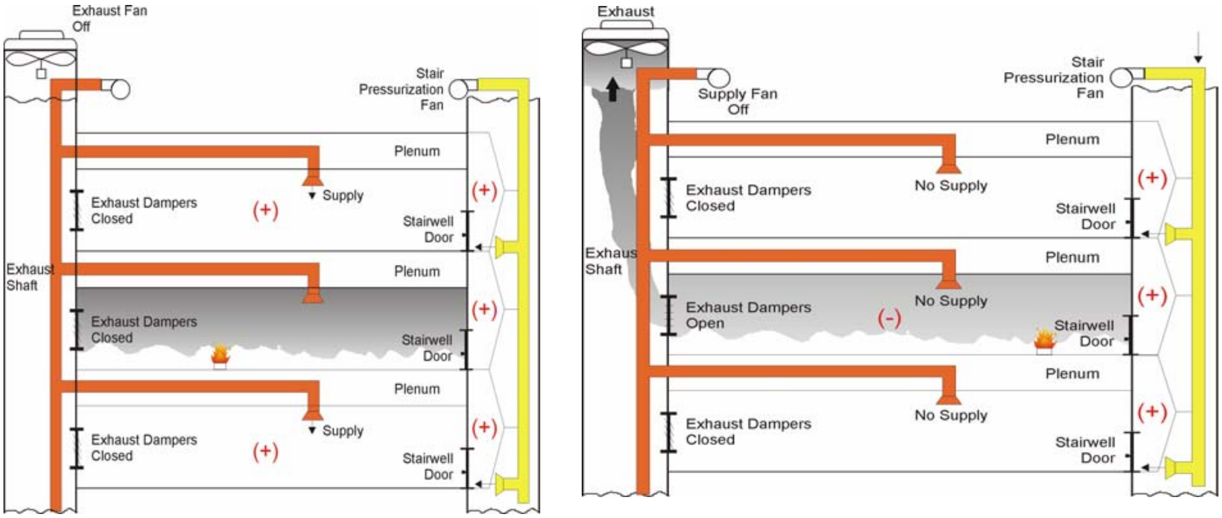


Figure 5–1. Positive (left side) and negative (right side) pressurization smoke management systems.

Stair pressurization is a type of positive pressurization smoke management system and is designed to limit smoke spread into the stairways of buildings such as high-rise buildings. The intent of stairway pressurization systems is to maintain the primary egress paths of a building clear of smoke.

The performance of a building's smoke management systems can be impacted by a number of factors, including stack effect, wind effects, air movement caused by the building's HVAC systems, and temperature effects associated with the fire (i.e., buoyancy and expansion of hot combustion products). Stack effect (or chimney effect) refers to the airflows induced due to the difference in temperature between the indoors and outdoors and, in New York City, is especially an issue in high-rise buildings during the cold winter months when this temperature difference is at its greatest. Wind can act to promote horizontal as well as vertical air movement through a building, depending on the areas open to the outside, resulting in smoke spread from the primary air inlets to the points of outward leakage. For buildings with relatively tight exterior walls and no operable exterior windows, wind effects tend to be minimal on smoke spread within the building. However, should windows be broken out, wind can have a greater impact on smoke spread.

HVAC systems that are not shut down during a fire, or are set in a mode that re-circulates air through the building, may directly cause smoke spread through the building. HVAC ductwork systems are often equipped with duct smoke detectors that shut down the associated fans in an effort to prohibit smoke spread via the fan. However, the open ductwork system may provide another conduit for smoke spread from floor-to-floor, particularly if the ductwork contains fire dampers rather than smoke dampers. Smoke dampers are designed to prevent the passage of smoke when closed as opposed to fire dampers which are designed to hamper the spread of fire – fire/smoke dampers do both. Also, fire dampers are closed by the presence of heat which physically severs a fusible link, whereas, smoke dampers are closed by a signal from a smoke detector or building control system. Further, smoke dampers are typically designed to fail in the closed position in the event that power is lost to the electronic actuator that closes the device.

Temperature effects are caused by the elevated temperature of the fire/smoke. For an unsprinklered fire, buoyancy of hot fire gases can be a significant contributor to smoke movement through a building. Smoke will form a layer in the upper part of the fire compartment and adjacent spaces, and spread vertically via shaft openings and other openings to floors above. For a sprinklered fire, the contribution of these buoyant forces to overall smoke movement in the building is minimized. Sprinkler water spray tends to cool the hot gases, reducing buoyancy, and stirs the smoke layer, resulting in a more uniform smoke concentration within a compartment.

5.1.2 History of Smoke Management

The following provides a history of smoke management. More details and a detailed review of the evolution of smoke control system requirements in the model building codes are presented in NIST NCSTAR 1-4D.

The origin of smoke management in buildings can be traced to an article that appeared in the National Fire Protection Association (NFPA) Quarterly in 1939, titled *Smoke Hazards of Air–Conditioning Systems* (NBFU 1939). In short, the article states that in the event of fire occurring in an air-conditioned building, it is necessary to shut down the "blowers" so that the movement of air will not augment the fire, and to interrupt the continuity of the duct system using dampers so that smoke, flame, and heat may not travel from their source to the places where damage may be caused. The current air-conditioning standard published by the NFPA, NFPA 90A, contains requirements that are consistent with the findings of the National Board of Fire Underwriters (NBFU) study on which the article is based (Klote 1994). Of note is the idea that the NBFU study examined the use of automatic smoke-tight dampers activated by photoelectric smoke detectors and that such a requirement would not make its way into the building codes until a much later time. The article also states that "with some changes in design, an air-conditioning system could be arranged so as to reverse its flow at time of fire and eject smoke and products of combustion from the building."

The issue of smoke management in buildings did not gain further momentum until the late 1960s/early 1970s, right about the time that the WTC complex was being designed and built. The first edition of UL 555–*Standard for Fire Dampers* was published in 1968, and over the next few years several symposia and an international conference were held to address fire hazards in buildings and air-handling systems (Klote 1994). Throughout the 1970s, test programs examined the effectiveness of smoke management systems (Klote 1995), including full-scale tests to evaluate the effectiveness of stairway pressurization. In each of these test programs, pressurization smoke management systems were shown to be effective in managing the spread of smoke created by full-scale unsprinklered test fires. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) introduced a handbook chapter titled *Fire and Smoke Control*, providing general information about fire protection, smoke production, smoke movement, and smoke control (Klote 1994). In subsequent years ASHRAE sponsored a series of seminars to educate design professionals on smoke management system design.

In 1983, ASHRAE published the first version of a document that outlined the engineering principles pertaining to smoke management system design (Klote and Fothergill 1983; Klote and Milke 1995, 2002) and, Underwriters Laboratories published the first edition of UL 555S–*Leakage Rated Dampers for use in Smoke Control Systems*. The 1985 edition of NFPA 90A–*Installation of Air Conditioning and Ventilation Systems* required that smoke dampers be installed in ducts which penetrate smoke barriers, and that the smoke dampers satisfy the provisions of UL 555S. In 1985, the NFPA formed its Technical Committee on Smoke Management Systems. This committee authored the first edition of NFPA 92A–*Recommended Practice for Smoke-Control Systems*, published in 1988. NFPA 92A was intended to be used for systems designed based on the pressurization method of smoke control and brought together many of the previous developments in smoke management system design, referencing UL 555 for fire dampers, UL 555S for smoke dampers, and NFPA 90A for HVAC system design, as well as the ASHRAE text *Design of Smoke Control Systems in Buildings* (Klote and Fothergill 1983) for further guidance on detailed design information. The committee went on to author the first edition of NFPA 92B–*Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, published in 1991.

In 1989, NIST conducted a series of tests of zoned smoke control systems at the Plaza Hotel in Washington, D.C. (Klote 1990). Fans were used to pressurize the stairway, exhaust the fire floor, and pressurize the floors above and below the fire floor. The experiments demonstrated that the smoke control system worked as intended (Klote 1995). The approach used in these tests would later become what is commonly referred to as “sandwich pressurization.”

5.1.3 Applicable Codes and Standards

Construction drawings for WTC 1, 2, and 7 were required by The Port Authority of New York and New Jersey (PANYNJ or Port Authority) to conform to the requirements of the BCNYC. WTC 1 and WTC 2 were constructed under the 1968 edition of the Building Code of the City of New York (BCNYC). WTC 7 was constructed under the 1968 BCNYC, including amendments to January 1, 1985, incorporated in the following local laws enacted after 1968:

- Local Law No. 5, Fire Safety Requirements and Controls, January 18, 1973
- Local Law No. 16, Local Laws of the City of New York for the Year 1984, March 27, 1984
- Local Law No. 33, Local Laws of the City of New York for the Year 1978, October 6, 1978
- Local Law No. 54, Local Laws of the City of New York for the Year 1970, November 17, 1970
- Local Law No. 55, Local Laws of the City of New York for the Year 1976, November 1, 1976
- Local Law No. 84, Fire Safety Pressurization Requirements in Certain Office Buildings, December 13, 1979
- Local Law No. 86, Dates for Compliance with the Local Laws Enacted for Fire Safety Requirements and Controls in Certain Buildings, December 13, 1979

The BCNYC differs from other building codes in that changes to a building code generally affect only new buildings and are applied to an existing building only when a major renovation or change in occupancy occurs within the building. Many provisions contained within the local laws amending the BCNYC are applied retroactively; thus, these provisions are required to be implemented in existing buildings.

To be consistent with the BCNYC requirements, WTC 1, 2, and 7 were required to be equipped with fire dampers at all duct openings into vertical shaft enclosures and at penetrations of fire resistance rated floors or ceilings. Smoke dampers were required in the main supply duct and main return duct for HVAC systems having a capacity of over 15,000 ft^3/min and were arranged to close automatically by the operation of duct smoke detectors. Smoke detectors were required at the return shaft inlet on each floor. Activation of a detector was required to stop air supply to and return from the affected floor. In addition, WTC 7 was required to have either a combined fire/smoke damper or independent fire and smoke dampers at any penetration of construction required to have a fire resistance rating, under the provisions of Local Law #16 pertaining to smoke control.

Local Law #5 required that unsprinklered high-rise buildings be subdivided by fire separations into fire compartments on each floor of the building. WTC 1 and WTC 2 were originally subdivided into quadrants to meet this requirement, but were later provided with full automatic sprinkler protection, negating this requirement. WTC 7 was not required to provide compartmentation, as the building was fully sprinklered at the time of its construction.

Local Law #5 required existing office buildings to be provided with one or more smoke shafts by means of which smoke and heat could be mechanically vented to the outdoors. In lieu of providing smoke shafts, all enclosed exit stairs could be provided with stair pressurization. This requirement applied retroactively to WTC 1 and WTC 2.

Local Law #16 added the requirements for smoke control that included the provision of smoke dampers in HVAC ductwork and separation of ventilation systems serving specified areas of buildings. In addition, a mechanical means to exhaust six air changes per hour, or 1 cfm/ft^2 (whichever is greater) from the largest floor of a building, operated manually to exhaust one floor at a time, was required. These provisions of Local Law #16 applied to WTC 7.

Local Law #16 required that an emergency power system be provided having the capacity to operate life safety related equipment in high-rise buildings, including ventilation systems for smoke venting or control and stair pressurization. This provision applied to WTC 7 but did not apply retroactively to WTC 1 and WTC 2.

5.2 BUILDING DESCRIPTIONS

Building construction details and building systems in WTC 1, 2, and 7 were evaluated to develop an understanding of building features that may have impacted smoke movement within the buildings or the design/function of smoke management systems. Building HVAC systems are described in somewhat greater detail in order to understand the capabilities of the HVAC systems to perform smoke management functions.

5.2.1 WTC 1 and WTC 2

WTC 1 and WTC 2 were comprised of 110 stories above grade and seven levels below grade and had an approximate footprint area of 42,900 ft^2. WTC 1 and WTC 2 were similar architecturally, with differences in layout as shown in Figs. 5–2 and 5–3. The interior of each floor differed due to the particular tenant build-out on that floor. In addition, the service core for the north tower (WTC 1) was oriented east/west while the service core for the south tower (WTC 2) was oriented north/south. The service cores contained the elevators, exit stairs, bathrooms, and miscellaneous equipment rooms. The service core gradually decreased in size on the upper floors of the building as the numbers of elevators contained on the floors decreased.

The core spaces were separated from the perimeter spaces in the building by a 2 h fire resistance rated barrier extending slab-to-slab (i.e., between the floor and ceiling slabs). The perimeter office spaces were generally open-plan office spaces containing office cubicles. Individual office spaces on the perimeter were generally separated by non-fire resistance rated partitions extending only to the drop ceiling (i.e., not all the way up to the ceiling slab). The ventilation air plenum above the drop ceiling was open around the perimeter of the floor.

Each tower was provided with three emergency exit stairways, enclosed in 2 h fire resistance rated gypsum wallboard construction. The plan location of the stairways shifted at some levels in order to reduce the occurrence of continuous vertical shafts that extended the entire height of the building. Ninety-nine elevator shafts were located in each building. A system of express and local elevators was installed in the buildings. High-speed express elevators shuttled people from the lobby to sky lobbies on the 44th floor and 78th floor of the building. Escalators connected the sky lobbies to the floors immediately above and below. Local elevators provided access from the sky lobby floors to the upper floors of the building. Freight elevators 49 and 50 extended to different heights in the building, with only freight elevator 50 extending the full height of the building.

Building ventilation (heating and cooling) was provided in WTC 1 and WTC 2 by HVAC systems located in four mechanical equipment rooms (MERs) located on the 7th, 41st, 75th, and 108th floors of each building. Each MER was approximately two stories tall and had an upper and lower level. With the exception of the 108th floor MER, which was located at the top of the building, above the floors that it served, the MERs served the floors immediately above and below the floors on which they were located. The aircraft impact into WTC 1 occurred in the uppermost portion of the building (92nd–98th floors), served from above by the 108th floor MER. The aircraft impact into WTC 2 occurred slightly lower in the building (77th–84th floors), served from below by the 75th floor MER. Figure 5–4 shows the locations of the MERs in elevation view and the location of the aircraft impacts relative to the MERs.

HVAC supply fans were located on the lower level of each MER. Supply air was provided to the building via core, interior, and peripheral HVAC units. There were two core supply ventilation zones (north/south in WTC 2, east/west in WTC 1, due to the orientation of the core), four interior space HVAC zones (corresponding to the four quadrants of the building), and four perimeter zones (north/south/east/west). Each supply fan delivered air to a supply duct network serving the respective HVAC zone associated with the supply fan.

Figure 5–2. Floor layout, 95th floor, WTC 1, North Tower.

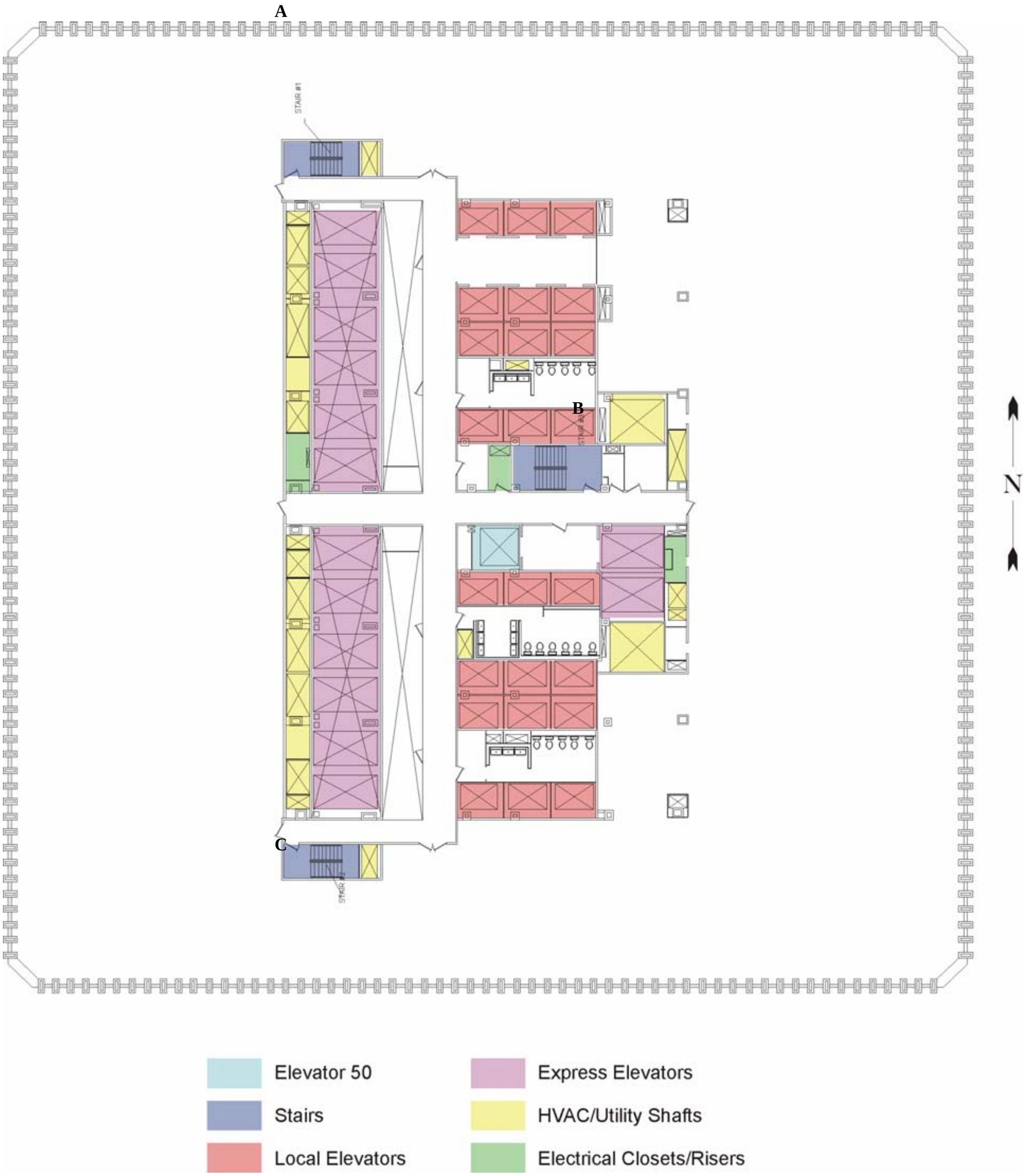


Figure 5–3. Floor layout, 80th Floor, WTC 2, South Tower.

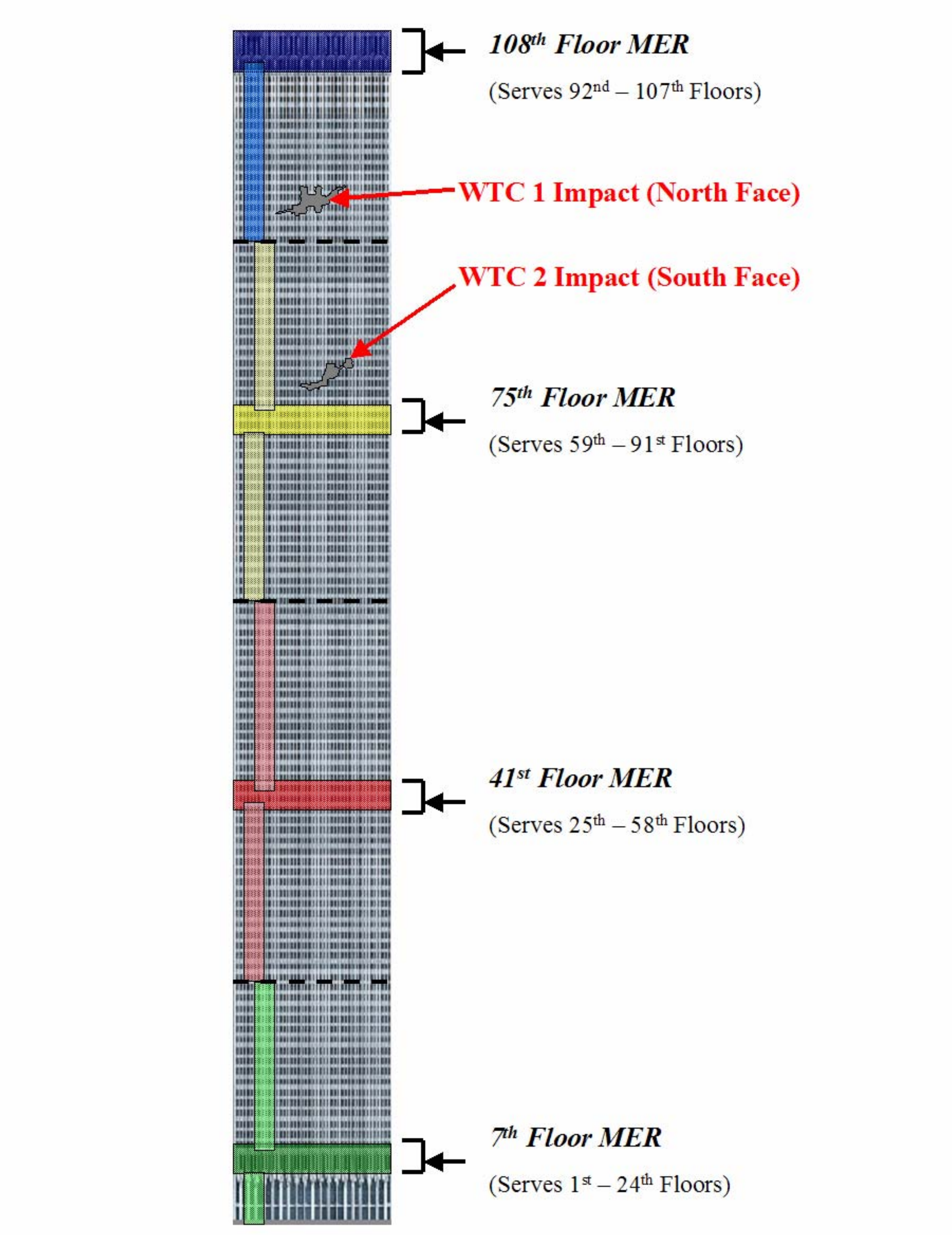


Figure 5–4. Location of MERs, WTC 1 and WTC 2.

Exhaust fans were located on the upper level of each MER. These fans drew air from four sets of vertical return air shafts located along the east and west sides of the core . The gypsum wallboard shafts were connected to return air plenums located above the drop ceiling in the four interior quadrants of each floor via openings between the shaft and plenum. Air was drawn up from the occupied space, through return grilles located in the ceiling tiles and into the ceiling plenum. Return air was then drawn vertically to the MER exhaust fans via the gypsum wallboard shafts. In this manner, the exhaust fan acted to "return" air from the occupied space back to the MER where it could be recirculated back to the supply fans or exhausted out of the building depending on positioning of the main supply, return, and exhaust air dampers. Details of the interaction between the supply and exhaust systems are provided in NIST NCSTAR 1-4D.

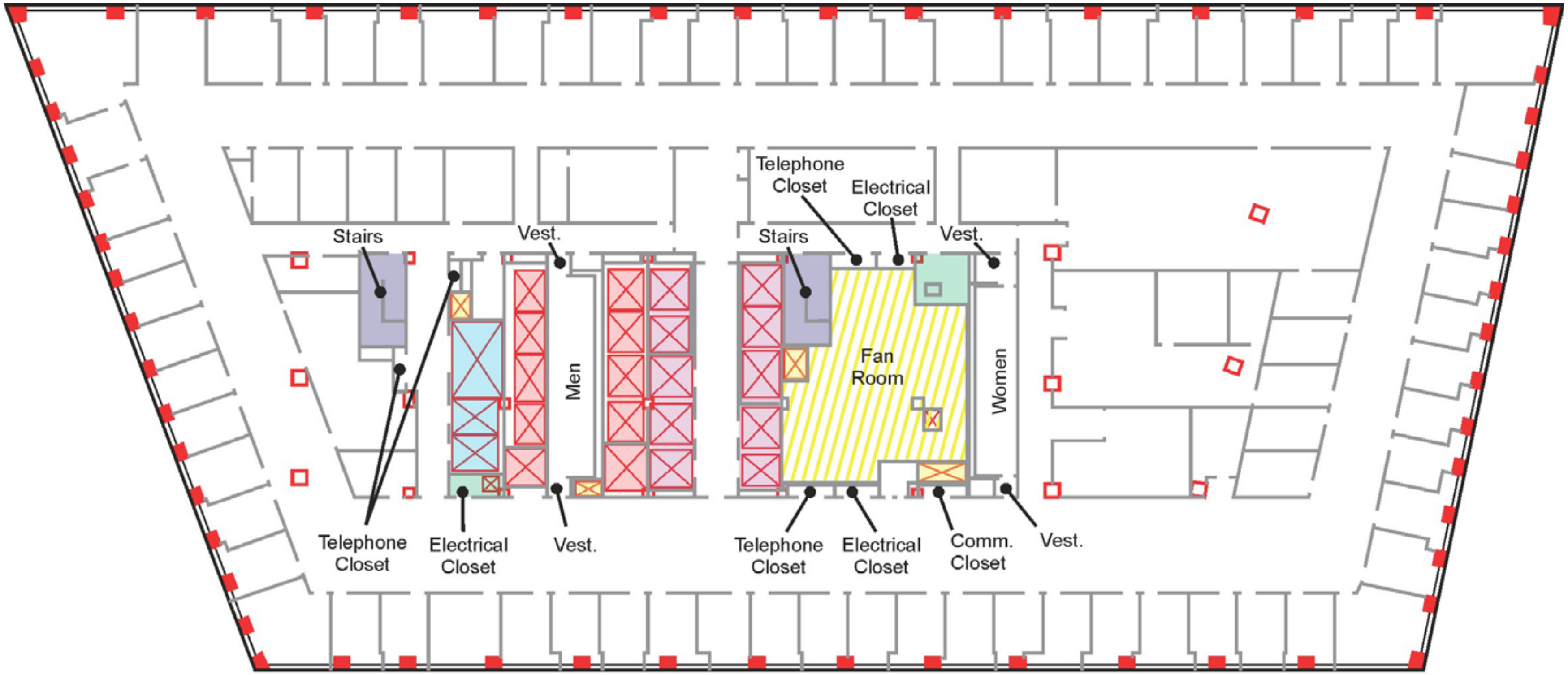
The smoke management system (smoke purge) for WTC 1 and WTC 2 utilized only the interior air systems and core systems, which were not modified substantially as a result of tenant retrofits. Perimeter air was not used for smoke management. Further, the return air plenum arrangement and total air quantities remained unchanged, despite individual tenant retrofit configurations. While smoke movement may have been impacted on a given floor due to changes to the ventilation system on individual floors, overall pressure differentials were be expected to remain the same.

5.2.2 WTC 7

WTC 7 consisted of 47 stories above-grade and had a footprint area of approximately 48,000 ft^2. As shown in Fig. 5–5, the service core for the building was located in the east-west direction and contained the elevators, exit stairs, bathrooms, and mechanical/electrical equipment rooms. The perimeter spaces were generally either open-plan office spaces, containing cubicles, or hard-walled individual office spaces. Individual office spaces were generally separated by non-fire resistance rated partitions extending only to the drop ceiling. The ventilation plenum above the drop ceiling was open around the perimeter of the floor. The building was protected throughout by automatic sprinklers with the exception of certain electrical equipment spaces, generator rooms, and bathrooms throughout the building.

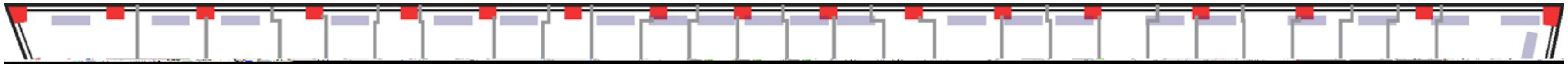
The building was served by low-rise (floors 7–20), mid-rise (floors 21–37), and high-rise (floors 38–45) elevators, as well as service and freight elevators that ran the entire height of the building. There were 31 total elevators serving the building. Two exit stairs served the building, and were referred to as Stair 1 (or Stair A) and Stair 2 (or Stair B). The position of Stair 1 remained constant on each floor of the building. The position of Stair 2 shifted at the 23rd floor, due to the location of the low-rise elevators serving the lower floors.

The original building layout consisted of a mechanical equipment room located on each floor. Building ventilation was provided on the tenant floors (floors 7 through 47) for the base building configuration in WTC 7 by supply air fans located on each floor. As shown in Fig. 5–6, conditioned air was distributed to the floor in two zones, corresponding to the north/east, and south/west portions of the building. The fan room served as a return plenum. Return air was drawn into the fan room via ducts that connected the fan room to the return air plenums above the occupied space of each floor. Make-up (outdoor) air was drawn into the fan room via make-up air shafts that connected to the exterior of the building either at the roof or at the 6th floor via louvers through the side of the building.



[redacted]

Figure 5–5. Floor layout, 24th floor, WTC 7.



[redacted]

Figure 5–6. Air distribution system, 24th floor, WTC 7.

Consistent with the BCNYC, the WTC 7 HVAC systems were designed to incorporate a smoke purge mode, by which each floor of the building could be exhausted/purged of smoke manually on a floor-by-floor basis from the fire command center, which was located on the 3rd floor of the building at the main lobby security desk. Two smoke exhaust fans were originally located within the building on the 6th floor and 47th floor. The return air ductwork was connected to the exhaust duct. Return air either dumped into the fan room via the return dampers in each branch duct or was exhausted via the smoke exhaust riser. A smoke exhaust damper would open at the shaft within each mechanical room, and the return dampers closed to exhaust smoke in the smoke purge mode. Curtain fire dampers were located throughout the building where ductwork crossed fire rated shaft walls, consistent with the BCNYC. Separate pneumatic smoke dampers were used in the fan room to direct airflow within HVAC ductwork.

During the early 1990s, Salomon Smith Barney (SSB) performed a major tenant retrofit to floors 28 through 45. The retrofit included the combining of adjacent floors into single floors, the relocation of HVAC shafts, and the provision of new HVAC equipment to supplement base building equipment. This renovation included changes to the smoke management system, detailed in NIST NCSTAR 1-4D.

5.3 SMOKE MANAGEMENT SYSTEM DESIGN AND INSTALLATION

This section documents the design and installation of the smoke management systems in the towers (WTC 1 and WTC 2) and WTC 7 on September 11, 2001, and compares the system designs to applicable code requirements. The designs were compared to the prevailing requirements of the BCNYC at the time of the event.

In order to document the smoke management systems, multiple sources were reviewed in order to determine how the systems were designed and operated. In the case of WTC 1 and WTC 2, information obtained on the operation of smoke management systems presented conflicting versions of how the systems operated. In the case of WTC 7, the base building systems installed when the building was constructed was modified/supplemented to add smoke management system capabilities during tenant retrofits. Instances where conflicting or incomplete information was provided are fully documented in the full report, NIST NCSTAR 1-4D.

5.3.1 WTC 1 and WTC 2

The tower buildings (WTC 1 and WTC 2) were equipped with a non-dedicated smoke management system (a smoke purge system) that utilized the base building HVAC systems that provided normal ventilation to the buildings. No dedicated smoke management systems were installed in the buildings.

The normal base building HVAC systems could be manually aligned in a smoke purge mode that allowed smoke to be removed from the building. Smoke purge could only be accomplished for an entire ventilation zone served by a particular MER; thus, in the smoke purge mode the entire ventilation zone represented a single smoke zone. Because no operable fire/smoke dampers were present within the ventilation ductwork, it was not possible to provide the smoke purge, or any other smoke management sequence, on a floor-by-floor basis.

Smoke detectors were located at the exhaust duct inlets on each floor and within the HVAC system ductwork in the MER to provide automatic shutdown of individual fans in the presence of smoke. Automatic shutdown of the ventilation systems could be overridden in the smoke purge mode.

The fire safety plan for WTC 1 and WTC 2, revised in January of 1999, defines *smoke purge* as the removal of smoke and other gaseous combustion products from the (fire) area "after a fire has been extinguished." As documented in the fire safety plan, mechanical systems could be manually adjusted to perform the smoke purge function by the Port Authority mechanical section staff when requested by the chief officer of the responding Fire Department of the City of New York (FDNY) units. The FDNY would ask the WTC fire safety director to provide a smoke purge for a given zone. The WTC fire safety director would then instruct the mechanical section staff to perform the requested action.

The smoke purge sequence is documented in WTC Instruction Manual No. 23, *Operation and Maintenance of Fire Protection System*, dated February 1986. The documented sequence involves using the interior exhaust fans to exhaust an entire multi-floor ventilation zone. Based on the information contained in the fire safety plan for WTC 1 and WTC 2 and WTC Instruction Manual No. 23, it could be concluded that the buildings were equipped with a manual purge system that utilized the interior zone exhaust fans serving the four quadrants of the building to remove smoke after a fire was extinguished. Core supply/exhaust fans and peripheral supply fans would be shut down. Smoke purge could be accomplished within each HVAC zone, the largest of which consisted of 32 floors.

During the course of this investigation, a number of sources were found containing conflicting information regarding how the smoke purge system functioned and how it was intended to be used. Accounts of the 1975 fire, discussed in Chapter 2 (Powers 1975; Lathrop 1975), state that the smoke purge sequence pressurized the core with 100 percent outside air and exhausted 100 percent from the office spaces. These accounts also state that during the 1975 fire, the smoke purge sequence for the fire floor and adjacent floors was initiated from the appropriate MER shortly after discovery of the fire, once police had examined the fire floor and identified the presence of a significant fire. This documented sequence of events is important, as it signifies that the system was used at that time as an active fire protection system, to control smoke during the fire event and that the mode of operation differed from the that contained in the 1986 Instruction Manual No. 23.

As part of this investigation, the Port Authority was asked to clarify the operation of the smoke purge sequence, since the available information regarding its intended operation provided conflicting accounts of smoke purge operation. According to the Port Authority, smoke purge would occur by starting the supply and exhaust fans serving one of the four interior quadrants within a ventilation zone. Core supply/exhaust fans and peripheral supply fans would be shut down. HVAC systems serving the other ventilation zones in the building would be left operating unless they were shut down at the direction of FDNY. The Port Authority further recognized that WTC Instruction Manual No. 23 had not been updated since the base building fire alarm system was upgraded after the 1993 bombing. Therefore, this manual did not always reflect the most current fire protection system configuration.[8]

Operation of the smoke management system for WTC 1 and WTC 2 could be achieved by controlling the equipment within the individual MERs or at a central control panel located in the Operations Control

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[8] E-mail communication from the PANYNJ, dated February 18, 2004, responding to questions posed by NIST.

Center (OCC) located on the B1 level of WTC 2. At either location, building personnel had to perform two distinct operations:

- Configuring the HVAC systems in smoke purge mode
- Starting the appropriate HVAC fans

Operation of the purge switch aligned all dampers that served as part of that quadrant's HVAC systems in a 100 percent outside air configuration. This would mean that supply and spill dampers would be fully open and that recirculation dampers would be closed.

To achieve the smoke purge, it was up to the operator of the systems to turn on those fans necessary to achieve system operation. It would have been equally possible to initiate an exhaust only type sequence as outlined in the fire safety plan, the core pressurization sequence (supply and exhaust operating) reportedly initiated during the 1975 fire, or the sequence stated by the Port Authority as the smoke purge sequence in effect on September 11, 2001. Alignment of the system would be up to the understanding of the operator as to the proper function of the smoke purge sequence, when called upon to initiate this sequence.

With regard to the use of the smoke purge function to aid in active smoke management system during a fire event versus during post-fire cleanup operations, it would be up to the responding fire department personnel to initiate system operation. Depending on the type of fire event, it was possible that the system could have been used either during the fire or after it was extinguished.

At the time the buildings were constructed, the ability to provide a smoke purge from each HVAC zone was the only smoke management system provided in the buildings. Local Law #5 retroactively imposed the requirements for smoke shafts for existing high-rise buildings, when it was enacted in 1973. In lieu of such smoke shaft(s), stair pressurization systems could be provided.

In order to respond to the requirements of Local Law #5, the Port Authority initiated a pilot study into the requirements for pressurizing the exit stairs in WTC 1 and WTC 2. Stair pressurization was examined as a means of meeting the requirements of Local Law #5 since the smoke shaft requirements would have been prohibitive for a building the size of WTC 1 and WTC 2. Existing buildings that were sprinklered throughout were exempt from the smoke shaft and optional stair pressurization requirement by the requirements of Local Law #86 (enacted in 1979). A decision was made at some subsequent time to fully sprinkler the WTC buildings. Therefore, the Port Authority did not move forward with the stair pressurization option. Because WTC 1 and WTC 2 were fully retrofitted with automatic sprinklers, smoke and heat venting and/or stair pressurization was not required in WTC 1 and WTC 2 on September 11, 2001.

As shown in Fig. 5–7, WTC 1 and WTC 2 were equipped throughout with fire dampers at duct penetrations into vertical shafts, consistent with the BCNYC. Combination fire/smoke dampers were not required by the code to be provided in existing buildings. Since tenant retrofit projects generally connected to the existing base building systems, fire/smoke dampers at HVAC shafts were not generally provided during tenant retrofits.

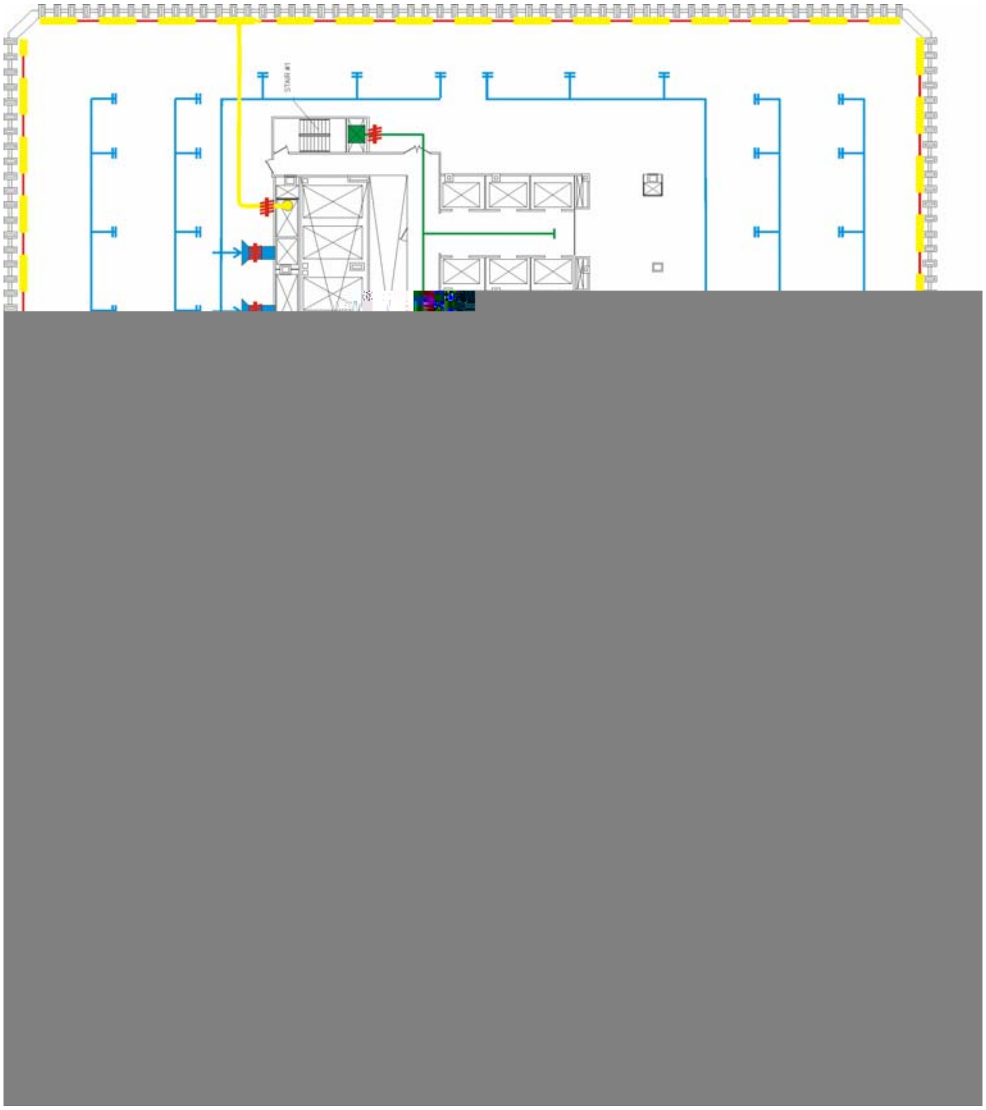

Figure 5–7. Air distribution system, 80th floor, WTC 2.

Emergency power was not retroactively required by the BCNYC, but was provided subsequent to the 1993 bombing for WTC 1 and WTC 2, serving all emergency systems (lighting, fire alarm system, etc.) and the building elevators. While one account summarizing the building restoration activities following the 1993 bombing suggested that emergency power was provided for smoke purge fans, the Port Authority stated that emergency power was not provided to WTC 1 and WTC 2 base building smoke purge fans.[9] However, the MERs were equipped with redundant power sources from different substations.

No other redundant features were identified with respect to the HVAC systems used to accomplish the smoke purge functions. No backup system or emergency power was provided.

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[9] E-mail communication from the PANYNJ, dated February 18, 2004, responding to questions posed by NIST.

5.3.2 WTC 7

WTC 7 was equipped with a dedicated smoke management system (a smoke purge system) that utilized dedicated HVAC equipment that served only a smoke management function. This type of system differed from that used in WTC 1 and WTC 2, which utilized the HVAC systems that provided normal ventilation to the buildings to perform the smoke purge function. In WTC 7, dedicated smoke exhaust fans/dampers could be manually aligned at the fire command center to provide smoke purge from a specified floor within the building. Since the smoke purge function could be provided on a floor-by-floor basis, each floor of the building constituted an individual smoke control zone.

The building operations manual for WTC 7 specified three alarm modes pertaining to operation of the building HVAC systems. ALARM-1 initiated shutdown of HVAC equipment based on duct smoke detection. ALARM-2 initiated smoke purge on the affected floor. ALARM-3 specified the smoke purge sequence for non-affected floors. The smoke management sequence pertaining to the smoke purge function involved exhausting the fire floor and pressurizing the remaining floors with supply air.

Local Law #16 required that all buildings in occupancy group E (business) be provided a manual override capability to be capable of exhausting one floor at a time at a rate of six air changes per hour, or 1 cfm/ft^2, whichever is greater. For WTC 7, with a footprint area of approximately 48,000 ft^2, this would require an exhaust capacity of at least 48,000 ft^3/min (81,552 m^3/h). The base building system serving the lower floors of the building provided a smoke exhaust capacity of 36,000 ft^3/min (61,164 m^3/h), which was not consistent with the minimum value specified by code. An 84,000 ft^3/min (142,716 m^3/h) exhaust fan was provided for the SSB floors during the tenant retrofit, which exceeded the capacity required by code.

WTC 7 was sprinklered throughout and was, therefore, exempted from the requirement for stair pressurization systems. The building was provided with a Class E fire alarm system consistent with the code, was provided with emergency power serving all emergency systems, and was equipped throughout with fire dampers at duct penetrations into vertical shafts, consistent with the BCNYC.

5.4 EVALUATION OF SYSTEM PERFORMANCE ON SEPTEMBER 11, 2001

This section documents the normal operation of the fully functional smoke management systems on smoke conditions in WTC 1 and WTC 2 on September 11, 2001. Elements of this task involved the evaluation of expected system performance for postulated design fires in business occupancies, as well as documentation of the expected performance of fully functional smoke management systems in the towers.

The smoke management systems in WTC 1 and WTC 2 were designed to provide a manually-initiated smoke purge function. Given the design and intended operation of the smoke management systems, two key questions were sought to be answered to ascertain the performance of the system on September 11, 2001:

- Was the smoke purge system in either WTC 1 or WTC 2 manually initiated by emergency response personnel?
- Were the systems capable of operating given the damage caused by the aircraft impacts on each building?

In order to answer the second question, damage to both the building electrical and mechanical systems needed to be evaluated. It was first necessary to determine whether electrical power was available to the building mechanical systems subsequent to impact so that they were capable of operating. Then, potential damage to HVAC system components was evaluated to determine if the systems were capable of performing as designed.

5.4.1 Actions of Emergency Response Personnel

The events of September 11, 2001, clearly represented an extreme challenge, both to emergency response personnel and to the installed building systems. The damage caused by an aircraft impact into a building is outside the range of typical design considerations for the design of most building systems, including fire protection systems.

The WTC fire safety director on duty stated that no recommendation was given on his part to initiate a smoke purge sequence, nor was smoke purge performed on September 11, 2001, to his knowledge.[10] NIST found no record of FDNY personnel having initiated a smoke purge sequence in WTC 1 or WTC 2.

5.4.2 Damage to System Components

The exact extent of damage within individual floors of WTC 1 and WTC 2 may never be known, since the collapse of the buildings prohibited a detailed inspection of the impact area. However, the potential extent of damage was estimated based on the results of engineering analysis and based on observations recorded by people located within WTC 1 and WTC 2 at the time of the events.

Potential damage estimates were overlaid onto representative floor plans for the impact areas in WTC 1 and WTC 2 in order to determine the potential damage to key electrical/mechanical system components located in the core spaces. The damage estimates were corroborated to a certain extent using observations made by people located in various locations in the buildings after aircraft impact. The observations primarily have to do with stair shaft damage, damage to freight elevator 50, and in some cases elevator shafts. HVAC shaft data could be corroborated using visual evidence of smoke spread seen from the exterior of the building. An attempt was also made to corroborate the extent of core damage using observations as to the presence of power in the building.

5.4.3 Summary of System Performance on September 11, 2001

Examination of the available evidence provided strong indications that the smoke management systems in WTC 1 and WTC 2 played no role in the events that occurred on September 11, 2001. There was no evidence to support the fact that an attempt was made to activate the smoke purge sequence.

If a decision had been made to attempt to align the building ventilation systems into the smoke purge mode, it is unclear that this would have had any impact on overall smoke conditions within the building. Since the WTC 1 impact occurred near the boundary between ventilation zones at the 91st/92nd floors, smoke purge may have been inadvertently initiated for the 59th–91st floor HVAC zone in WTC 1, rather than the HVAC zone for the upper floors.

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[10] PANYNJ Interview 3, fall 2003.

The aircraft impacts caused significant damage to the core spaces in both WTC 1 and WTC 2, making it unlikely that the smoke purge could have been accomplished in either building. In WTC 1, it is likely that the impact eliminated or significantly impaired electrical power on floors above the impact zone. Therefore, because power would not have been available at the 108th floor MER (which served the zone of impact) HVAC systems likely would not have been operational. In addition, the ventilation shafts for at least the north half of the building were likely damaged, thus reducing the possibility for the smoke purge to function properly even if the HVAC systems had been operable.

In WTC 2, it is possible that electrical power may have been available to the fans located in the 75th floor MER, which was located below the impact zone in this building. Survivor accounts indicate that power may have been available up to the 75th floor and visual evidence suggests power was available even above the floors of impact (Beyler 2002). Initially, all fans would have shut down due to detection of substantial quantities of smoke by the duct smoke detectors. The HVAC shafts utilized to accomplish smoke purging would likely have been damaged on the east side of the building, eliminating half of the smoke venting capacity for the floor. Even if the ventilation shafts on the west side of the building remained intact, the performance of the smoke venting system would have been reduced. This would have had a particularly detrimental impact on WTC 1, where smoke conditions deteriorated in the uppermost portions of the building at a much faster rate than WTC 2.

5.5 EVALUATION OF POTENTIAL SMOKE MANAGEMENT SYSTEM EFFECTIVENESS

In order to fully understand the potential impact of smoke management systems for events like those occurring on September 11, 2001, it is important to analyze how various smoke management system configurations might have performed in WTC 1 and WTC 2 had they been available on September 11, 2001. To develop an understanding of the capabilities of the various smoke management system configurations that were evaluated, it is also important to analyze their performance for other hypothetical fire scenarios in high-rise buildings, both typical/expected design scenarios and worst case scenarios. All of the smoke management approaches analyzed utilized some variation of the pressurization method of smoke management.

The performance of each of the smoke management approaches, given the postulated design fire scenarios, was evaluated using the CONTAM building airflow and contaminant dispersal model (Dols and Walton 2002). CONTAM is a recognized tool for the evaluation of smoke management systems that are based on the pressurization method of smoke management.

The various codes and standards that reference the use of pressurization smoke control require the provision of 0.05 in. H_2O (12.5 Pa) pressure differentials in sprinklered buildings and 0.1 in. H_2O (25 Pa) in non-sprinklered buildings to contain smoke. It is important to note, however, that these pressures are measured with a building’s HVAC systems placed in smoke management mode, without the presence of a fire. The required pressure differentials are high enough to contain heated smoke were a fire to be present in sprinklered and non-sprinklered occupancies, and are used for design purposes.

5.5.1 Smoke Management System Approaches

Five distinct smoke management approaches were examined for the WTC towers. These approaches are as follows:

- Smoke Purge
- Core Pressurization
- Building Pressurization
- Sandwich Pressurization
- Zoned Smoke Control with Stair Pressurization

The smoke purge approach is based on the documented smoke purge sequence for WTC 1 and WTC 2 as it appears in WTC Instruction Manual No. 23, *Operation and Maintenance of Fire Protection System*, dated February 1986. The sequence involved placing the interior HVAC zone exhaust fans and core exhaust fans (toilet exhausts, elevator machine room (EMR) exhausts) in the multi-floor ventilation zone containing the fire in 100 percent exhaust mode. HVAC systems in all other ventilation zones in the buildings were aligned in a summer normal mode. Peripheral supply fans were shut down.

The core pressurization approach is a slight variation of the documented smoke purge sequence for WTC 1 and WTC 2, in that the supply fans, rather than the exhaust fans, in the core were activated to pressurize the core, in an effort to prohibit smoke spread into the core from the surrounding office spaces. Accounts of the 1975 fire and other sources cite this variation as being the “smoke purge” sequence provided for the building.

The building pressurization approach was recommended to be used in the event of a severe fire involving a substantial portion of one floor of the building, where windows were observed to be broken out (HAI/DCE 1996). The approach involves turning on the supply fans in the entire building and turning on the exhaust fans only in the ventilation zone of fire origin. The intent of this approach was to exhaust smoke, where possible, from the floor containing the fire and to induce a substantial airflow toward the floor of fire origin to force smoke out of the broken windows.

The sandwich pressurization approach typically involves exhausting the floor of fire origin and pressurizing the floors above and below. The HVAC systems in WTC 1 and WTC 2 were not equipped with operable fire/smoke dampers; thus, it was not possible to configure the system to exhaust and supply to only single floors within a ventilation zone. Instead, an approach was examined where the sandwich was achieved by ventilation zones. In the event of a fire, the ventilation zone of origin would have all of its exhaust fans turned on, and supply fans turned off. The ventilation zones above and below would have all supply fans activated and exhaust fans turned off. These actions would create a multi-floor sandwich effect in the building, with the net effect being the creation of a pressure differential between the core and perimeter spaces within the HVAC zone of fire origin.

The final approach, zoned smoke control with stair pressurization, was a hypothetical approach based on best practices in smoke management system design considered relevant as of September 11, 2001. It was assumed that the building was retrofitted with stair pressurization systems, as required for all new high-rise construction by the model building codes in the United States, and was capable of exhausting on a floor by floor basis within the ventilation zone containing the fire to create the desired pressure differential with respect to the floors above and below. Other ventilation zones were assumed to operate in the summer normal mode. It was assumed that operable fire/smoke dampers were also installed in all supply/exhaust ducts at the appropriate shaft connections and that these dampers were closed within the zone of fire origin.

5.5.2 Design Fire Scenarios

Several different design fire scenarios were evaluated for WTC 1 and WTC 2, encompassing the range of expected fires that could be envisioned within the office spaces of the building. The fire scenarios were limited to those that could occur on the above-grade office floors of the building. Other fire scenarios are possible that could result in smoke migration through the towers due to a fire in the sub-grade areas or adjacent spaces within the WTC complex (i.e., truck dock fire, car fire in the garage, fire in the concourse). Because the focus of this report is on examining the fires that occurred on September 11, 2001, (which occurred on the uppermost floors of the building) and bounding these events with other comparable fires, it was desirable to examine only those fire scenarios on the office floors of the building. The design fire scenarios that were evaluated are as follows:

- Sprinklered Fire
- Full-Floor Burnout
- Two-Floor Fire
- WTC 1 and WTC 2, September 11, 2001 Fire Scenarios (No Shaft Damage)
- WTC 1 and WTC 2, September 11, 2001 Fire Scenarios (Shaft Damage Assumed)

The first fire scenario assumes that a typical fire in a sprinklered building would either be controlled or extinguished by the automatic sprinkler system. It was assumed that the temperature in the zone of origin never exceeded the operation temperature of the sprinklers, which were assumed to have an activation temperature of 165 °F (74 °C). Given the large size of the majority of the office spaces in the towers, some of which encompassed an entire floor, the average temperature throughout the floor would be expected to be less than the assumed 165 °F.

The second fire scenario, the full-floor burnout scenario, is considered a worst-case design scenario for a fire involving the contents of a typical office building. In a fully-sprinklered building, a full-floor burnout would only be possible given some sort of catastrophic failure of the sprinkler system or given a fuel load that exceeded the capacity of the sprinkler system. The full floor burnout fire scenario evaluated in this report assumed a temperature on the floor of fire origin of 1,800 °F (1,000 °C). It was further assumed that 58 windows on each face were broken out.

The third fire scenario, the two-floor fire scenario, corresponds to a multi-floor event. The purpose of this fire scenario was to examine smoke management system performance for a multi-floor fire scenario of far less severity than the aircraft impact scenario that occurred on September 11, 2001. It was assumed that an explosion had opened up a 100 ft^2 (9.3 m^2) hole in the floor slab at the midpoint along one of the faces of the building. The average temperature on the two floors was assumed to be identical to that of the sprinklered fire scenario, 165 °F (74 °C).

The fourth fire scenario was a hypothetical fire scenario in which the majority of the structural damage occurring on September 11, 2001, was modeled, but with no shaft damage occurring in the building's core. This scenario, although unlikely, was modeled to estimate the performance of the candidate smoke management system approaches for a scenario involving a multi-floor fire event with high temperatures throughout the fire compartment and large openings in the exterior of the building.

The fifth fire scenario was an attempt to model smoke management system performance given conditions close to what actually may have existed in WTC 1 and WTC 2 on September 11, 2001. Estimates made as to the size of the exterior openings after aircraft impact, including impact damage and window breakage, were used along with the preliminary damage estimates to model the damage to shafts within the core of each building. Where the extent of damage was unknown, estimates had to be made with regard to the extent of damage. Temperatures of 750 °F (400 °C) and 1,800 °F (1,000 °C) were used to model the temperature throughout the impact zone. For all cases, the outside air temperature was modeled as 70 °F (21 °C) with the wind out of the north at 11.2 mi/h (5 m/s).

5.5.3 Results of the Analysis

Five candidate smoke management system approaches were evaluated to determine whether each of these approaches could provide adequate pressurization to contain smoke to the zone of fire origin for five postulated fire scenarios.

The *smoke purge* approach and the *core pressurization* approach were shown to create adequate pressure differentials for only the sprinklered fire scenario. Substantial negative pressure differentials, indicating flow of smoke from the zone of fire origin into the core, occurred for each of the other fire scenarios.

The *building pressurization* approach created high pressure differentials from the core to the perimeter office spaces for all fire scenarios except the multi-floor September 11 aircraft impact scenarios. Positive pressures were demonstrated for both the undamaged core and shaft damage September 11 scenarios in WTC 1, but sufficient airflow velocity was not created to prohibit smoke spread via large openings in ventilation shafts and in the core/office space boundaries resulting from aircraft impact damage. Use of the building pressurization method could potentially create excessive door opening forces that could hinder or prohibit the egress of building occupants. The magnitude of the door opening forces is a function of the fire scenario, size of interior and exterior openings, and location of the floor(s) of fire origin relative to the location of the MER.

The *zoned smoke control with stair pressurization* approach was shown to be effective for the sprinklered fire scenario, the full-floor burnout, and the two-floor fire. For each of these fire scenarios, however, stack effect was shown to have a substantial impact on the performance of the system, in some cases causing airflow from the floor of fire origin into the core. Therefore, this approach might not be effective using a single speed fan, or set airflow quantity. It is likely that fan speed would have to be adjusted based on differential pressure readings to ensure the success of a smoke management system using this approach. Because the zoned smoke control method involves exhausting from a single floor of the building, it was not effective for the multi-floor aircraft impact scenarios. In addition, stair pressurization did not prohibit smoke spread into the stairs when large openings in the stairway walls were present due to aircraft impact damage.

The sandwich pressurization approach was determined to be effective for the sprinklered fire, full-floor burnout, and two-floor fire scenarios, even in the presence of stack effect. Positive pressures were demonstrated in the model scenarios for both the undamaged core and shaft damage September 11 scenarios in WTC 1, but sufficient airflow velocity was not created to prohibit smoke spread via large openings into ventilation shafts or the core resulting from aircraft impact damage.

5.6 SUMMARY OF RESULTS

The following is a summary of findings based upon the review of the building designs and analysis of various smoke management systems as documented in the full report (NIST NCSTAR 1-4D):

- The smoke management systems in WTC 1 and WTC 2, which provided the capability for a manual smoke purge within an individual HVAC zone on a quadrant-by-quadrant basis, were not initiated on September 11, 2001.

- Had the smoke purge sequence been initiated in WTC 1 or WTC 2, it is unlikely the system would have functioned as designed, due to loss of electrical power and/or damage to the HVAC shafts and other structural elements in the impact zone that were an integral part of the smoke purge system.

- WTC 1 and WTC 2 were not required by the 1968 BCNYC, as amended by Local Law 5 and Local Law 86, to have active smoke and heat venting and/or stair pressurization because they contained automatic sprinklers throughout.

- None of the potential smoke management system configurations evaluated in this report would have provided sufficient pressure differentials to contain smoke for the postulated aircraft impact damage scenarios, even if these systems were capable of operation after the building sustained damage from the aircraft impact.

- During the events occurring on September 11, 2001, stair pressurization would have been ineffective in improving conditions for occupants trying to exit the building.

- Installation of combination fire/smoke dampers in HVAC ductwork, which was not required in WTC 1 or WTC 2, may have acted to slow the development of hazardous conditions on the uppermost floors of the b g Flr1 Tf 732 TD i7.3(ers)]TJ 9a02(i)6.1(ng to Tc 0 T3TJ <007itionsJ 2031738

Mechanical Failure, Malfunction

51 Part failure, leak, break.
52 Automatic control failure.
53 Manual control failure.
54 Short circuit, ground fault.
55 Other electrical failure.
56 Lack of maintenance, worn out.
57 Backfire.
59 Mechanical failure, malfunction not classified above.
50 Mechanical failure, malfunction, undetermined.

Design, Construction, Installation Deficiency

61 Design deficiency.
62 Construction deficiency.
63 Installed too close to combustibles.
64 Other installation deficiency.
65 Property too close to.
69 Design, construction, installation deficiency not classified above.
60 Design, construction, installation deficiency, undetermined.

Operational Deficiency

71 Collision, overturn, knockdown.
72 Accidentally turned on, not turned off.
73 Unattended.
74 Overloaded.
75 Spontaneous heating.
76 Improper startup, shutdown procedures.
79 Operational deficiency not classified above.
70 Operational deficiency, undetermined.

Natural Condition

81 High wind.
82 Earthquake.
83 High water, including floods.
84 Lightning.
89 Natural condition not classified above.
80 Natural condition, undetermined.

Other Ignition Factor

91 Animal.
92 Rekindled from a previous fire.
99 Other ignition factor not classified above.
00 Ignition factor undetermined or not reported.

Construction Class

0 No Building Involved.
1 Fireproof Structure
2 Fire Protected Structure.
3 Non-fireproof Structure.
4 Wood Frame Structure.
5 Metal Structure.
6 Heavy Timber Structure.

Classification of Building By Use—Commercial

01 Bank.
02 Brewery.
03 Coal Pocket.
04 Department Store.
05 Electrical Power Plant.
06 Factory: Multi Occupancy.
07 Factory: Single Occupancy.
08 Foundry.
09 Freight Depot.
10 Garage: Non-Storage.
11 Garage: Storage.
12 Gas Works.
13 Lumber Yard.
14 Motor Vehicle Repair Shop.
15 Office Building.
16 Oil Selling Station.
17 Oil Storage Plant.
18 Pier, Wharve, Dock, Bulkhead Building.
19 Restaurant, diner.
20 Shed, Newsstand, Shanty.
21 Shipyard, Drydock.
22 Stable.
23 Steam Generating Plant.
24 Store Building, Taxpayer.
25 Warehouse, Storehouse.
26 Store Building & Private Dwelling.
39 Other Commercial.

Classification of Building By Use—Public

40 Airport Building.
41 Asylum.
42 Bridge.
43 Bus Terminal.
44 Church, Synagogue.
45 Dance Hall, Banquet Hall.
46 Dispensary, Clinic.
47 Ferry Terminal.
Government Buildings—(Not otherwise classified):
48 City.
49 Interstate.
50 Federal.
51 Foreign.
52 State.
53 Hospital, Infirmary.
54 Nursing Home.
55 Railroad Station.
56 School: College, University.
57 School: Private High.
58 School: Public High.
59 School: Public Jr. High.
60 School: Private Elementary.
61 School: Public Elementary.
62 School: Children's Nursery.
63 School: Other.
64 Television Studio.
65 Theatre, Legitimate.
66 Theatre, Motion Picture.
67 Transit System—Station Structure.
68 Tunnel.
69 Other Public.

Residential

80 Apartment Hotel "A."
81 Apartment House "A."
82 Boarding House, Rooming House "B."
83 Convent, Rectory, Monastery, etc.
84 Dormitory—School, Club, Lodge.
85 Hotel "B."
86 Lodging House "B."
87 Motel.
88 Private Dwelling: One Family.
89 Private Dwelling: Two Family.
90 Tenement: New Law "A."
91 Tenement: Old Law "A."
92 Converted Dwelling "A."
99 Other Residential.

Building Status

1 Occupied.
2 Partly Occupied, Good Condition.
3 Partly Occupied, Deteriorating.
4 Vacant.
5 Under Demolition.
6 Under Construction.

Damage (to Building or Contents)

0 None.
1 1 to 15%.
2 16 to 49%.
3 50% or Greater.

Area Fire Origin—Floor

00 Outside Building.
01 1st Floor.
to
94 94th and Higher.
95 Attic.
96 Roof.
97 Basement.
98 Cellar.
99 Sub-cellar.

Area Fire Origin—Room or Area

10 Area Not in Building.
11 Attic.
12 Awning.
13 Balcony.
14 Basement.
15 Bathroom Toilet.
16 Bedroom, Sleeping Area.
17 Ceiling.
18 Cellar.
19 Chimney.
20 Classroom Lecture Area.
21 Closet.
22 Cockloft.
23 Court—Exterior.
24 Court—Interior.
25 Dining Room, Dining Area.
26 Duct—Air Conditioning.
27 Duct—Exhaust.
28 Flooring.
29 Furnace Room.
30 Hallway—Private.
31 Hallway—Public.
32 Incinerator Closet or Room.
33 Kitchen, Cooking Area.
34 Living Room.
35 Lobby.
36 Machinery Room.
37 Office Area.
38 Operating Laboratory Area.
39 Partition.
40 Porch.
41 Projection Booth.
42 Recreation Area.
43 Roof.
44 Sales Showroom Display Area.
45 Shaft—Duct, Pipe.
46 Shaft—Dumbwaiter.
47 Shaft—Elevator.
48 Shaft—Exterior Light.
49 Shaft—Interior Light.
50 Shaft—Vent.
51 Shipping Receiving Loading Area.
52 Stage.
53 Stairway.
54 Storage Room Area.
55 Vacant—Room, Apartment or Area.
56 Work Area, Workroom.
57 Other Areas, Not Classified (state area)

Area Fire Origin—Occupancy Classification—Commercial

Factory:

99 Chemicals.

Clothing:

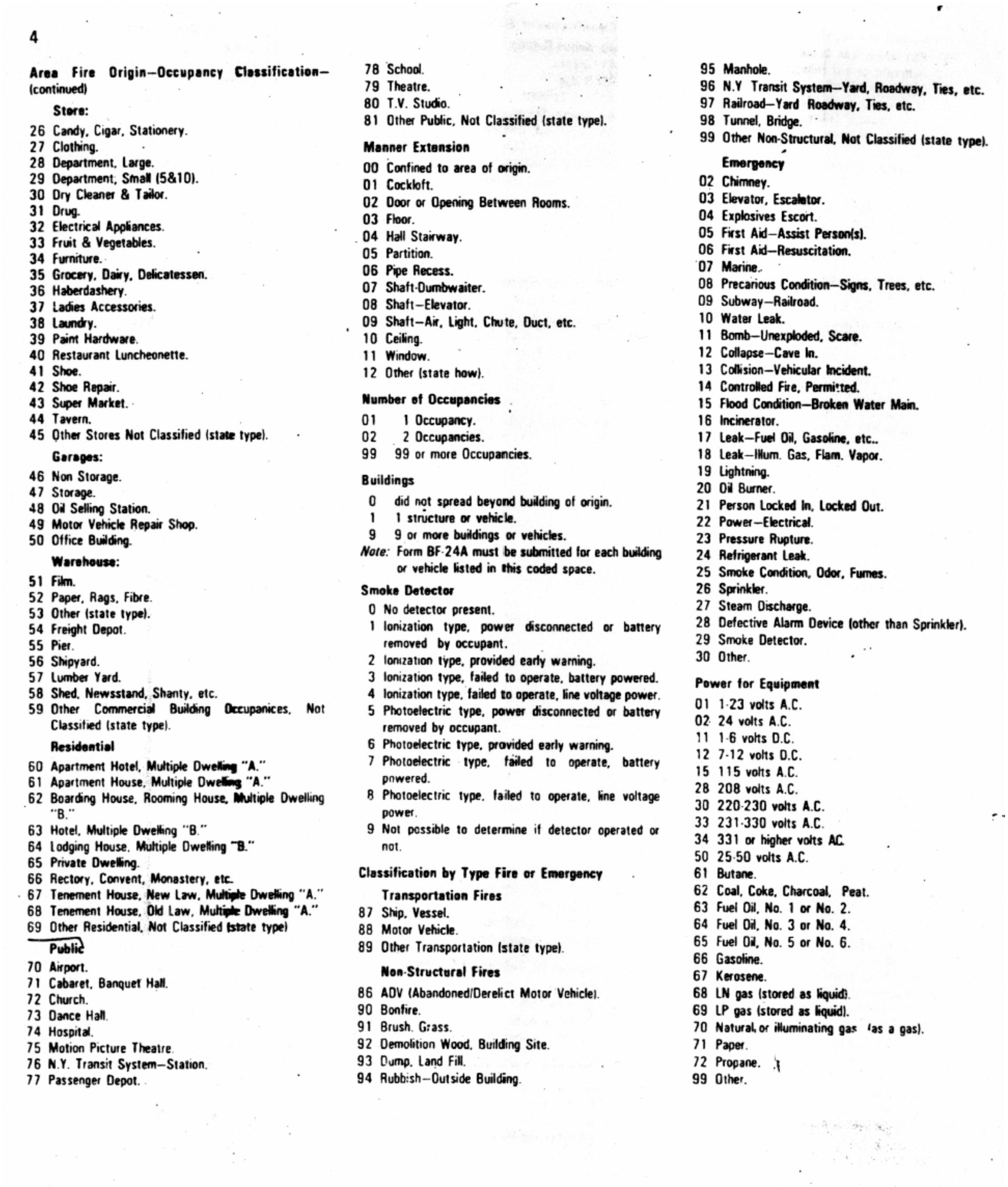
01 Dresses.
02 Undergarment.
03 Other (state type).
04 Dry Cleaning Laundry.
05 Electrical Products.
06 Food & Drink Products.
07 Furniture.
08 Furs, Fur Goods.

Hats:

09 Men's.
10 Women's.
11 Leather, Leather Products.
12 Machine Shop Metal Works.
13 Paints.
14 Paper Products.
15 Petroleum Products.
16 Plastics, Rubber.
17 Printing & Allied Industries.
18 Shoes.
19 Textiles.
20 Toy or Doll.
21 Woodworking.
22 Other Factories Not Classified (state type).

Store:

23 Auto Accessories.
24 Bakery.
25 Butcher.



Area Fire Origin—Occupancy Classification— (continued)

Store:

26 Candy, Cigar, Stationery.
27 Clothing.
28 Department, Large.
29 Department, Small (5&10).
30 Dry Cleaner & Tailor.
31 Drug.
32 Electrical Appliances.
33 Fruit & Vegetables.
34 Furniture.
35 Grocery, Dairy, Delicatessen.
36 Haberdashery.
37 Ladies Accessories.
38 Laundry.
39 Paint Hardware.
40 Restaurant Luncheonette.
41 Shoe.
42 Shoe Repair.
43 Super Market.
44 Tavern.
45 Other Stores Not Classified (state type).

Garages:

46 Non Storage.
47 Storage.
48 Oil Selling Station.
49 Motor Vehicle Repair Shop.
50 Office Building.

Warehouse:

51 Film.
52 Paper, Rags, Fibre.
53 Other (state type).
54 Freight Depot.
55 Pier.
56 Shipyard.
57 Lumber Yard.
58 Shed, Newsstand, Shanty, etc.
59 Other Commercial Building Occupanices, Not Classified (state type).

Residential

60 Apartment Hotel, Multiple Dwelling "A."
61 Apartment House, Multiple Dwelling "A."
62 Boarding House, Rooming House, Multiple Dwelling "B."
63 Hotel, Multiple Dwelling "B."
64 Lodging House, Multiple Dwelling "B."
65 Private Dwelling.
66 Rectory, Convent, Monastery, etc.
67 Tenement House, New Law, Multiple Dwelling "A."
68 Tenement House, Old Law, Multiple Dwelling "A."
69 Other Residential, Not Classified (state type)

Public

70 Airport.
71 Cabaret, Banquet Hall.
72 Church.
73 Dance Hall.
74 Hospital.
75 Motion Picture Theatre.
76 N.Y. Transit System—Station.
77 Passenger Depot.
78 School.
79 Theatre.
80 T.V. Studio.
81 Other Public, Not Classified (state type).

Manner Extension

00 Confined to area of origin.
01 Cockloft.
02 Door or Opening Between Rooms.
03 Floor.
04 Hall Stairway.
05 Partition.
06 Pipe Recess.
07 Shaft-Dumbwaiter.
08 Shaft—Elevator.
09 Shaft—Air, Light, Chute, Duct, etc.
10 Ceiling.
11 Window.
12 Other (state how).

Number of Occupancies

01 1 Occupancy.
02 2 Occupancies.
99 99 or more Occupancies.

Buildings

0 did not spread beyond building of origin.
1 1 structure or vehicle.
9 9 or more buildings or vehicles.

Note: Form BF-24A must be submitted for each building or vehicle listed in this coded space.

Smoke Detector

0 No detector present.
1 Ionization type, power disconnected or battery removed by occupant.
2 Ionization type, provided early warning.
3 Ionization type, failed to operate, battery powered.
4 Ionization type, failed to operate, line voltage power.
5 Photoelectric type, power disconnected or battery removed by occupant.
6 Photoelectric type, provided early warning.
7 Photoelectric type, failed to operate, battery powered.
8 Photoelectric type, failed to operate, line voltage power.
9 Not possible to determine if detector operated or not.

Classification by Type Fire or Emergency

Transportation Fires

87 Ship, Vessel.
88 Motor Vehicle.
89 Other Transportation (state type).

Non-Structural Fires

86 ADV (Abandoned/Derelict Motor Vehicle).
90 Bonfire.
91 Brush, Grass.
92 Demolition Wood, Building Site.
93 Dump, Land Fill.
94 Rubbish—Outside Building.
95 Manhole.
96 N.Y Transit System—Yard, Roadway, Ties, etc.
97 Railroad—Yard Roadway, Ties, etc.
98 Tunnel, Bridge.
99 Other Non-Structural, Not Classified (state type).

Emergency

02 Chimney.
03 Elevator, Escalator.
04 Explosives Escort.
05 First Aid—Assist Person(s).
06 First Aid—Resuscitation.
07 Marine.
08 Precarious Condition—Signs, Trees, etc.
09 Subway—Railroad.
10 Water Leak.
11 Bomb—Unexploded, Scare.
12 Collapse—Cave In.
13 Collision—Vehicular Incident.
14 Controlled Fire, Permitted.
15 Flood Condition—Broken Water Main.
16 Incinerator.
17 Leak—Fuel Oil, Gasoline, etc..
18 Leak—Illum. Gas, Flam. Vapor.
19 Lightning.
20 Oil Burner.
21 Person Locked In, Locked Out.
22 Power—Electrical.
23 Pressure Rupture.
24 Refrigerant Leak.
25 Smoke Condition, Odor, Fumes.
26 Sprinkler.
27 Steam Discharge.
28 Defective Alarm Device (other than Sprinkler).
29 Smoke Detector.
30 Other.

Power for Equipment

01 1-23 volts A.C.
02 24 volts A.C.
11 1-6 volts D.C.
12 7-12 volts D.C.
15 115 volts A.C.
28 208 volts A.C.
30 220-230 volts A.C.
33 231-330 volts A.C.
34 331 or higher volts AC
50 25-50 volts A.C.
61 Butane.
62 Coal, Coke, Charcoal, Peat.
63 Fuel Oil, No. 1 or No. 2.
64 Fuel Oil, No. 3 or No. 4.
65 Fuel Oil, No. 5 or No. 6.
66 Gasoline.
67 Kerosene.
68 LN gas (stored as liquid).
69 LP gas (stored as liquid).
70 Natural or illuminating gas (as a gas).
71 Paper.
72 Propane.
99 Other.

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Appendix C
EXPLANATION OF NUMERIC CODES FROM 1987 TO PRESENT

Explanation of Numeric Codes Used on Fire and Emergency Reports -

From June 1, 1987, to present

MO3-1 H1-911268-5-R25-115

FIRE RECORD CODE LIST

1

14.1 TYPE OF REPORT

Code No.
1 Structural
2 Transportation Fire
3 Non-Structural Fire
4 Emergency Response
5 False Alarm
6 Additional data (BF-24A)

14.2 HOW REPORTED

Code No.
10 Telephone
20 Street — Manual
21 Class 3 — Manual
30 Class 3 — P.F.A.
31 Class 3 Valve, Sprinkler — P.F.A.
32 Class 3, Other Automatic — P.F.A.
40
50 Verbal
60 Pre-Recorded Telephone Alarm
70 Tie Line (Direct Line to Dispatcher — Pipeline Corp.)
80 Street Box — ERS
81 Class 3 — ERS
90 Cable Television Link

Note: 1. P.F.A. stands for Private Fire Alarm. These are received using the 3-Box-Terminal Designation.

2. If the alarm was encountered while responding to or returning from another alarm, it is considered a verbal alarm.

3. A pre-recorded telephone alarm (PRTA) is used to designate those telephone alarms received from recording or pre-dialed machines, whether directly to 911, 7-digit telephone or an alarm service.

14.3 INITIAL ALARM

Code No.
0 Special Call Other Than Engine Only — No Chief
1 Box (Street or Class 3)
5 Special Call Engine Only — No. Chief
6 Special Call (Chief Operated)
9 Still

14.4 HIGHEST ALARM

Code No.
0 Initial Alarm
1 More than the Initial Alarm & Less than 3 Engines & 2 Ladder Cos. at work.
2 2nd Alarm
3 3rd Alarm
4 4th Alarm
5 5th Alarm
6 Simultaneous
7 Signal 7-5

14.5 BOROUGHS

Code No.
1 Manhattan
2 Bronx
3 Staten Island
4 Brooklyn
5 Queens

14.6 HAZARDOUS MATERIALS

14.6.1 Class to be obtained from D.O.T. required labels or placard or from shipping papers or other documents.

Code No.
00 No Hazardous Materials Involved
11 Class A Explosives
12 Class B Explosives
13 Class C Explosives
15 Blasting Agents
21 Flammable Gases
22 Non-Flammable Gases
23 Poison Gases
24 Chlorine
25 Oxygen
31 Flammable Liquids, flashpoint 100 degrees or less.
33 Combustible Liquids, flashpoint greater than 100 degrees.
41 Flammable Solids
42 Spontaneously Combustible Materials
43 Materials Dangerous when Wet
51 Oxidizers
52 Organic Peroxides
61 Poisons
62 Etiologic (Infectious) Substances
63 Irritants
71 Radioactive I Materials
72 Radioactive II Materials
73 Radioactive III Materials
81 Corrosives
98 Multiple Classes (More than one hazardous material)
99 Other

14.6.2 Amount & Unit — the letter designating the unit of measurement shall follow the two digits indicating the amount. *Example:* 3000 gals. of gasoline would be correctly coded as 07G in the "Amount" field.

000 No Hazardous Material Involved
01 Less than 1
02 1-9
03 10-49
05 100-499
06 500-999
07 1,0000-4,999
08 5,000-9,999
09 10,000-49,999
10 50,000-99,999
11 100,000 and more

F Cubic feet, for gases only
G Gallon
M Multiple Units — *Ex:* a spill involves a liquid and a solid
P Pound
T Ton

14.7 HEATING EQUIPMENT INVOLVED— TYPE OF FUEL USED

Code No.
1. Kerosene
2. L.P.G.
3. Electric
4. Wood
5. Coal
6. Oil
7. Natural Gas
8. Gasoline
9. Other
0. No Heating Equipment Involved

14.8 HOW EXTINGUISHED

Code No.
0. Before Arrival
1. Hand Extinguishers
2. Sprinkler Heads (State Number of heads that operated in Operations Section)
3. Booster Stream
4. Low Pressure Hydrant Stream
5. One 1¾" or larger hoseline from a pumping unit or a standpipe outlet, regardless of line termination (Controlling Nozzle, Deckpipe, Stang, Multi Versal, Ladder Pipe, T/L, Foam Nozzle, etc.)
6. Two 1¾" or larger hoselines as above.
7. Three 1¾" or larger hoselines as above.
8. Four or more 1¾" or larger hoselines as above.
9. Other (State How).

14.9 SPRINKLER PERFORMANCE—If sprinklers were present or a factor in this operation, record their performance.

1. Equipment Operated
2. Equipment in service, did not operate
3. Equipment present, fire to small to operate
4. Equipment operated, did not extinguish fire
8. No equipment present
9. Equipment present, not in service. (Record action taken in Operations Section)

14.10 STANDPIPE PERFORMANCE—If a standpipe system was present or used in this operations, record its performance.

1. Standpipe serviceable and used
2. Standpipe present but not used
8. No standpipe present
9. Equipment present, not in service. (Record action taken in Operations Section)

14.11 CONDITION ON ARRIVAL CODES

0 No indication of fire
1 Overheat
2 Smoldering
3 Open Flame
8 Out on Arrival

14.12 EQUIPMENT INVOLVED IN IGNITION

1. HEATING SYSTEMS
10. Solar panel.
11. Central heating unit, furnace
12. Water heater.
13. Woodstove, wall furnaces, fixed local heating unit
14. Indoor fireplace
15. Portable heating unit
16. Chimney, gas vent flue
17. Chimney vent connector
18. Heat transfer system, ducts, pipes.
19. Not classified above.

2. COOKING EQUIPMENT
21. Fixed, stationary surface unit, stove
22. Fixed, stationary oven
23. Fixed, stationary food warming applicance.
24. Deep fat fryer
25. Portable cooking, warming unit
26. Open fired grill
27. Grease hood, duct.
29. Not classified above

3. AIR CONDITIONING, REFRIGERATION EQUIPMENT
31. Central air conditioning, refrigeration equipment
32. Water Cooling device, tower
33. Cold boxes, freezers, refrigerators.
34. Fixed, stationary local air conditioning unit
35. Portable air conditioning, regrigeration unit, dehumidifier.
39. Not classified above.

4. ELECTRICAL DISTRIBUTION EQUIPMENT
41. Fixed Wiring, power lines, junction boxes.
42. Transformer, overcurrent or disconnect equipment.
43. Meter, meter box.
44. Power Switch gear, fused, circuit breakers.
45. Switch, receptacle outlet.
46. Lighting fixture, lamp-holder ballast, sign.
47. Cord, plug
48. Lamp, light bulb.
49. Not classified above.

5. APPLIANCES EQUIPMENT
50. Dishwasher.
51. Television, radio, sound or picture.
52. Clothes dryers.
53. Washing machine.
54. Floor care equipment, vacuum,
55. Separate motor, generator.
56. Hand tools, soldering irons, drills.
57. Controlled heat appliance, elcetrical blankets, steam irons, heat tapes.
58. Electrical razors, can openers.
59. Not classified above.

6. SPECIAL EQUIPMENT
61. Electronic equipment, radar, x-rays, computer, telephone, transmitter equipment.
62. Vending machine, drinking fountain.
63. Office machines.
64. Biomedical equipment, device.
65. Separate pump, compressor, sump pump.
66. Internal combustion engine.
67. Conveyor
68. Printing press.
69. Not classified above.

7. PROCESSING EQUIPMENT
71. Furnace, oven, kiln.
72. Casting, molding, forging.
73. Heat treating, quench tank.
74. Working, shaping, machine saws, grinders, sanders, etc.
75. Coating machine, asphalt saturating, rubber spreading machines.
76. Painting, dipping, spraying.
77. Chemical process, distilling.
78. Waste recovery.
79. Not classified above.

8. SERVICE, MAINTENANCE EQUIPMENT
81. Incinerator.
82. Bearing, brake.
83. Rectifier, charger, battery.
84. Tarpot, tar kettle.
85. Arc, oil lamp, gas mantles.
86. Elevator.
87. Torches, bunsen burners.
88. Not classified above.

9. OTHER OBJECTS, EXPOSURE FIRE
96. Vehicle, exhaust systems, vehicle parts.
98. No equipment involved.
99. Other object, Exposure Fire not classified above.

14.13 FORM OF HEAT IGNITION

1. HEAT FROM FUEL-FIRED, FUEL-POWERED OBJECT

The difference between subdivision 11 and subdivision 12 is whether a spark, ember or flame actually excaped from the equipment, or whether it was simply overheating of outside surface of the equipment (or its internal heat) causing the ignition of nearby combustibles.

11. Spark, ember, flame escaping from gas fueled equipment.
12. Heat from gas fueled equipment, pilot lights, normal flames.
13. Spark, ember, flame escaping from liquid fueled equipment.
14. Heat from liquid fueled equipment, pilot lights.
15. Spark, ember, flame escaping from solid fueled equipment.
16. Heat from solid fueled equipment.
17. Spark, ember, flame escaping from equipment, fuel not known.
18. Heat from equipment; fuel not known.
19. Not classified above.

2. HEAT FROM ELECTRICAL EQUIPMENT ARCING, OVERLOADED.
21. Water caused short circuit arc.
22. Short circuit arc from mechanical damage.
23. Short circuit arc from defective, worn insulation,
24. Unspecified short circuit arc.
25. Arc from faulty contact, loose connection, broken conductor.
26. Arc, spark from operating equipment or switch.
27. Heat from overloaded equipment, wires, motors.
28. Fluorescent light ballast.
29. Not classified above.

3. HEAT FROM SMOKING MATERIAL
31. Cigarette.
32. Cigar.
33. Pipe.
39. Not classified above.

4. HEAT FROM OPEN FLAME, SPARK
41. Cutting torch operation (separating metals).
42. Welding torch operation (joining metals).
43. Blow torches, plumbers torches, Bunsen Burners, soldering, paint stripping.
44. Candle, taper.
45. Match.
46. Lighter (flame type).
47. Campfires, bonfires, warning flares, rubbish fires.
48. Backfire from internal combustion engine.
49. Not classified above.

5. HEAT FROM HOT OBJECT
51. Heat, spark from friction, overheated tires.
52. Molten metal, hot forging and hot glass.
53. Hot ember, ash.
54. Electric lamp, light bulbs.
55. Rekindle, reignition.
56. Heat from properly operating electrical.
57. Heat from improperly operating electrical equipment.
59. Not classified above.

6. HEAT FROM EXPLOSIVES, FIREWORKS
61. Explosives, bombs, ammunition.
62. Blasting agent.
63. Fireworks, sparklers.
64. Paper cap, party popper.
65. Model rocket, not amateur rocketry.
66. Incendiary device.
67. Not classified above.

7. HEAT FROM NATURAL SOURCE
71. Sun's heat.
72. Spontaneous ignition, chemical reaction.
73. Lightning discharge.
74. Static discharge.
79. Not classified above.

8. HEAT SPREADING FROM ANOTHER HOSTILE FIRE (EXPOSURE)
81. Heat from direct flame, convection currents.
82. Radiated heat.
83. Heat from flying brand, ember, spark.
84. Conducted heat.
89. Not classified above.

9. OTHER FORM OF HEAT OF IGNITION
97. Multiple forms of heat of ignition.
99. Not classified above.

14.14 TYPE OF MATERIAL IGNITED

1. GAS
11. Natural gas.
12. LP-City Gas (LP and air mix).
13. Manufactured gas.
14. LP-Gas.
15. Anesthetic gas.
16. Acetylene.
17. Specialty gas other than anesthetic.
19. Not classified above.

2. FLAMMABLE, COMBUSTIBLE LIQUID
21. Ethyl ether, pentane and ethylene oxide (Class 1A).
22. Acetone, ethyl alcohol, JP-4 jet fuel and methyl ethyl ketone,
(Class 1B).
23. Gasoline.
24. Butyl alcohol, propyl alcohol styrene and turpentine. (Class IC).
25. Kerosene, Fuel Oil 1, 2, 4, 5 and Diesel Fuel
26. No. 6 fuel oil, cottonseed oil and creosete oil, (Class IIIA).
27. Cooking oil, transformer and lubicating oil. (Class IIIB)
29. Not classified above.

3. VOLATILE SOLID, CHEMICAL
31. Fat, grease (food).
32. Grease (nonfood), petroleum jellies.
33. Polish, paraffin, was.
34. Creosote, pitch, adhesive, resin, tar, gelatin, rosin, asphalt.
35. Applied paint, varnish.
36. Combustible metal magnesium titanium and zirconium.
37. Solid chemical, explosives.
38. Radioactive material.
39. Not classified above.

4. PLASTIC
41. RIGID PLASTICS
Included are molded plastics such as appliance cases, floor tile, decorative kitchen laminates.
42. RIGID FOAM PLASTICS
Included are rigid thermal foam insulation for walls and refrigerators.
43. FLEXIBLE PLASTICS
Included is electrical wire insulation.
44. FLEXIBLE FOAMPLASTICS
Included are mattresses, furniture interior foam and carpet pads.
45. FILM PLASTICS
Included are polyethylene trash bags, photographic film and coated wallpaper.
49. Plastic not classified above.

5. NATURAL PRODUCTS
51. Rubber.
52. Cork.
53. Leather.
54. Grass, leaves, hay and straw.
55. Grain, feathers, felt, kapok, hemp, jute, cotton, before processing.
56. Coal, coke, briquettes, peat.
57. Food, starch, excluding fat and grease.
58. Tobacco.
59. Not classified above.

6. WOOD, PAPER
61. Growing wood, tree.
62. Felled but unsawn wood.
63. Finished lumber, finished wood.
64. Wood shavings, sawdust excelsior.
65. Hardboard, plywood.
66. Fiberboard, wood pulp, press board.
67. Paper, untreated, uncoated.
68. Cardboard.
69. Not classified above.

7. FABRIC, TEXTILE, FUR
71. Man-made fabric, fiber, furnished goods.
72. Cotton, rayon, cotton fabric.
73. Wool, wool mixture, fabric.
74. Fur, silk, other fabric.
75. Wig.
76. Human hair.
79. Not classified above.

8. MATERIAL COMPOUNDED WITH OIL
81. Linoleum.
82. Oil cloth.
83. Treated and/or coated paper, wax paper.
84. Waterproof canvas.
85. Oily rags.
86. Asphalt treated material.
89. Not classified above.

9. OTHER TYPE OF MATERIAL IGNITED
97. Multiple types of material first ignited.
99. Not classified above.

14.15 FORM OF MATERIAL IGNITED

1. STRUCTURAL COMPONENT, FINISH
11. Exterior roof covering, surface, finish.
12. Exterior sidewall, covering surface, finish, eaves.
13. Doors, purches and platforms.
14. Tile, carpet, rug flooring and stairs.
15. Interior wall covering.
16. Ceiling covering surface.
17. Structural member, framing.
18. Thermal, acoustical insulation, within wall or ceiling.
19. Not classified above.

2. FURNITURE
21. Upholstered sofa, chair, vehicle seats.
22. Nonupholstered chair, bench.
23. Cabinetry, filing cabinets, pianos, dressers, desks, tables and bookcases.
24. Ironing board.
25. Appliance housing or casing.
29. Not classified above.

3. SOFT GOODS, WEARING APPAREL
31. Mattress, pillow.
32. Bedding, blanket, sheet, comforter, heating pad.
33. Linen, towels, tablecloths.
34. Wearing apparel not on a person.
35. Wearing apparel on a person.
36. Curtain, blind, drapery, tapestry.
37. Fabrics, yard goods.
38. Luggage.
39. Not classified above.

4. ADORNMENT, RECREATIONAL MATERIAL
41. Christmas tree.
42. Decoration for special event.
43. Book.
44. Magazine, newspaper, writing paper, files.
45. Toy, game.
46. Awning, canopy.
47. Tarpaulin, tent.
49. Not classified above.

5. SUPPLIES, STOCK
51. Box, carton, bag.
52. Basket, barrel.
53. Pallet, skid.
54. Rope, cord, twine, yarn.
55. Packing, wrapping material.
56. Bale storage.
57. Bulk storage.
58. Brooms, brushes, mops, cleaning cloths, cleaning supplies.
59. Not classified above.

6. POWER TRANSFER EQUIPMENT, FUEL
61. Electrical wire, cable insulation.
62. Transformer.
63. Conveyor belt, drive belt, v-belt.
64. Tire.
65. Fuel.
69. Not classified above.

7. GENERAL FORM
71. Argicultural product.
72. Fence, pole.
73. Fertilizer.
74. Forests, brush and grass.
75. Film, creosote, rubbish, trash, waste.
76. Cooking materials.
77. Sign.

8. SPECIAL FORM
81. Dust, fiber, lint, sawdust.
82. Pyrotechnics, explosives.
83. Atomized, vaporized liquid.
84. Chips.
85. Material stored on pallets.
86. Accelerants.
87. Rolled material.
88. Adhesive.

9. OTHER FORM OF MATERIAL
97. Multiple form of material ignited.
99. Not classified above.

14.16 IGNITION FACTOR (CAUSE)

1. INCENDIARY
11. Incendiary.
12. Incendiary, during civil disturbance.

2. SUSPICIOUS
21. Suspicious.
22. Suspicious, during civil disturbance.

3. MISUSE OF HEAT OF IGNITION
31. Abandoned, discarded material, cigarette, etc.
32. Thawing.
33. Falling asleep.
34. Inadequate control of open fire.
35. Cutting, welding too close to.
36. Children with matches, lighter, etc.
37. Unconscious, mental, physical impairment.
39. Not classified above.

4. MISUSE OF MATERIAL IGNITED
41. Fuel spilled, released accidentally.
42. Improper fueling technique.
43. Flammable liquid used to kindle fire.
44. Washing part, cleaning, refinishing, painting.
45. Improper container.
46. Combustible too close to heat.
47. Improper storage.
49. Not classified above.

5. MECHANICAL FAILURE, MALFUNCTION
51. Part failure, leak, break.
52. Automatic control failure.
54. Short circuit, ground fault.
55. Other electrical failure.
56. Lack of maintenance, worn out, failure to clean.
57. Backfire.
59. Not classified above.

6. DESIGN, CONSTRUCTION, INSTALLATION DEFICIENCY
61. Design deficiency, catalytic converter failure.
62. Construction deficiency.
63. Installed too close to combustibles.
64. Other installation deficiency.
65. Property too close to. Included are exposure fires.
69. Not classified above.

7. OPERATIONAL DEFICIENCY
71. Collision, overturn, knockdown.
72. Accidentally turned on, not turned off.
73. Unattended.
74. Overloaded.
75. Spontaneous heating.
76. Improper startup, shutdown procedures.
79. Not classified above.

8. NATURAL CONDITION
81. High wind.
82. Earthquake.
83. High water, including floods.
84. Lightning.
89. Not classified above.

9. OTHER IGNITION FACTORS
91. Animal.
92. Rekindled from a previous fire.
99. Not classified above.
00. No Fire.

14.17 JUVENILE INVOLVED IN IGNITION

0. Juvenile Not Involved in Ignition or No information that a Juvenile was involved.
1. Juvenile Involved in Ignition.

14.18 CONSTRUCTION CLASS

Code No.
0. No building Involved.
1. Fireproof Structure.
2. Fire Protected Structure.
3. Non Fireproof Structure.
4. Wood Frame Structure.
5. Metal Structure.
6. Heavy Timber Structure.

14.19 CLASSIFICATION OF BUILDING BY USE

COMMERCIAL
592 Bank.
723 Brewery.
895 Coal Storage.
581 Department Store.
615 Electrical Power Plant.
708 Factory: Multi-Occupancy.
709 Factory: Single Occupancy.
771 Foundry.
894 Freight Depot.
882 Garage: Non-Storage.
889 Garage: Storage.
767 Gas Works, Natural Gas Plant.
851 Lumber Yard.
573 Motor Vehicle Repair Shop, Paint Shop.
591 Office Building, State, City, Federal or Commercial.
571 Oil Selling Station.
841 Oil Storage Plant.
898 Pier, Wharf, Dock, Bulkhead Building.
161 Restaurant, Diner.
925 Shed, Newstand, Shanty.
781 Shipyard, Drydock.
815 Stable.
614 Steam Generating Plant.
539 Storebuilding, Taxpayer.
891 Warehouse Storehouse.
410 Store Building & Private Dwelling.
580 Other Commercial.

PUBLIC
171 Airport Building.
361 Asylum.
921 Bridge.
173 Bus Terminal.
133 Church, Synagogue.
121 Dance Hall, Banquet Hall.
334 Dispensary, Clinic.
177 Ferry Terminal.
331 Hospital, Infirmary.
311 Nursing Home.
174 Railroad Station, Street Level.
175 Railroad Station, Below Grade.
176 Railroad Station, Above Grade.
241 School: College, University.
215 School: High School.
214 School: Junior High.
213 School: Elementary.
211 School: Children's Nursery.
210 School: Other.
185 Television Studio.
181 Theatre, Legitimate.
183 Theatre, Motion Picture.
170 Transit System—Station Structure.
922 Tunnel.
119 Other Public.

RESIDENTIAL
469 Apartment Hotel "A".
429 Apartment House "A".
439 Boarding House, Rooming House "B".
465 Convent, Rectory, Monastery, etc.
461 Dormitory—School, Club, Lodge.
449 Hotel "B".
430 Lodging House "B".
440 Motel.
411 Private Dwelling: One Family.
414 Private Dwelling: Two Family.
420 Tenement: New Law "A".
423 Tenement: Old Law "A".
422 Converted Dwelling "A".
490 Other Residential.

SPECIAL PROPERTIES
972 Airport Runway.
934 Cemetery.
981 Construction Site.
932 Dump, Landfill.
931 Open Land, Fields.
965 Parking Area, Lot.
963 Pipeline, Power Line Right-of-Way.
962 Public Street.
952 Railroad Switching Yard, marshalling yard.
936 Vacant Lots.
939 Outdoor Property Not Classified.

14.20 BUILDING STATUS CODE

Code	Description
1	Occupied: The building is normally fully occupied or is intended to be fully occupied. A few vacant areas, which are rentable, may exist.
2	Partly Occupied: The building is in good condition and more than 25 percent of the areas are vacant.
3	Partly Occupied, Deteriorating: The building has some vacant areas and these are expected to remain vacant until demolition or alteration because of the condition of the building or its surroundings.
4	Vacant: The building is entirely vacant. (Even if squatters are present.)
5	Under Demolition: The building is in the process of being torn down.
6	Under Construction: The building is under construction and does not have any occupants.
7	Under Construction: The building is partially occupied, whether under a temporary certificate of occupancy or not.
	Note: The status code applies to the building, not the fire area. Therefore, codes 1, 2 and 3 may be used whether the fire itself occurred in a vacant or occupied area, and code 1 may apply even if the fire occurred in a vacant area (for example, a fire in a vacant apartment being repainted for a new tenant). The occupied or vacant status of the fire area is now recorded on the "Area of Origin" Code. (see Paragraph 2.19.2)

4

14.21 COMPLEX

11. PUBLIC RECREATION COMPLEX
Included are zoos, amusement parks and general recreation parks.
12. STADIUM, EXHIBITION HALL COMPLEX
Included ballparks, racetracks, sports gardens and armories.
14. CLUB COMPLEX
Included are golf clubs, tennis clubs and country clubs.
20. EDUCATIONAL COMPLEX
Included are schools, colleges and universities.
33. MEDICAL CARE COMPLEX
Included are Hospitals, Medical Centers, Mental Institutions.
34. PRISON COMPLEX
40. BUSINESS WITH RESIDENTIAL COMPLEX
Included are apartments over stores.
41. DWELLING COMPLEX (ONE AND TWO-FAMILY)
42. APARTMENT COMPLEX
44. HOTEL COMPLEX
Included are motels, inns and lodges.
47. MOBILE HOME PARK COMPLEX
58. SHOPPING COMPLEX
Included are department stores malls, discount houses and shopping centers. Also included are groups of business and commercial establishments which may contain theaters and other places of assembly.
59. OFFICE COMPLEX
Included are non-military government office complexes.
61. POWER PRODUCTION COMPLEX
63. MILITARY RESERVATION DEFENSE COMPANY
65. FARM COMPLEX
70. INDUSTRIAL PLANT, MANUFACTURING COMPLEX
80. WAREHOUSE, STORAGE COMPLEX
91. CONSTRUCTION COMPLEX
Included are demolition operations.
93. CAMPSITE COMPLEX
94. WATERFRONT COMPLEX
Included are marinas.
95. RAILROAD TRANSPORT COMPLEX
96. ROAD COMPLEX
Included are highways, streets and all public ways.
97. AIRPORT COMPLEX
98. NO COMPLEX
If other properties meeting the definition for a complex as defined above are identified, they may be indicated by Complex Code 99.

AREA FIRE ORIGIN

14.22 FLOOR CODE NO.

00 OUTSIDE BUILDING
01 1st Floor
to to
94 94th and Higher
95 Attic
96 Roof
97 Basement
98 Cellar
99 Sub-Cellar

14.23 AREA FIRE ORIGIN—OCCUPANCY CLASSIFICATION

00 NOT IN BUILDING

COMMERCIAL

07 Furniture
08 Furs, Fur Goods
09 Men's Hats
10 Women's Hats
11 Leather, Leather Products
12 Machine Shop Metal Works
13 Paints
14 Paper Products
15 Petroleum Products
16 Plastics, Rubber
17 Printing and Allied Industries
18 Shoes
19 Textiles
20 Toy or Doll
21 Woodworking
22 Other Factories not classified (state type)

Store:
23 Auto Accessories
24 Bakery
25 Butcher
26 Candy, Cigar, Stationary
27 Clothing
28 Department, large
29 Department, small (5 & 10)
30 Dry Cleaner & Tailor
31 Drug
32 Electrical Applicance
33 Fruits and Vegetables
34 Furniture
35 Grocery, Dairy, Delicatessan
36 Haberdashery
37 Ladies Accessories
38 Laundry
39 Paint, Hardware
40 Restaurant Luncheonette
41 Shoe
42 Shoe Repair
43 Supermarket
44 Tavern
45 Other Stores not classified (state type)

Garages:
46 Non storage
47 Storage
48 Oil Selling Station
49 Motor Vehicle Repair Shop
50 Office Building

Warehouse:
51 Film
52 Paper, Rags, Fibre
53 Other (state type)
54 Freight Depot
55 Pier
56 Shipyard
57 Lumber yard
58 Shed, Newstand, Shanty, etc.
59 Other Commercial Building Occupancies, not classified (state type)

Residential:
60 Apartment, Hotel, Multiple Dwelling "A"
61 Apartment House, Multiple Dwelling "A"
62 Boarding House, Rooming House, Multiple Dwelling "B"
63 Hotel, Multiple Dwelling "B"
64 Lodging House, Multiple Dwelling "B"
65 Private Dwelling
66 Rectory, Convent, Monastery, etc.
67 Tenement House, New Law, Multiple Dwelling "A"
68 Tenement House, Old Law, Multiple Dwelling "A"
69 Other Residential, not classified (state type)

Public:
70 Airport
71 Cabaret, Banquet Hall
72 Church

14.24 AREA OF FIRE ORIGIN

0. MEANS OF EGRESS
01. Hallway, corridor, mall.
02. Exterior stairway.
03. Interior stairway.
04. Escalator.
05. Lobby, entrance way.
09. Not classified above.

1. ASSEMBLY AREA
11. Fixed seats (100 or more persons).
12. Without fixed seats (100 or more persons).
13. With or without fixed seats. (less than 100 persons)
14. Living room, family room, lounge area.
15. Sales, showroom area.
16. Library, art galleries, exhibit.
17. Swimming pool area.
19. Not classified above.

2. FUNCTION AREAS
21. Bedrooms, patient rooms, cells, lockups.
22. Wards, dormitories, barracks.
23. Dining area, lunchroom, cafeteria.
24. Kitchen, cooking area, cloakroom.
26. Laundry area.
28. Health clubs, massage parlors, barber, beauty.

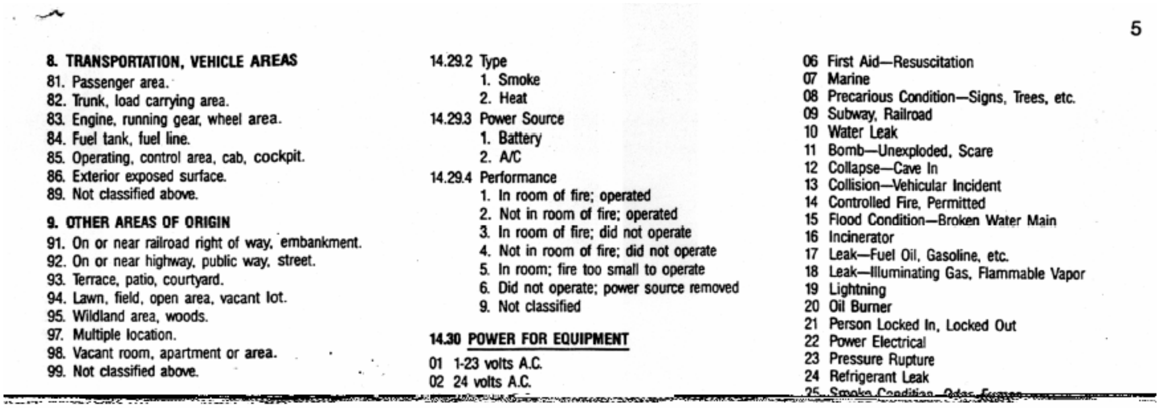
3. FUN AREAS (continued)
31. Laboratrory.
32. Printing or photographic room.
33. First aid, treatment room.
34. Operating room.
35. Electronic, computer, telephone room, telephone booth.
36. Performance, stage area, indoor sports.
37. Projection room, stage light.
38. Process, manufacturing area.
39. Not classified above.

4. STORAGE AREAS
41. Tank, bin, product storage room.
42. Closet.
43. Supply room.
44. Records storage room, vault.
45. Shipping, receiving, loading mail room.
46. Trash or rubbish container, compactor.
47. Garage, carport, vehicle storage.
49. Not classified above.

5. SERVICE FACILITIES
51. Elevator, dumwaiter.
52. Electrical, plumbing, ventilation shaft.
53. Light shaft.
54. Laundry or mail chute.
55. Duct.
56. Display window.
57. Chimney, flue, stovepipe.
58. Conveyor.
59. Not classified above.

6. SERVICE, EQUIPMENT AREA
61. Machinery room.
62. Heating equipment, water heater area.
63. Switchgear area, transformer vault.
64. Incinerator room area.
65. Maintenance shop, workshop, paint shop, welding shop.
66. Test cell.
67. Enclosure with pressurized air.
68. Enclosure with enriched oxygen atmosphere.
69. Not classified above.

7. STRUCTURAL AREAS, NON-FUNCTIONAL
71. Crawl space, cellar, substructural area.
72. Exterior balcony,



8. TRANSPORTATION, VEHICLE AREAS

81. Passenger area.
82. Trunk, load carrying area.
83. Engine, running gear, wheel area.
84. Fuel tank, fuel line.
85. Operating, control area, cab, cockpit.
86. Exterior exposed surface.
89. Not classified above.

9. OTHER AREAS OF ORIGIN

91. On or near railroad right of way, embankment.
92. On or near highway, public way, street.
93. Terrace, patio, courtyard.
94. Lawn, field, open area, vacant lot.
95. Wildland area, woods.
97. Multiple location.
98. Vacant room, apartment or area.
99. Not classified above.

14.29.2 Type
  1. Smoke
  2. Heat

14.29.3 Power Source
  1. Battery
  2. A/C

14.29.4 Performance
  1. In room of fire; operated
  2. Not in room of fire; operated
  3. In room of fire; did not operate
  4. Not in room of fire; did not operate
  5. In room; fire too small to operate
  6. Did not operate; power source removed
  9. Not classified

14.30 POWER FOR EQUIPMENT

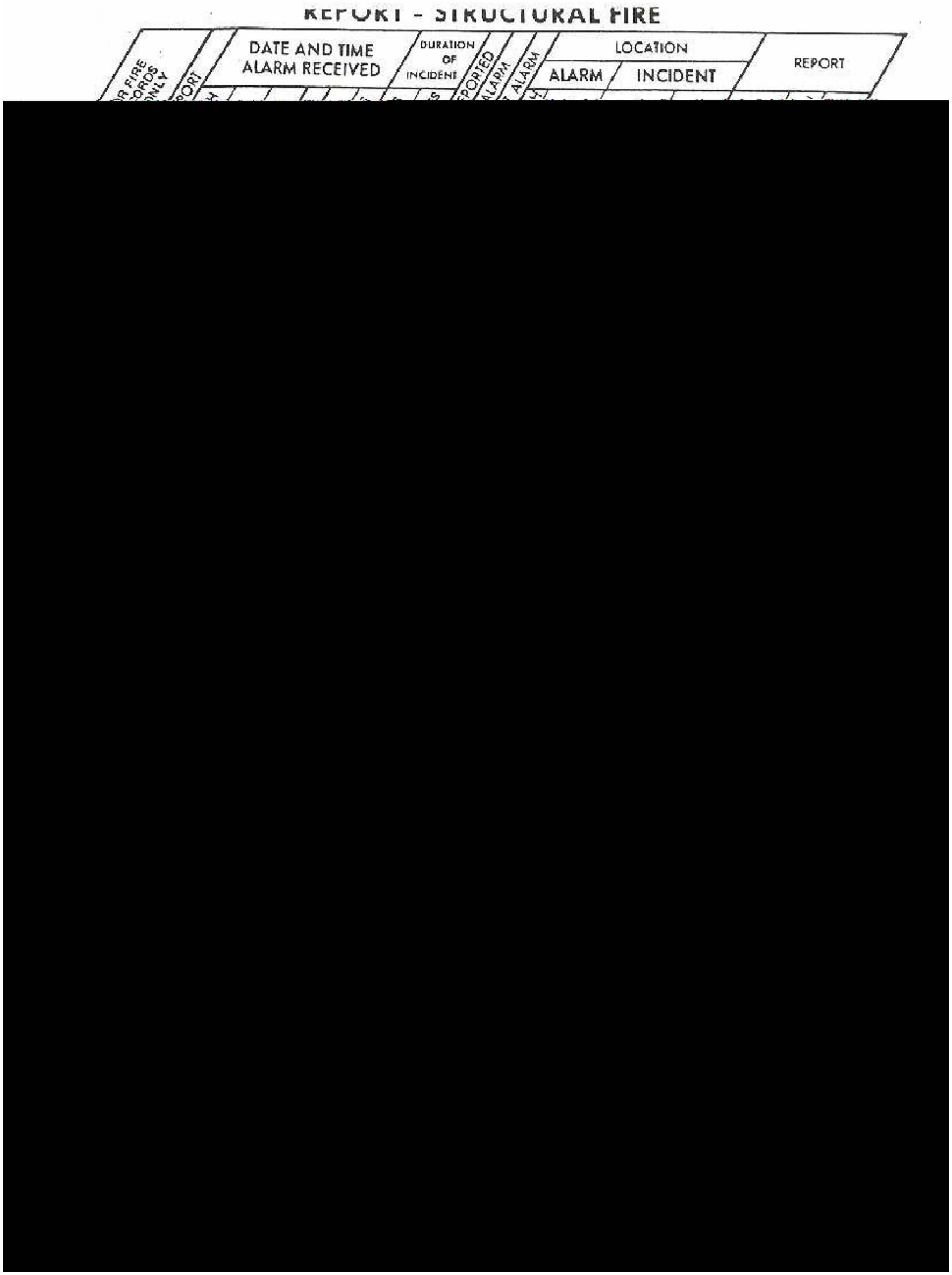
01 1-23 volts A.C.
02 24 volts A.C.

06 First Aid—Resuscitation
07 Marine
08 Precarious Condition—Signs, Trees, etc.
09 Subway, Railroad
10 Water Leak
11 Bomb—Unexploded, Scare
12 Collapse—Cave In
13 Collision—Vehicular Incident
14 Controlled Fire, Permitted
15 Flood Condition—Broken Water Main
16 Incinerator
17 Leak—Fuel Oil, Gasoline, etc.
18 Leak—Illuminating Gas, Flammable Vapor
19 Lightning
20 Oil Burner
21 Person Locked In, Locked Out
22 Power Electrical
23 Pressure Rupture
24 Refrigerant Leak
25 Smoke Condition—Odor, Fumes

Appendix D
SIGNIFICANT FIRES IN WTC 1

Significant fire incidents occurring in WTC 1

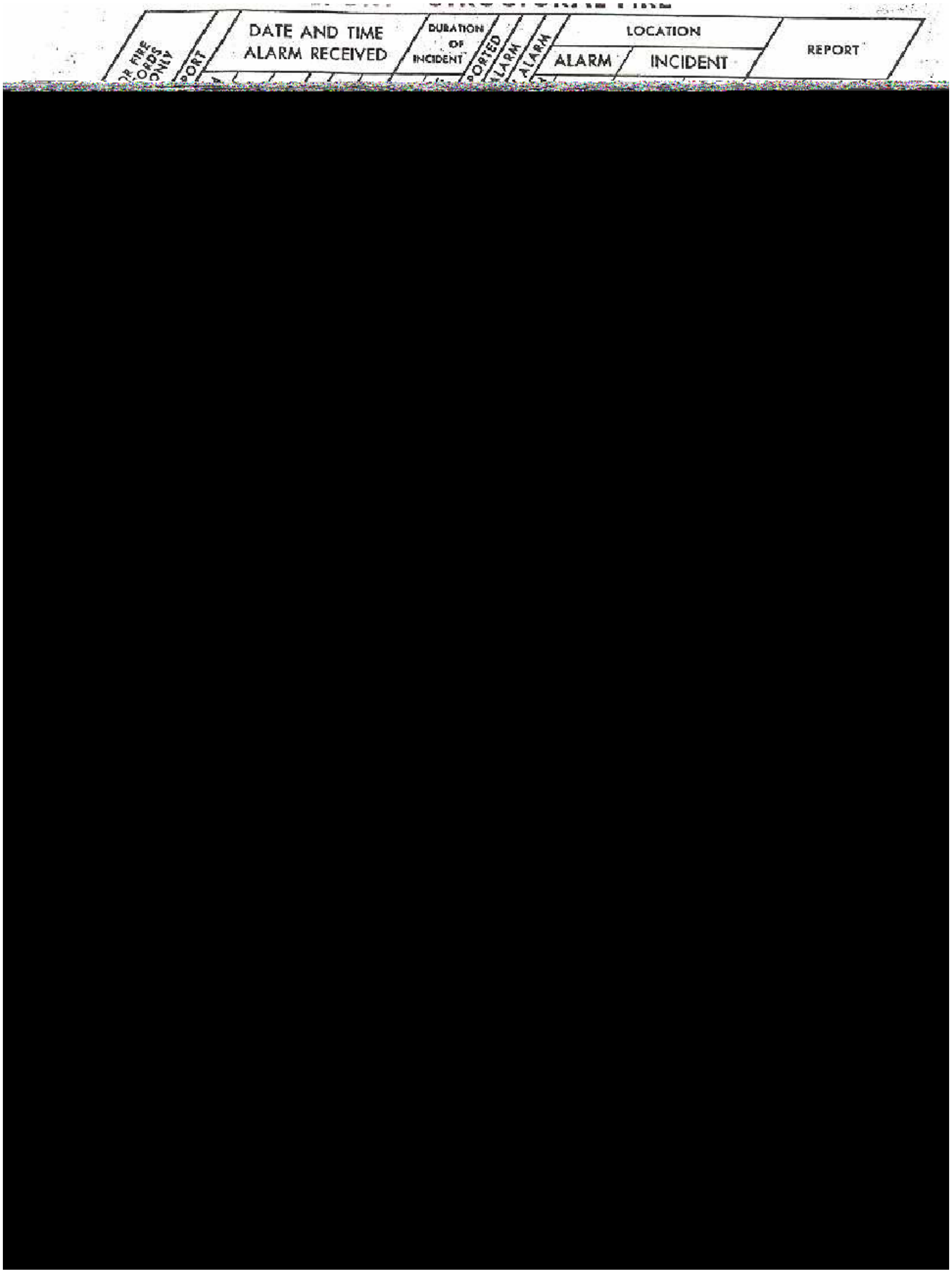
Significant Fire	Incident Date	Fire Location	# Sprinklers Activated	# Standpipes Activated	Cause of Fire	Material Ignited
1	9/9/77	B-6 level storage room	2		None listed	Not listed
2	9/23/77	Dumpster on B-4 level	2		Not classified	Trash/waste
3	10/16/81	Floor 19 office area	-	2	Discarded material	Furniture
4	12/23/83	2 dumpsters on B-4 level	2	1	Suspicious	Trash/waste
5	1/27/85	Office space on mezzanine level (floor 2)	2		Incendiary	Trash/waste
6	9/10/85	Garbage dumpster in service elevator lobby on floor 43	2	1	Suspicious	Trash/waste
7	11/1/85	Storage closet on B-4 level	3	1	Suspicious	Supplies/stock
8	6/7/86	Dumpster fire on floor 106, compactor room on floor 107	2	1	None listed	Trash/waste
9	9/30/91	Office on B-4 level	≥1	2	Discarded material	Trash/waste
10	11/19/91	Electrical closet on floor 93	0	2	Short circuit	Electrical wire or cable insulation
11	7/23/92	Level B-5 at the power distribution panel	0	2	Electrical failure	Electrical wire or cable insulation
12	11/10/99	Computer room on floor 104	3	≥1	None listed	Plastics, electronic equipment



REPORT - STRUCTURAL FIRE

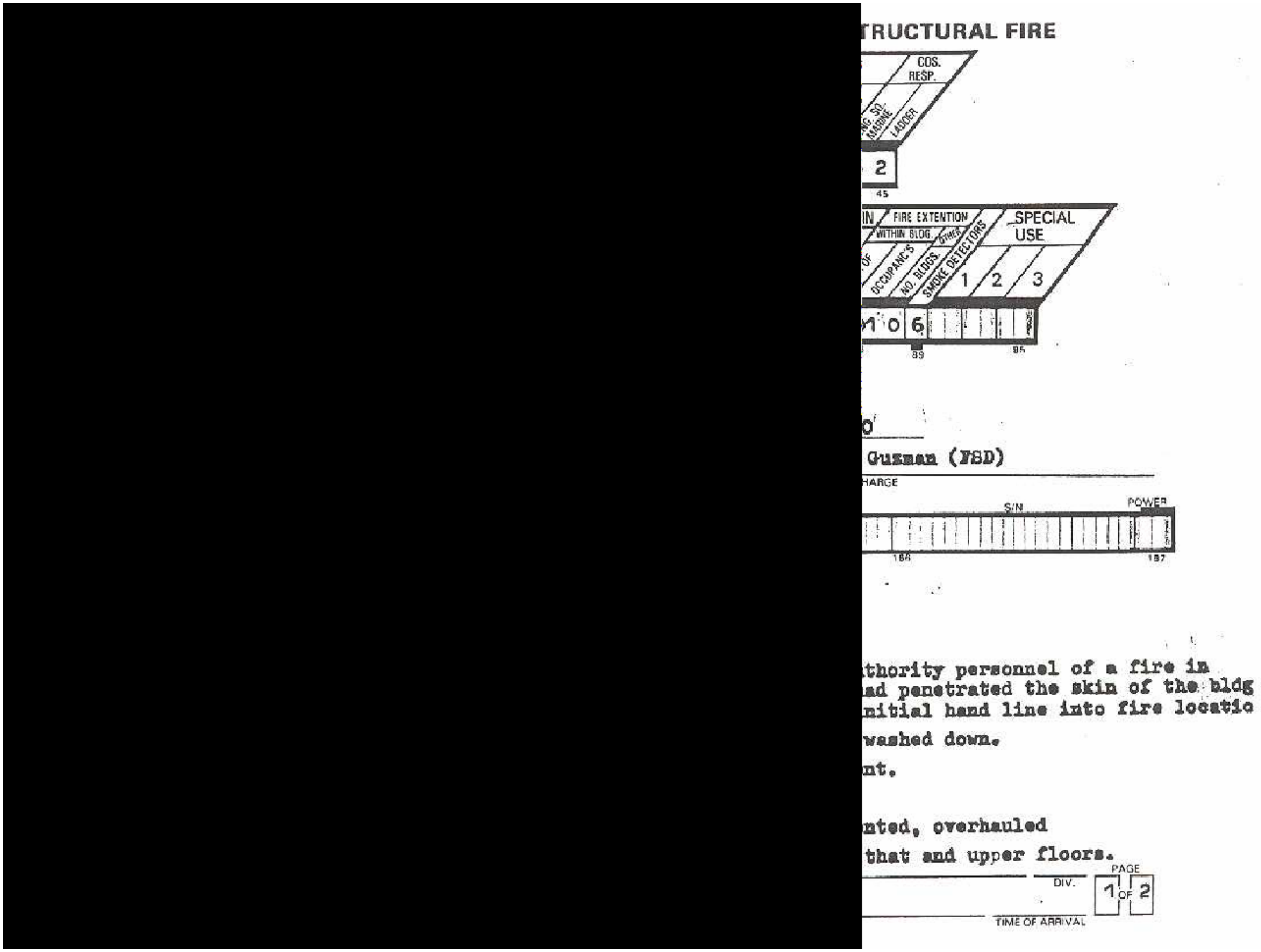
R FIRE CORDS ONLY	PORT	DATE AND TIME ALARM RECEIVED	DURATION OF INCIDENT	PORTED	ALARM	ALARM	LOCATION		REPORT
							ALARM	INCIDENT	

[redacted]



ONLY	DATE AND TIME ALARM RECEIVED	DURATION OF INCIDENT	ORTED	ALARM	ALARM	LOCATION	REPORT
						ALARM / INCIDENT	

[redacted]



[redacted]

TRUCTURAL FIRE

COS. RESP.

NG. SQ. MARINE

LADDER

2

45

IN

FIRE EXTENTION

WITHIN BLDG.

OTHER

OF

OCCUPANC'S

NO. BLDGS.

SMOKE DETECTORS

SPECIAL USE

1

2

3

1 0 6

89

95

0

Guzman (FSD)

HARGE

S/N

POWER

166

187

thority personnel of a fire in
ad penetrated the skin of the bldg
nitial hand line into fire locatio

washed down.

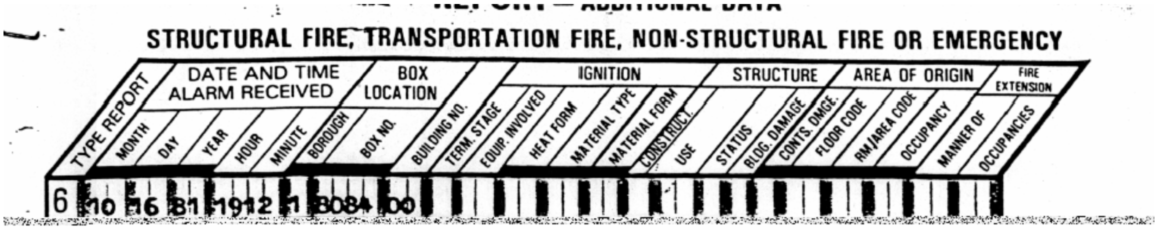
nt.

nted, overhauled
that and upper floors.

DIV.

TIME OF ARRIVAL

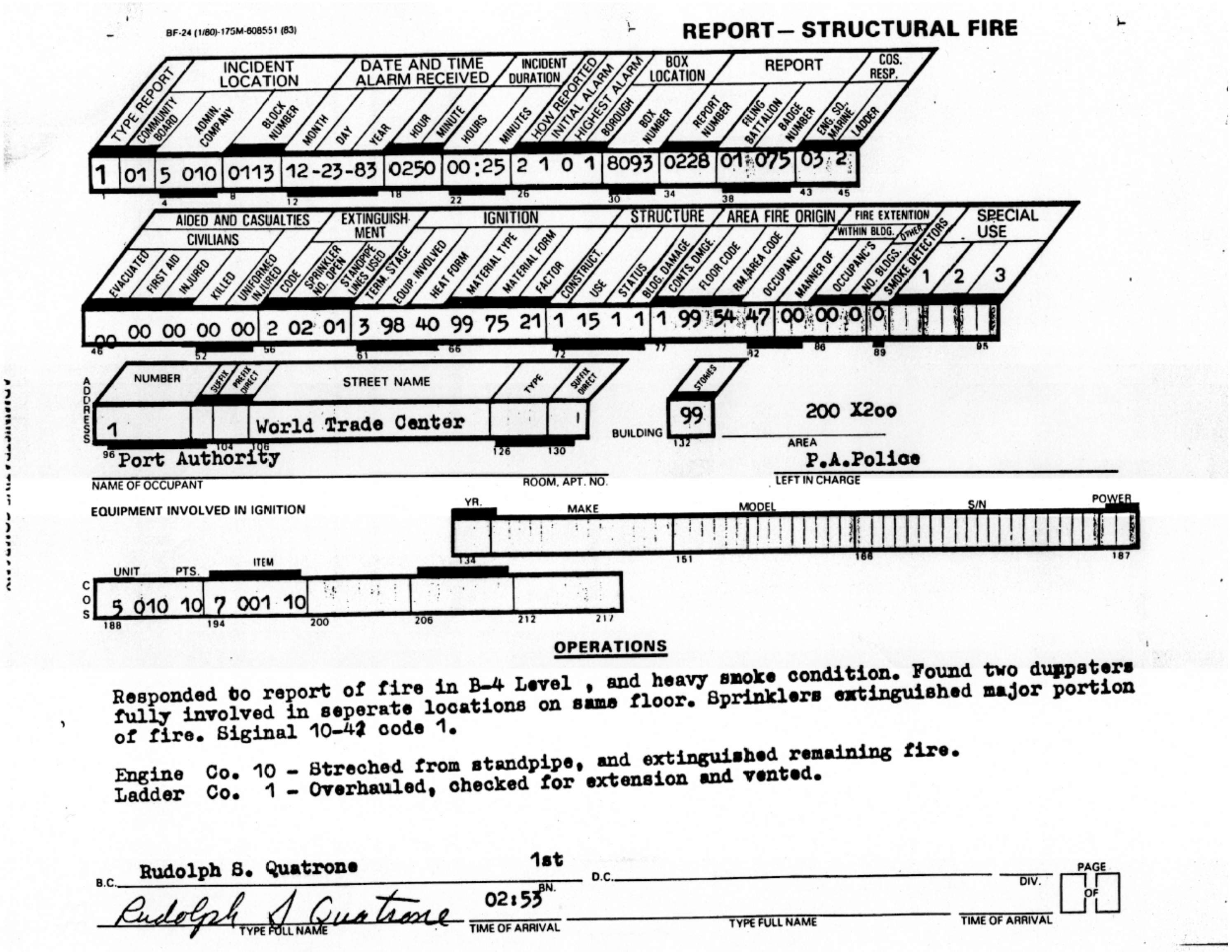
PAGE 1 OF 2



REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

	DATE AND TIME ALARM RECEIVED					BOX LOCATION				IGNITION						STRUCTURE			AREA OF ORIGIN			FIRE EXTENSION	
TYPE REPORT	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NO.	BUILDING NO.	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	FLOOR CODE	RM/AREA CODE	OCCUPANCY	MANNER OF	OCCUPANCIES
6	10	16	81	19	12	1	8084	00						1									



BF-24 (1/80)-175M-608551 (83)

REPORT — STRUCTURAL FIRE

TYPE REPORT	INCIDENT LOCATION			DATE AND TIME ALARM RECEIVED		INCIDENT DURATION					BOX LOCATION	REPORT			COS. RESP.	
	COMMUNITY BOARD	ADMIN. COMPANY	BLOCK NUMBER	MONTH DAY YEAR	HOUR MINUTE	HOURS MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	BOX NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER	ENG. SQ. MARINE	LADDER
1	01	5 010	0113	12-23-83	0250	00:25	2	1	0	1	8093	0228	01	075	03	2

1 4 8 12 18 22 26 30 34 38 43 45

AIDED AND CASUALTIES					EXTINGUISHMENT			IGNITION						STRUCTURE						AREA FIRE ORIGIN		FIRE EXTENTION				SPECIAL USE		
CIVILIANS																						WITHIN BLDG.		OTHER				
EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	CODE	SPRINKLER NO. OPEN	STANDPIPE LINES USED	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	FACTOR	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	FLOOR CODE	RM./AREA CODE	OCCUPANCY	MANNER OF	OCCUPANC'S	NO. BLDGS.	SMOKE DETECTORS	1	2	3
00	00	00	00	00	2	02	01	3	98	40	99	75	21	1	15	1	1	1	99	54	47	00	00	0	0			

46 52 56 61 66 72 77 82 86 89 95

ADDRESS

NUMBER	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECT
1			World Trade Center		1

96 104 106 126 130

BUILDING STORIES 99 132

AREA: 200 X2oo

NAME OF OCCUPANT: Port Authority

ROOM, APT. NO.

LEFT IN CHARGE: P.A.Police

EQUIPMENT INVOLVED IN IGNITION

YR.	MAKE	MODEL	S/N	POWER

134 151 166 187

COS

UNIT	PTS.	ITEM			
5 010	10	7 001 10			

188 194 200 206 212 217

OPERATIONS

Responded to report of fire in B-4 Level , and heavy smoke condition. Found two duppsters fully involved in seperate locations on same floor. Sprinklers extinguished major portion of fire. Siginal 10-42 code 1.

Engine Co. 10 - Streched from standpipe, and extinguished remaining fire.
Ladder Co. 1 - Overhauled, checked for extension and vented.

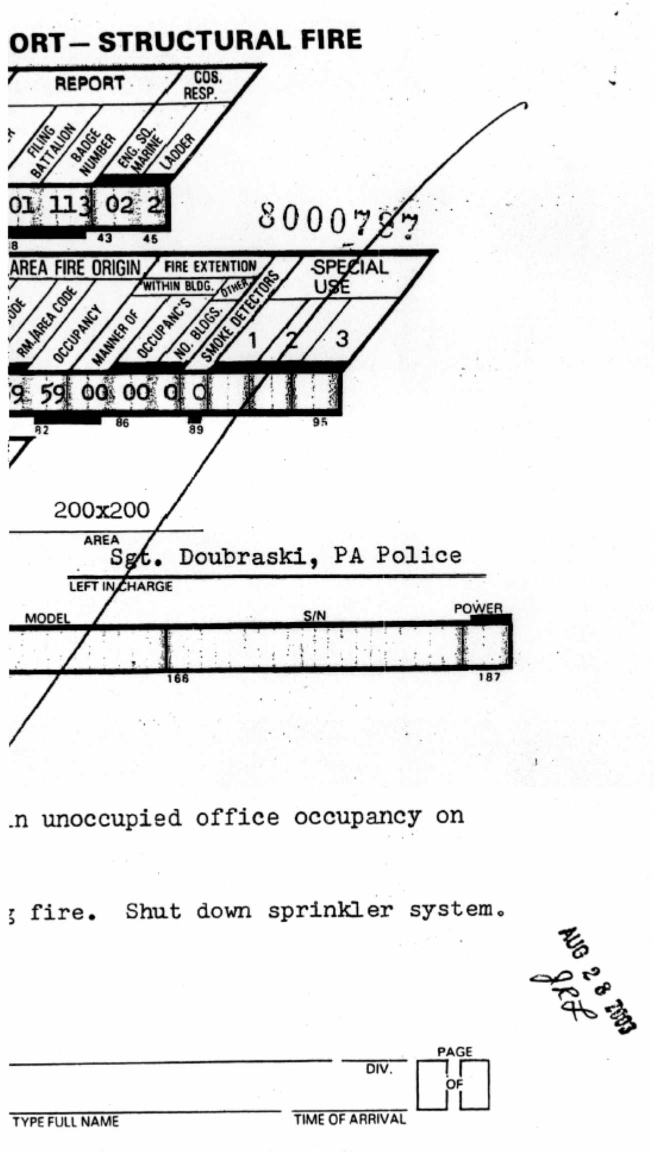
B.C. Rudolph S. Quatrone
Rudolph S Quatrone
TYPE FULL NAME

1st BN.
02:53
TIME OF ARRIVAL

D.C.
TYPE FULL NAME

DIV.
TIME OF ARRIVAL

PAGE ☐ OF ☐



ORT — STRUCTURAL FIRE

REPORT

FILING BATTALION	BADGE NUMBER	ENG. SQ. MARINE	LADDER	COS. RESP.
01	113	02	2	

8000787

RM./AREA CODE	OCCUPANCY	MANNER OF	OCCUPANC'S	NO. BLDGS.	SMOKE DETECTORS
9	59	00	00	0	0

AREA FIRE ORIGIN / FIRE EXTENTION WITHIN BLDG. / OTHER / SPECIAL USE 1 2 3

200x200
AREA

Sgt. Doubraski, PA Police
LEFT IN CHARGE

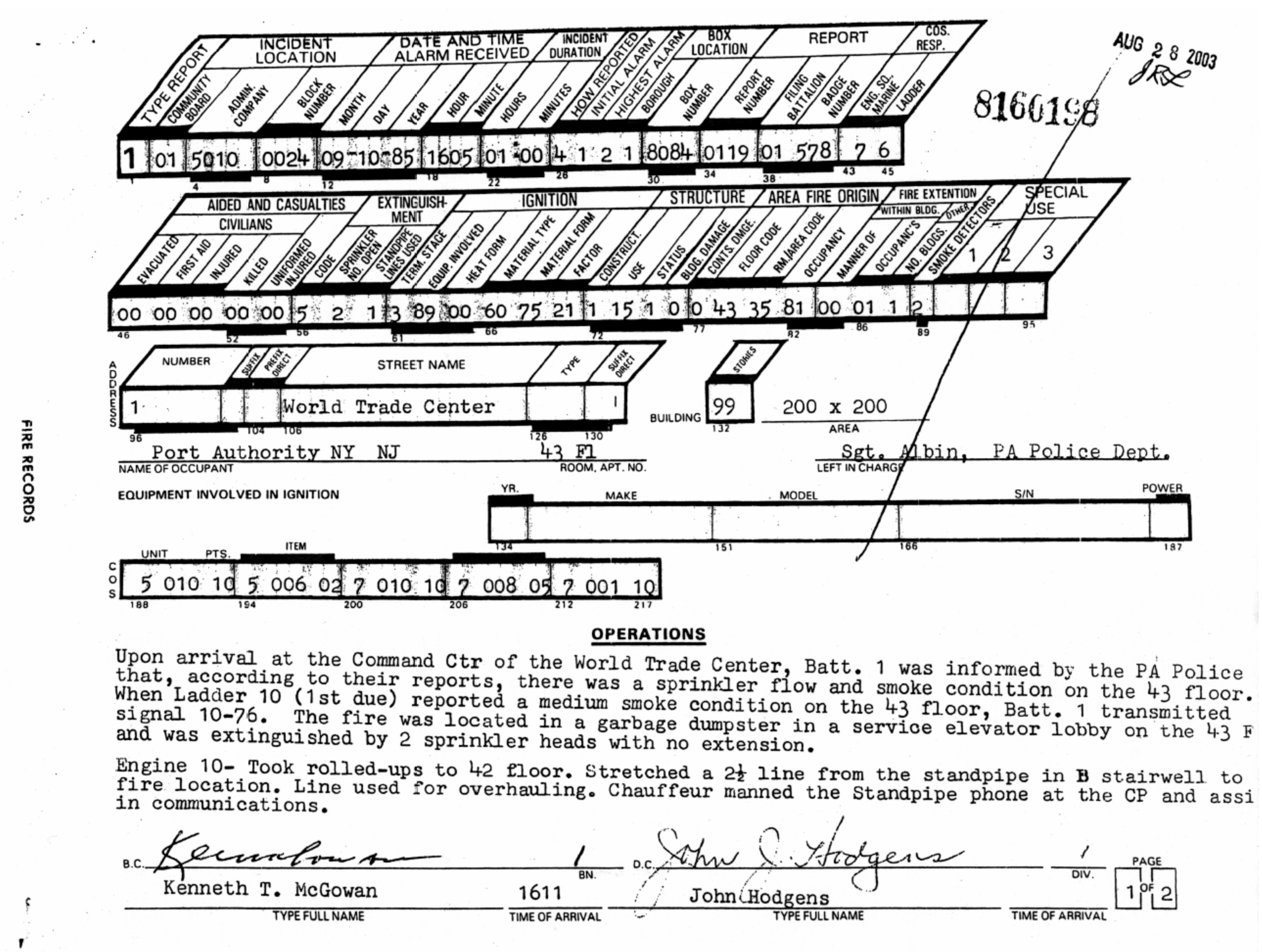
MODEL / S/N / POWER

.n unoccupied office occupancy on

; fire. Shut down sprinkler system.

AUG 2 8 2003
JRL

TYPE FULL NAME / DIV. / TIME OF ARRIVAL / PAGE OF



AUG 28 2003

8160198

TYPE REPORT	COMMUNITY BOARD	ADMIN. COMPANY	BLOCK NUMBER	MONTH	DAY	YEAR	HOUR	MINUTE	HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	BOX NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER	ENG. SQ. MARINE	LADDER
1	01	5010	0024	09	10	85	16	05	01	00	4	1	2	1	8084	0119	01	578	7	6

(INCIDENT LOCATION: Community Board, Admin. Company, Block Number; DATE AND TIME ALARM RECEIVED: Month, Day, Year, Hour, Minute; INCIDENT DURATION: Hours, Minutes; BOX LOCATION: Borough, Box Number; REPORT: Report Number, Filing Battalion, Badge Number; COS. RESP.: Eng. Sq. Marine, Ladder)

EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	CODE	SPRINKLER NO. OPEN	STANDPIPE LINES USED	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	FACTOR	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	FLOOR CODE	RM./AREA CODE	OCCUPANCY	MANNER OF	OCCUPANC'S	NO. BLDGS.	SMOKE DETECTORS	1	2	3
00	00	00	00	00	5	2	1	3	89	00	60	75	21	1	15	1	0	0	43	35	81	00	01	1	2			

(AIDED AND CASUALTIES – CIVILIANS: Evacuated, First Aid, Injured, Killed; Uniformed Injured; EXTINGUISHMENT: Code, Sprinkler No. Open, Standpipe Lines Used; IGNITION: Term. Stage, Equip. Involved, Heat Form, Material Type, Material Form, Factor; STRUCTURE: Construct., Use, Status, Bldg. Damage, Conts. Dmge.; AREA FIRE ORIGIN: Floor Code, Rm./Area Code, Occupancy; FIRE EXTENTION – WITHIN BLDG.: Manner of, Occupanc's; OTHER: No. Bldgs.; Smoke Detectors; SPECIAL USE: 1, 2, 3)

ADDRESS

NUMBER	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECT
1			World Trade Center		1

BUILDING STORIES: 99

AREA: 200 x 200

NAME OF OCCUPANT: Port Authority NY NJ

ROOM, APT. NO.: 43 Fl

LEFT IN CHARGE: Sgt. Albin, PA Police Dept.

EQUIPMENT INVOLVED IN IGNITION

YR.	MAKE	MODEL	S/N	POWER

COS

UNIT	PTS.	ITEM												
5	010	10	5	006	02	7	010	10	7	008	05	7	001	10

OPERATIONS

Upon arrival at the Command Ctr of the World Trade Center, Batt. 1 was informed by the PA Police that, according to their reports, there was a sprinkler flow and smoke condition on the 43 floor. When Ladder 10 (1st due) reported a medium smoke condition on the 43 floor, Batt. 1 transmitted signal 10-76. The fire was located in a garbage dumpster in a service elevator lobby on the 43 F

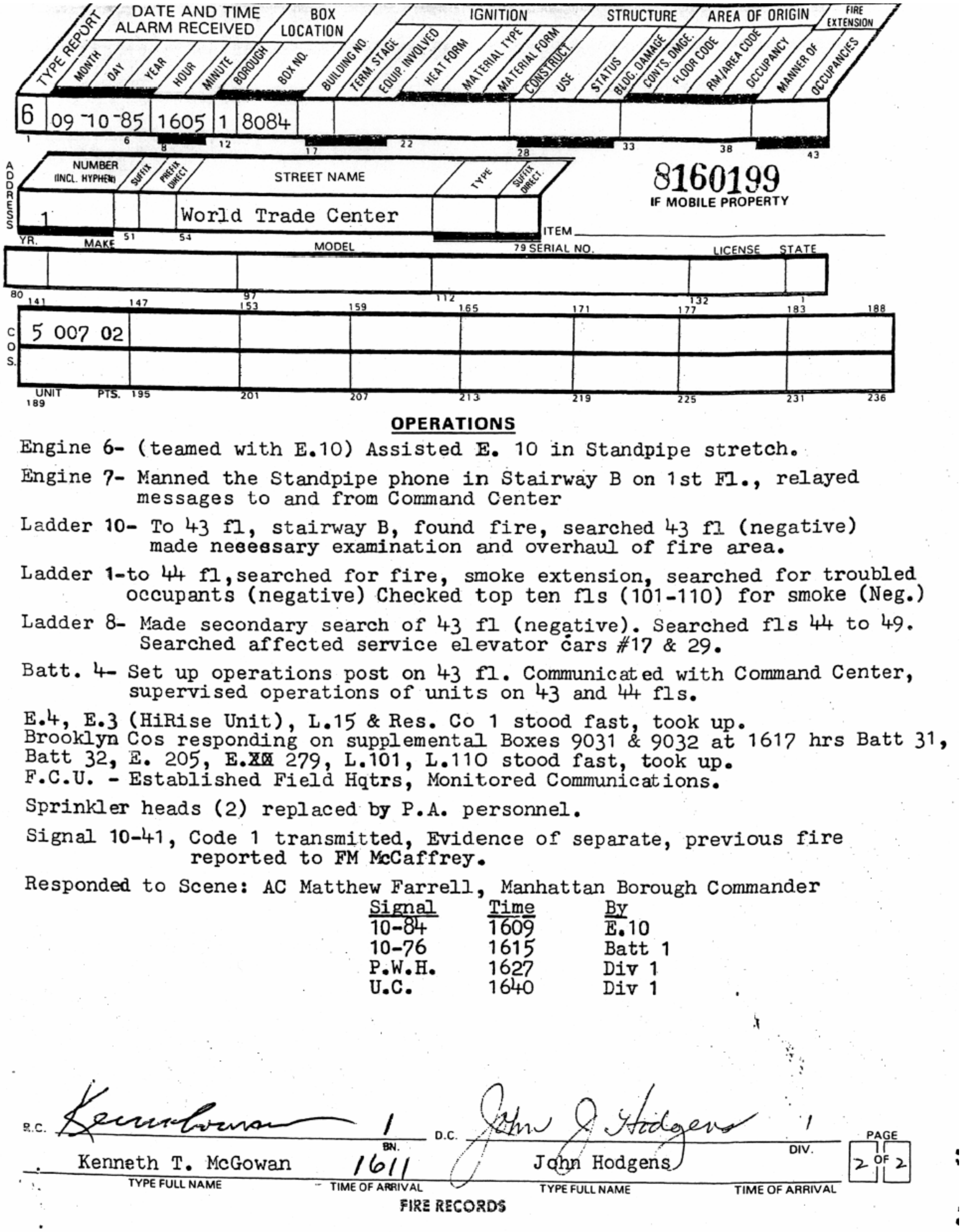
Engine 10- Took rolled-ups to 42 floor. Stretched a 2½ line from the standpipe in B stairwell to fire location. Line used for overhauling. Chauffeur manned the Standpipe phone at the CP and assi in communications.

B.C. Kenneth T. McGowan — BN. 1 — TIME OF ARRIVAL 1611
TYPE FULL NAME: Kenneth T. McGowan

D.C. John J. Hodgens — DIV. 1 — TIME OF ARRIVAL
TYPE FULL NAME: John Hodgens

PAGE 1 OF 2

FIRE RECORDS



TYPE REPORT	DATE AND TIME ALARM RECEIVED (MONTH, DAY, YEAR)	HOUR, MINUTE	BOX LOCATION: BOROUGH	BOX NO.	IGNITION	STRUCTURE	AREA OF ORIGIN	FIRE EXTENSION
6	09 10 85	1605	1	8084				

IGNITION: BUILDING NO., TERM. STAGE, EQUIP. INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM, CONSTRUCT., USE
STRUCTURE: STATUS, BLDG. DAMAGE, CONTS. DMGE., FLOOR CODE
AREA OF ORIGIN: RM/AREA CODE, OCCUPANCY
FIRE EXTENSION: MANNER OF, OCCUPANCIES

ADDRESS: NUMBER (INCL. HYPHEN) 1, SUFFIX, PREFIX DIRECT, STREET NAME World Trade Center, TYPE, SUFFIX DIRECT.

8160199
IF MOBILE PROPERTY
ITEM
YR. MAKE MODEL SERIAL NO. LICENSE STATE

C.O.S.: 5 007 02
UNIT PTS.

OPERATIONS

Engine 6- (teamed with E.10) Assisted E. 10 in Standpipe stretch.

Engine 7- Manned the Standpipe phone in Stairway B on 1st Fl., relayed messages to and from Command Center

Ladder 10- To 43 fl, stairway B, found fire, searched 43 fl (negative) made necessary examination and overhaul of fire area.

Ladder 1-to 44 fl, searched for fire, smoke extension, searched for troubled occupants (negative) Checked top ten fls (101-110) for smoke (Neg.)

Ladder 8- Made secondary search of 43 fl (negative). Searched fls 44 to 49. Searched affected service elevator cars #17 & 29.

Batt. 4- Set up operations post on 43 fl. Communicated with Command Center, supervised operations of units on 43 and 44 fls.

E.4, E.3 (HiRise Unit), L.15 & Res. Co 1 stood fast, took up.
Brooklyn Cos responding on supplemental Boxes 9031 & 9032 at 1617 hrs Batt 31, Batt 32, E. 205, E.~~XX~~ 279, L.101, L.110 stood fast, took up.
F.C.U. - Established Field Hqtrs, Monitored Communications.

Sprinkler heads (2) replaced by P.A. personnel.

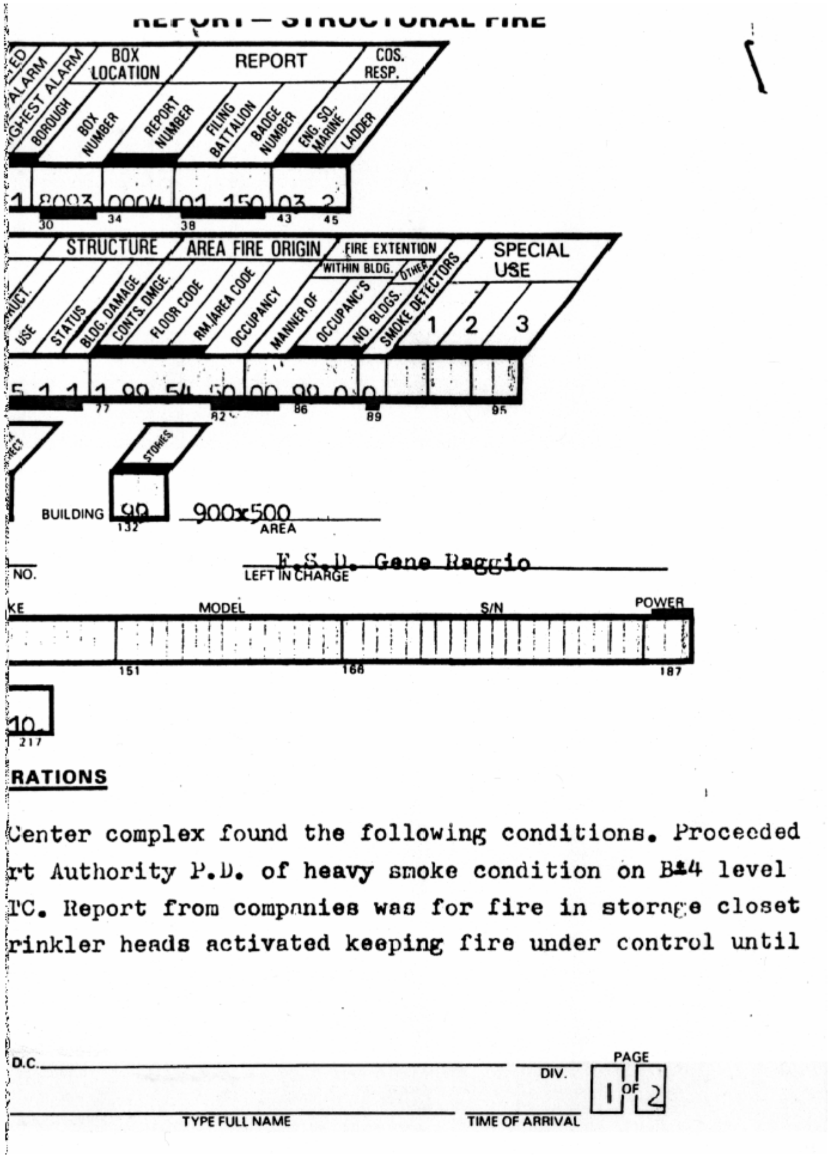
Signal 10-41, Code 1 transmitted, Evidence of separate, previous fire reported to FM McCaffrey.

Responded to Scene: AC Matthew Farrell, Manhattan Borough Commander

Signal	Time	By
10-84	1609	E.10
10-76	1615	Batt 1
P.W.H.	1627	Div 1
U.C.	1640	Div 1

B.C. Kenneth McGowan BN. 1 D.C. John J. Hodgens DIV. 1
Kenneth T. McGowan 1611 John Hodgens
TYPE FULL NAME TIME OF ARRIVAL TYPE FULL NAME TIME OF ARRIVAL
PAGE 2 OF 2

FIRE RECORDS



REPORT — STRUCTURAL FIRE

ED
ALARM
GHEST ALARM

BOX LOCATION
BOROUGH
BOX NUMBER

REPORT
REPORT NUMBER
FILING BATTALION
BADGE NUMBER

COS. RESP.
ENG. SQ. MARINE
LADDER

1 8093 0004 01 150 03 2

30 34 38 43 45

STRUCTURE
UCT.
USE
STATUS

AREA FIRE ORIGIN
BLDG. DAMAGE
CONTS. DMGE.
FLOOR CODE
RM./AREA CODE
OCCUPANCY

FIRE EXTENTION
WITHIN BLDG.
MANNER OF
OCCUPANC'S
OTHER
NO. BLDGS.
SMOKE DETECTORS

SPECIAL USE
1 2 3

5 1 1 1 99 54 50 00 99 0 0 0

77 82 86 89 95

ECT

STORIES

BUILDING 99 132

900x500
AREA

NO.

F.S.D. Gene Raggio
LEFT IN CHARGE

KE
MODEL
S/N
POWER

151 168 187

10 217

RATIONS

Center complex found the following conditions. Proceeded rt Authority P.D. of heavy smoke condition on B-4 level TC. Report from companies was for fire in storage closet rinkler heads activated keeping fire under control until

D.C. ______ DIV. ______

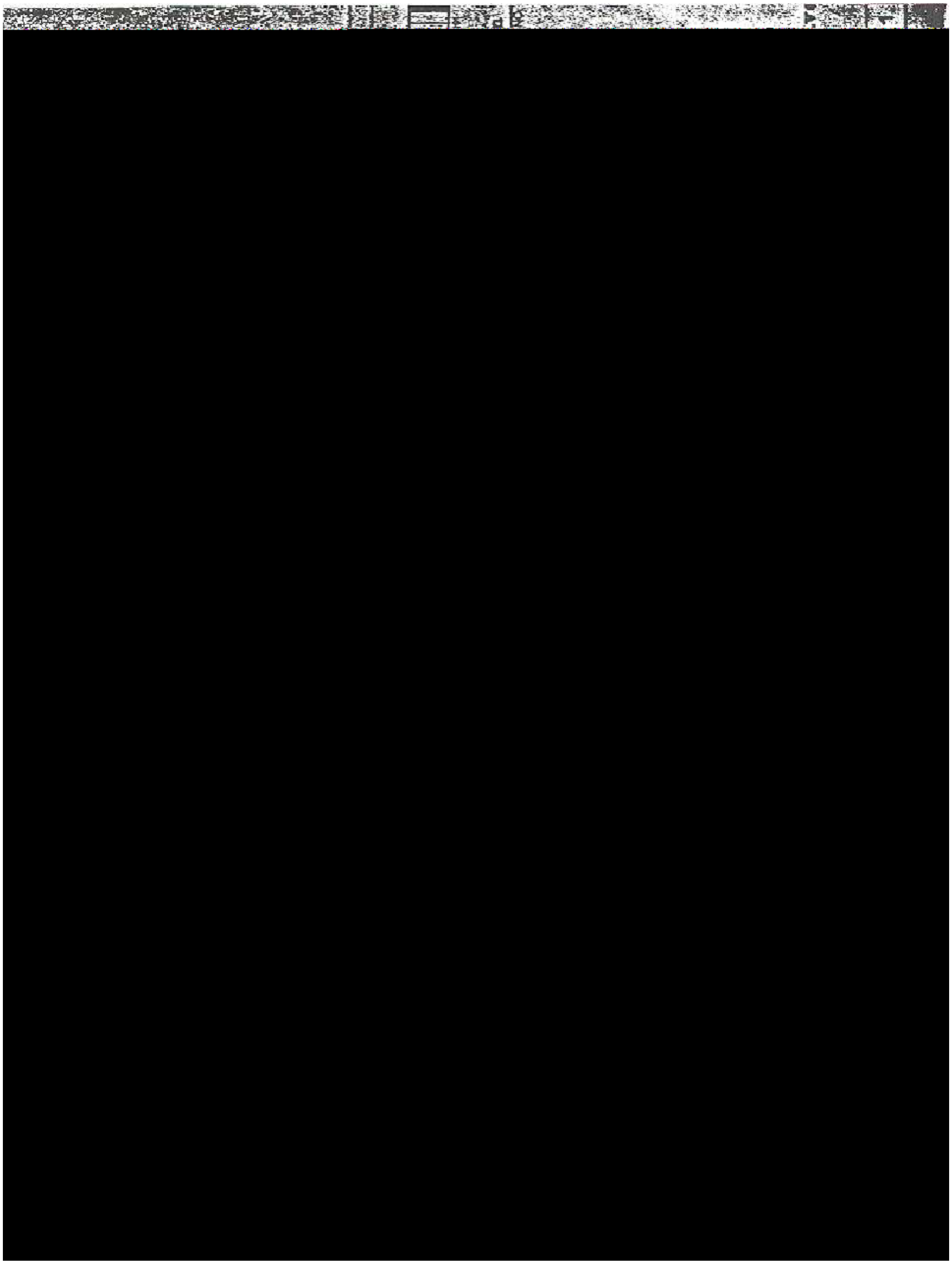
PAGE 1 OF 2

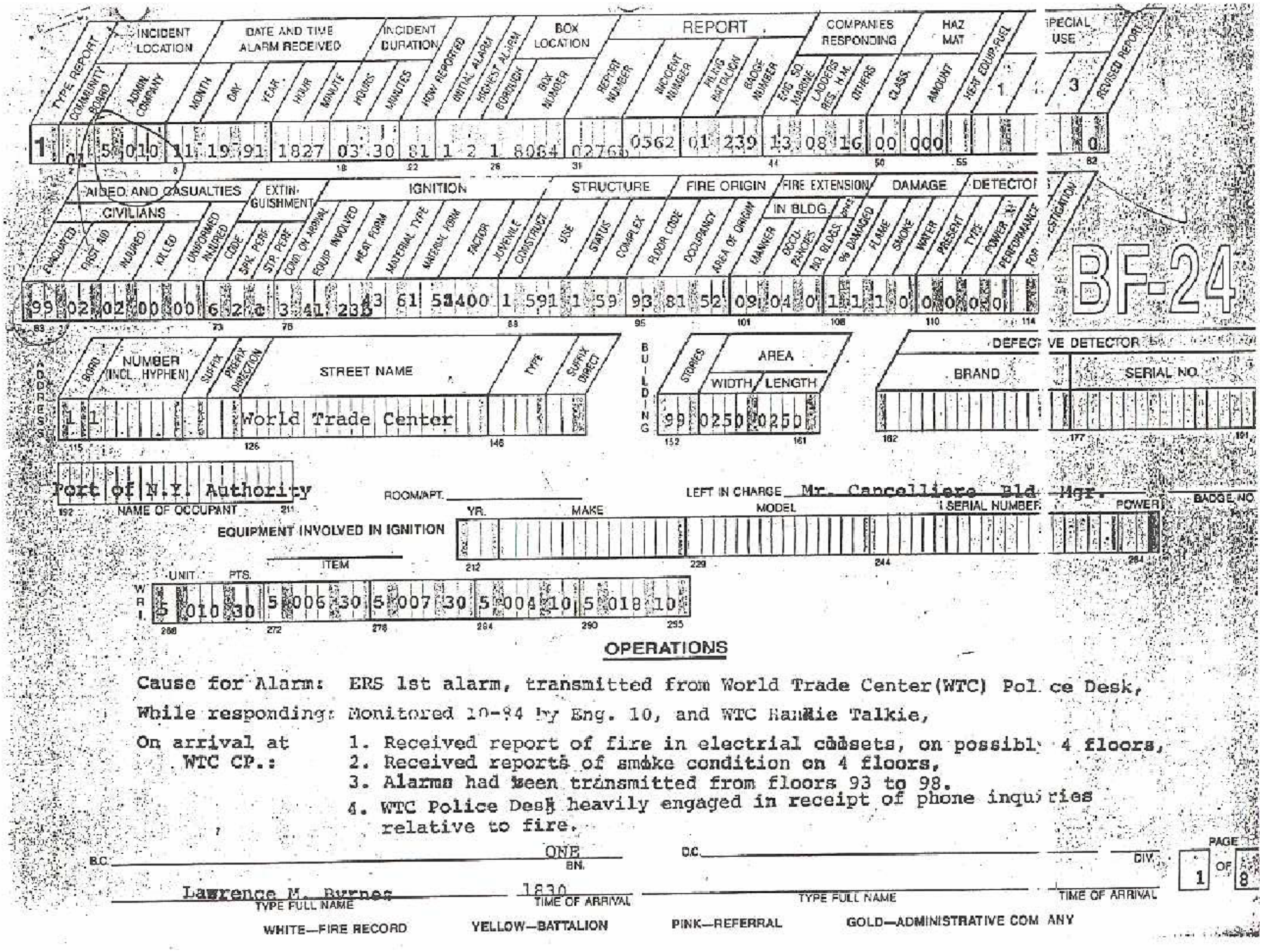
TYPE FULL NAME ______ TIME OF ARRIVAL ______

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT	DATE AND TIME ALARM RECEIVED					BOX LOCATION				IGNITION				STRUCTURE					AREA OF ORIGIN			FIRE EXTENSION	
	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NO.	BUILDING NO.	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	FLOOR CODE	RM/AREA CODE	OCCUPANCY	MANNER OF	OCCUPANCIES





BF-24

TYPE REPORT / INCIDENT LOCATION: COMMUNITY BOARD, ADMIN COMPANY / DATE AND TIME ALARM RECEIVED: MONTH, DAY, YEAR, HOUR, MINUTE / INCIDENT DURATION: HOURS, MINUTES / HOW REPORTED / INITIAL ALARM / HIGHEST ALARM / BOX LOCATION: BOROUGH, BOX NUMBER / REPORT: REPORT NUMBER, INCIDENT NUMBER, FILING BATTALION, BADGE NUMBER / COMPANIES RESPONDING: ENG. SQ. MARINE, LADDERS RES. H.M., OTHERS / HAZ MAT: CLASS, AMOUNT / HEAT EQUIP-FUEL / SPECIAL USE / REVISED REPORT

1 01 5 010 11 19 91 1827 03 30 81 1 2 1 8084 02766 0562 01 239 13 08 16 00 000 1 3 0

AIDED AND CASUALTIES: CIVILIANS: EVACUATED, FIRST AID, INJURED, KILLED; UNIFORMED INJURED / EXTINGUISHMENT: CODE, SPK. PERF., STP. PERF. / IGNITION: COND. ON ARRIVAL, EQUIP. INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM, FACTOR, JUVENILE / STRUCTURE: CONSTRUCT, USE, STATUS, COMPLEX, FLOOR CODE / FIRE ORIGIN: OCCUPANCY, AREA OF ORIGIN / FIRE EXTENSION: MANNER, IN BLDG.: OCCUPANCIES, NO. BLDGS. / DAMAGE: % DAMAGED, FLAME, SMOKE, WATER / DETECTOR: PRESENT, TYPE, POWER, PERFORMANCE / FOR INVESTIGATION

99 02 02 00 00 6 2 c 3 41 23 43 61 53 400 1 591 1 59 93 81 52 09 04 0 1 1 1 0 0 0 0 0

ADDRESS: BORO, NUMBER (INCL. HYPHEN), SUFFIX, PREFIX DIRECTION, STREET NAME, TYPE, SUFFIX DIRECT.

1 1 World Trade Center

BUILDING: STORIES, AREA: WIDTH, LENGTH

99 0250 0250

DEFECTIVE DETECTOR: BRAND, SERIAL NO.

Port of N.Y. Authority
NAME OF OCCUPANT

ROOM/APT. ______

LEFT IN CHARGE Mr. Cancelliere Bld. Mgr.

EQUIPMENT INVOLVED IN IGNITION: YR., MAKE, MODEL, SERIAL NUMBER, POWER

ITEM

BADGE NO.

W.R.I.: UNIT, PTS.

5 010 30 5 006 30 5 007 30 5 004 10 5 018 10

OPERATIONS

Cause for Alarm: ERS 1st alarm, transmitted from World Trade Center(WTC) Police Desk,

While responding: Monitored 10-84 by Eng. 10, and WTC Handie Talkie,

On arrival at WTC CP.:
1. Received report of fire in electrial closets, on possibly 4 floors,
2. Received reports of smoke condition on 4 floors,
3. Alarms had been transmitted from floors 93 to 98.
4. WTC Police Desk heavily engaged in receipt of phone inquiries relative to fire.

B.C. ______ ONE BN. ______ D.C. ______ DIV. ______

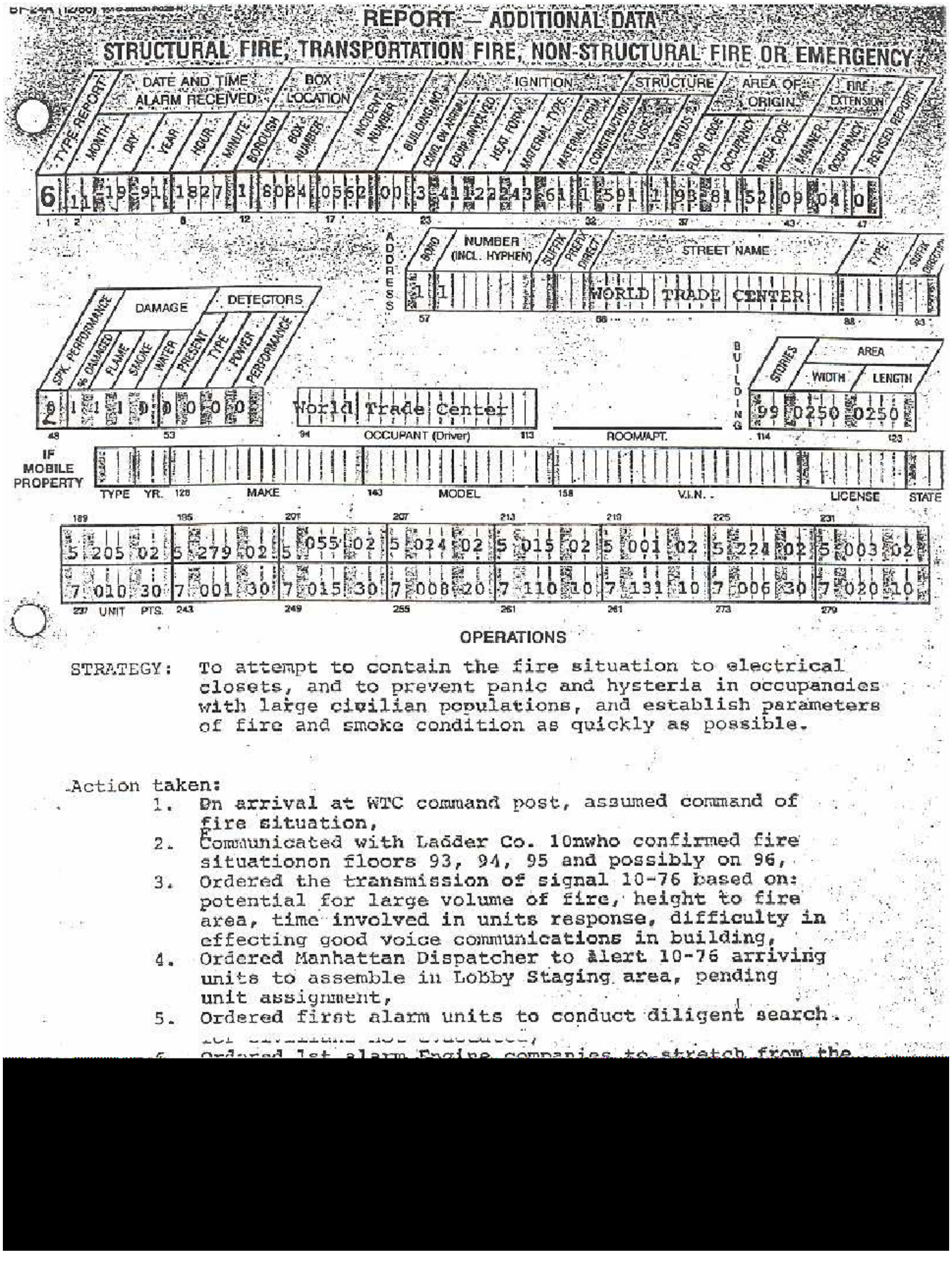
PAGE 1 OF 8

Lawrence M. Byrnes
TYPE FULL NAME

1830
TIME OF ARRIVAL

TYPE FULL NAME ______ TIME OF ARRIVAL ______

WHITE—FIRE RECORD YELLOW—BATTALION PINK—REFERRAL GOLD—ADMINISTRATIVE COMPANY



BF-24A (12/80)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT	DATE AND TIME ALARM RECEIVED: MONTH	DAY	YEAR	HOUR	MINUTE	BOX LOCATION: BOROUGH	BOX NUMBER
6	11	19	91	18	27	1	8084

INCIDENT NUMBER / BUILDING NO. / IGNITION: COND. ON ARRIVAL, EQUIP. INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM / STRUCTURE: CONSTRUCTION, USE, STATUS / AREA OF ORIGIN: FLOOR CODE, OCCUPANCY, AREA CODE / FIRE EXTENSION: MANNER, OCCUPANCY / REVISED REPORT

0562 00 3 41 22 2 43 61 1 59 1 1 93 81 52 09 04 0

1 2 8 12 17 23 32 37 43 47

ADDRESS: BORO 1 | NUMBER (INCL. HYPHEN) 1 | SUFFIX | PREFIX DIRECT. | STREET NAME WORLD TRADE CENTER | TYPE | SUFFIX DIRECTION

57 68 88 93

SPK. PERFORMANCE	DAMAGE: % DAMAGED	FLAME	SMOKE	WATER	DETECTORS: PRESENT	TYPE	POWER	PERFORMANCE
2	1	1	1	0	0	0	0	0

48 53

OCCUPANT (Driver): World Trade Center

94 113

ROOM/APT.

BUILDING: STORIES 99 | AREA: WIDTH 0250 | LENGTH 0250

114 123

IF MOBILE PROPERTY: TYPE | YR. | MAKE | MODEL | V.I.N. | LICENSE | STATE

128 143 158

189	195	201	207	213	219	225	231
5 205 02	5 279 02	5 055 02	5 024 02	5 015 02	5 001 02	5 224 02	5 003 02
7 010 30	7 001 30	7 015 30	7 008 20	7 110 10	7 131 10	7 006 30	7 020 10
237 UNIT PTS.	243	249	255	261	261	273	279

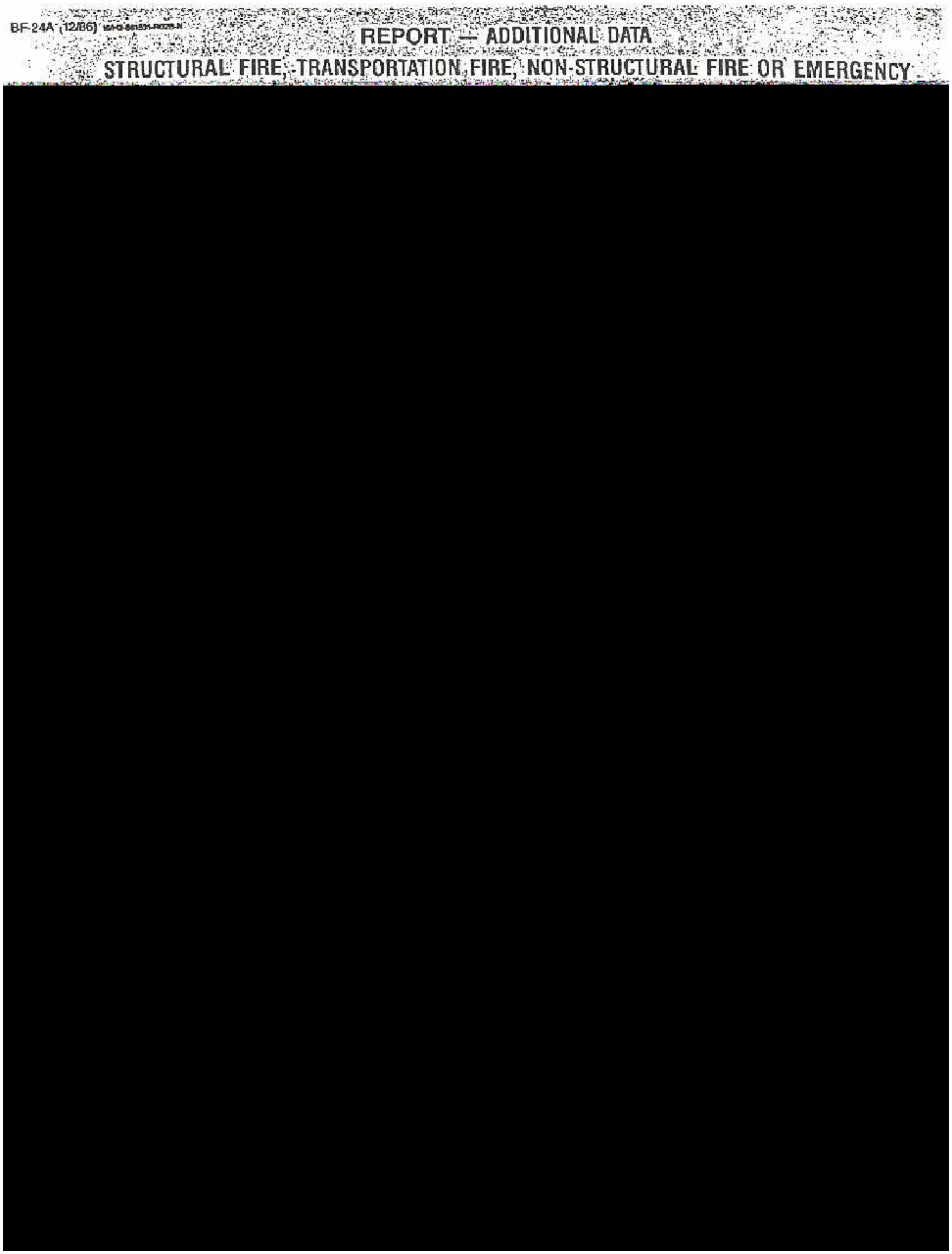
OPERATIONS

STRATEGY: To attempt to contain the fire situation to electrical closets, and to prevent panic and hysteria in occupancies with large civilian populations, and establish parameters of fire and smoke condition as quickly as possible.

Action taken:

1. On arrival at WTC command post, assumed command of fire situation,
2. Communicated with Ladder Co. 10nwho confirmed fire situationon floors 93, 94, 95 and possibly on 96,
3. Ordered the transmission of signal 10-76 based on: potential for large volume of fire, height to fire area, time involved in units response, difficulty in effecting good voice communications in building,
4. Ordered Manhattan Dispatcher to Alert 10-76 arriving units to assemble in Lobby Staging area, pending unit assignment,
5. Ordered first alarm units to conduct diligent search. for civilians not evacuated,
6. Ordered 1st alarm Engine companies to stretch from the

[redacted]



BF-24A (12/86)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

[redacted]

BF-24A (12/86)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

REPORT

DATE AND TIME ALARM RECEIVED

BOX LOCATION

IGNITION

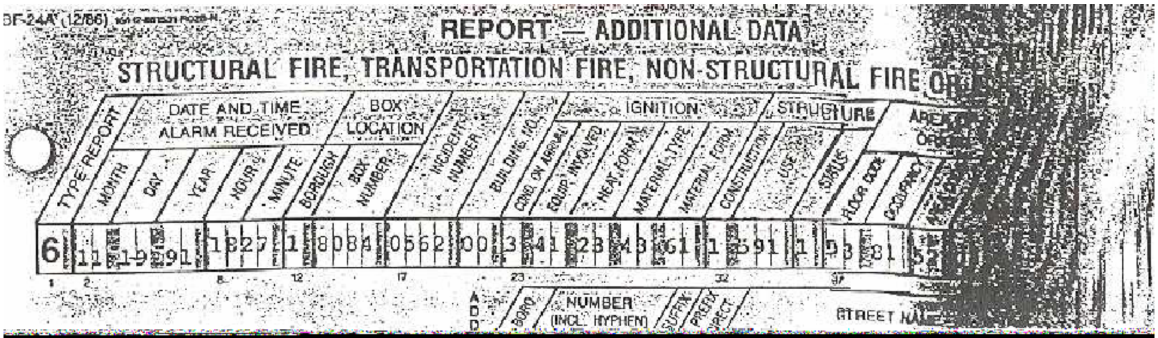
STRUCTURE

AREA OF ORIGIN

FIRE EXTENSION

BF-24A (12/86)

REPORT — ADDITIONAL DATA



BF-24A (12/86)

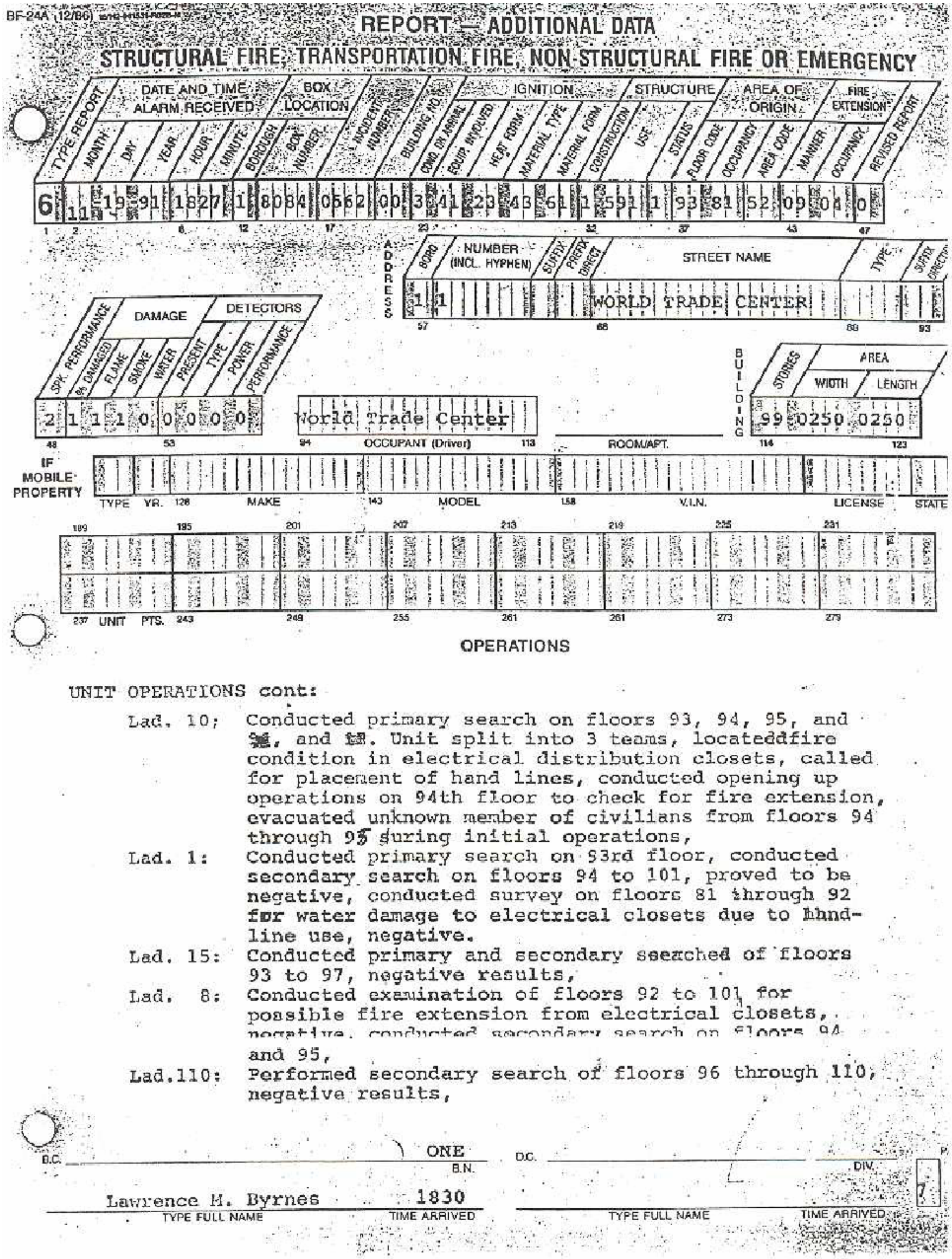
REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR

TYPE REPORT	DATE AND TIME ALARM RECEIVED					BOX LOCATION		INCIDENT NUMBER	BUILDING NO.	IGNITION					STRUCTURE				AREA OF
	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NUMBER			COND. ON ARRIVAL	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCTION	USE	STATUS	FLOOR CODE	OCCUPANCY
6	11	19	91	18	27	1	8084	0562	00	3	41	23	43	61	1	591	1	53	81
1	2			8		12		17		23					32		37		

ADD | BORO | NUMBER (INCL. HYPHEN) | SUFFIX | PREFIX | DIRECT. | STREET NA

[redacted]



BF-24A (12/86)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT	DATE AND TIME ALARM RECEIVED: MONTH	DAY	YEAR	HOUR	MINUTE	BOX LOCATION: BOROUGH	BOX NUMBER	INCIDENT NUMBER	BUILDING NO.	COND. ON ARRIVAL	IGNITION: EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	STRUCTURE: CONSTRUCTION	USE	STATUS	AREA OF ORIGIN: FLOOR CODE	OCCUPANCY	AREA CODE	FIRE EXTENSION: MANNER	OCCUPANCY	REVISED REPORT
6	11	19	91	18	27	1	8084	0562	00	3	41	23	43	61	1	591	1	93	81	52	09	04	0

ADDRESS: BORO 1 | NUMBER (INCL. HYPHEN) 1 | SUFFIX | PREFIX DIRECT | STREET NAME WORLD TRADE CENTER | TYPE | SUFFIX DIRECTION

SPK. PERFORMANCE 2 | DAMAGE: % DAMAGED 1 | FLAME 1 | SMOKE 1 | WATER 0 | DETECTORS: PRESENT 0 | TYPE 0 | POWER 0 | PERFORMANCE 0

OCCUPANT (Driver): World Trade Center

ROOM/APT.

BUILDING: STORIES 99 | AREA: WIDTH 0250 | LENGTH 0250

IF MOBILE PROPERTY: TYPE | YR. | MAKE | MODEL | V.I.N. | LICENSE | STATE

UNIT | PTS.

OPERATIONS

UNIT OPERATIONS cont:

Lad. 10; Conducted primary search on floors 93, 94, 95, and [illegible], and [illegible]. Unit split into 3 teams, locateddfire condition in electrical distribution closets, called for placement of hand lines, conducted opening up operations on 94th floor to check for fire extension, evacuated unknown member of civilians from floors 94 through 95 during initial operations,

Lad. 1: Conducted primary search on 93rd floor, conducted secondary search on floors 94 to 101, proved to be negative, conducted survey on floors 81 through 92 for water damage to electrical closets due to hand-line use, negative.

Lad. 15: Conducted primary and secondary searched of floors 93 to 97, negative results,

Lad. 8: Conducted examination of floors 92 to 101 for possible fire extension from electrical closets, negative, conducted secondary search on floors 94 and 95,

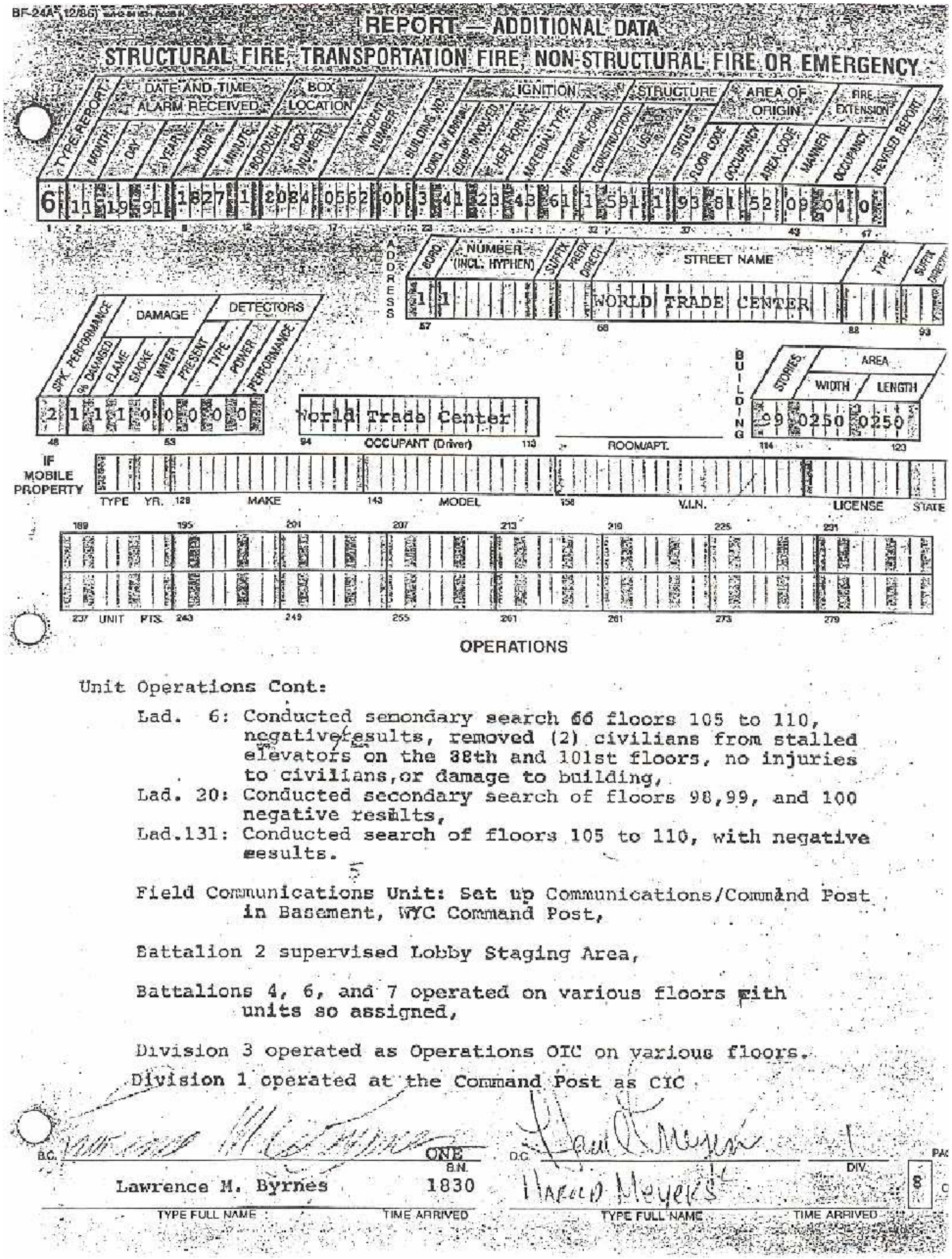
Lad.110: Performed secondary search of floors 96 through 110, negative results,

B.C. ONE B.N. D.C. DIV.

Lawrence M. Byrnes 1830

TYPE FULL NAME | TIME ARRIVED | TYPE FULL NAME | TIME ARRIVED

P. 7



BF-24A (12/86)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

Type Report		6
Date and Time Alarm Received	Month	11
	Day	19
	Year	91
	Hour	18
	Minute	27
Box Location	Borough	1
	Box Number	2084
Incident Number		0562
Building No.		00
Cond. on Arrival		3
Ignition	Equip. Involved	41
	Heat Form	23
	Material Type	43
	Material Form	61
Structure	Construction	1
	Use / Status	591
Area of Origin	Floor Code / Occupancy / Area Code	1 93 81
Fire Extension	Manner / Occupancy	52 09 04
Revised Report		0

Address: Boro 1; Number (Incl. Hyphen) 1; Suffix; Prefix Direct.; Street Name WORLD TRADE CENTER; Type; Suffix Direct.

Spk. Performance	% Damaged	Flame	Smoke	Water	Present	Type	Power	Performance
2	1	1	1	0	0	0	0	0

Occupant (Driver): World Trade Center

Room/Apt.:

Building: Stories 99; Area: Width 0250, Length 0250

If Mobile Property: Type; Yr.; Make; Model; V.I.N.; License; State

Unit; PTS.

OPERATIONS

Unit Operations Cont:

Lad. 6: Conducted senondary search 66 floors 105 to 110, negative results, removed (2) civilians from stalled elevators on the 38th and 101st floors, no injuries to civilians, or damage to building,

Lad. 20: Conducted secondary search of floors 98,99, and 100 negative results,

Lad.131: Conducted search of floors 105 to 110, with negative results.

Field Communications Unit: Set up Communications/Command Post in Basement, WTC Command Post,

Battalion 2 supervised Lobby Staging Area,

Battalions 4, 6, and 7 operated on various floors with units so assigned,

Division 3 operated as Operations OIC on various floors.

Division 1 operated at the Command Post as CIC.

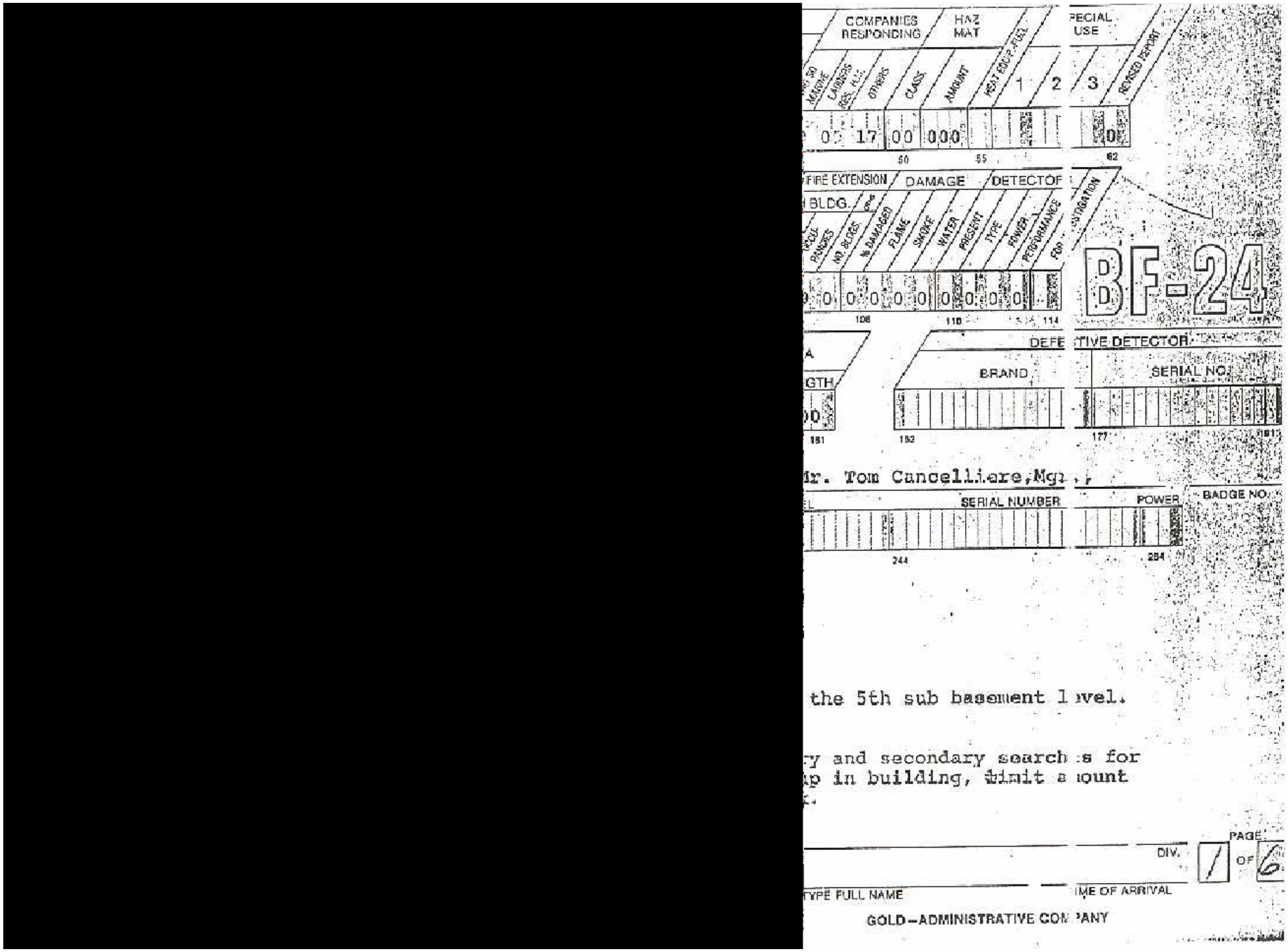
B.C. ONE B.N.

Lawrence M. Byrnes — Type Full Name; 1830 — Time Arrived

D.C. DIV.

Harold Meyers — Type Full Name; Time Arrived

PAGE 8



[redacted]

COMPANIES RESPONDING

MARINE

LADDERS

RES. RES.

OTHERS

HAZ MAT

CLASS

AMOUNT

HEAT EQUIP. FUEL

1

2

SPECIAL USE

3

REVISED REPORT

0 17 00 000

0

FIRE EXTENSION

BLDG.

DAMAGE

DETECTOR

NO. BLDGS.

% DAMAGED

FLAME

SMOKE

WATER

PRESENT

TYPE

POWER

PERFORMANCE

FOR

INVESTIGATION

0 0 0 0 0 0 0 0 0

BF-24

A

GTH

DEFECTIVE DETECTOR

BRAND

SERIAL NO.

Mr. Tom Cancelliere, Mgr.

SERIAL NUMBER

POWER

BADGE NO.

the 5th sub basement level.

y and secondary search s for
p in building, limit a ount

DIV.

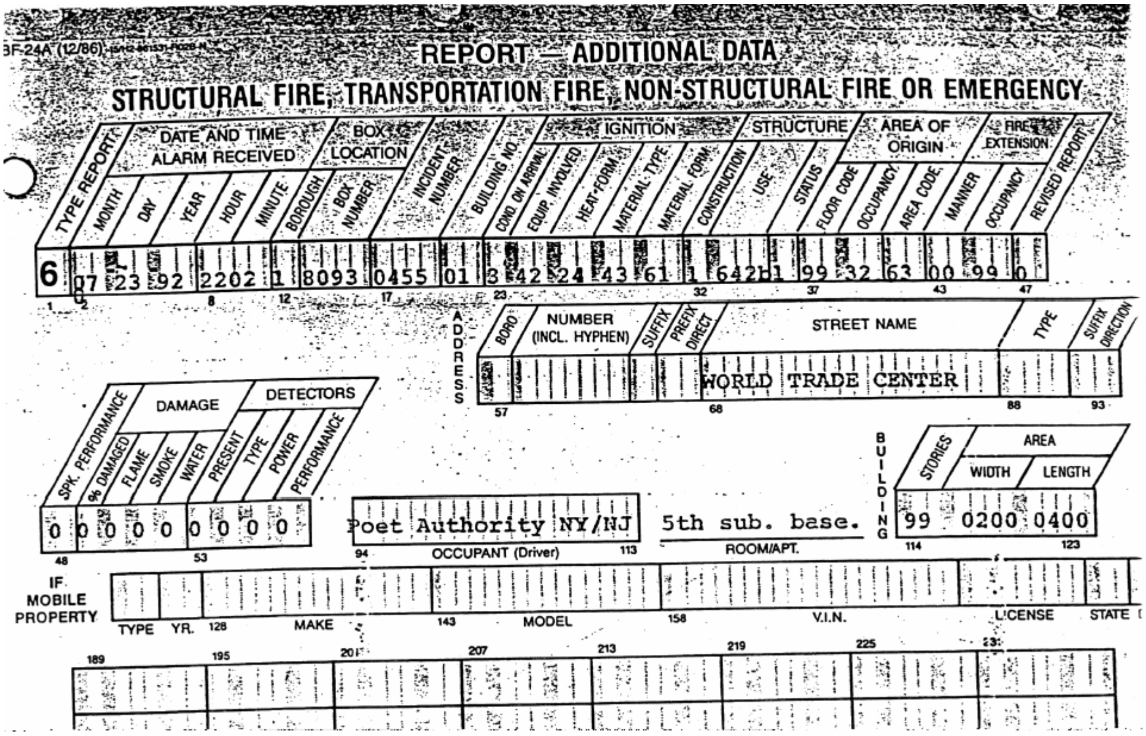
PAGE / OF 6

TYPE FULL NAME

TIME OF ARRIVAL

GOLD—ADMINISTRATIVE COMPANY

[redacted]



BF-24A (12/86)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

	DATE AND TIME ALARM RECEIVED					BOX LOCATION				IGNITION					STRUCTURE			AREA OF ORIGIN			FIRE EXTENSION		
TYPE REPORT	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NUMBER	INCIDENT NUMBER	BUILDING NO.	COND. ON ARRIVAL	EQUIP. INVOLVED	HEAT-FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCTION	USE	STATUS	FLOOR CODE	OCCUPANCY	AREA CODE	MANNER	OCCUPANCY	REVISED REPORT
6	07	23	92	22	02	1	8093	0455	01	3	42	24	43	61	1	642	1	99	32	63	00	99	0
1	2			8		12		17		23					32			37			43		47

ADDRESS						
BORO	NUMBER (INCL. HYPHEN)	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECTION
				WORLD TRADE CENTER		
57				68	88	93

	DAMAGE				DETECTORS			
SPK. PERFORMANCE	% DAMAGED	FLAME	SMOKE	WATER	PRESENT	TYPE	POWER	PERFORMANCE
0	0	0	0	0	0	0	0	0
48					53			

OCCUPANT (Driver): Poet Authority NY/NJ (94–113)

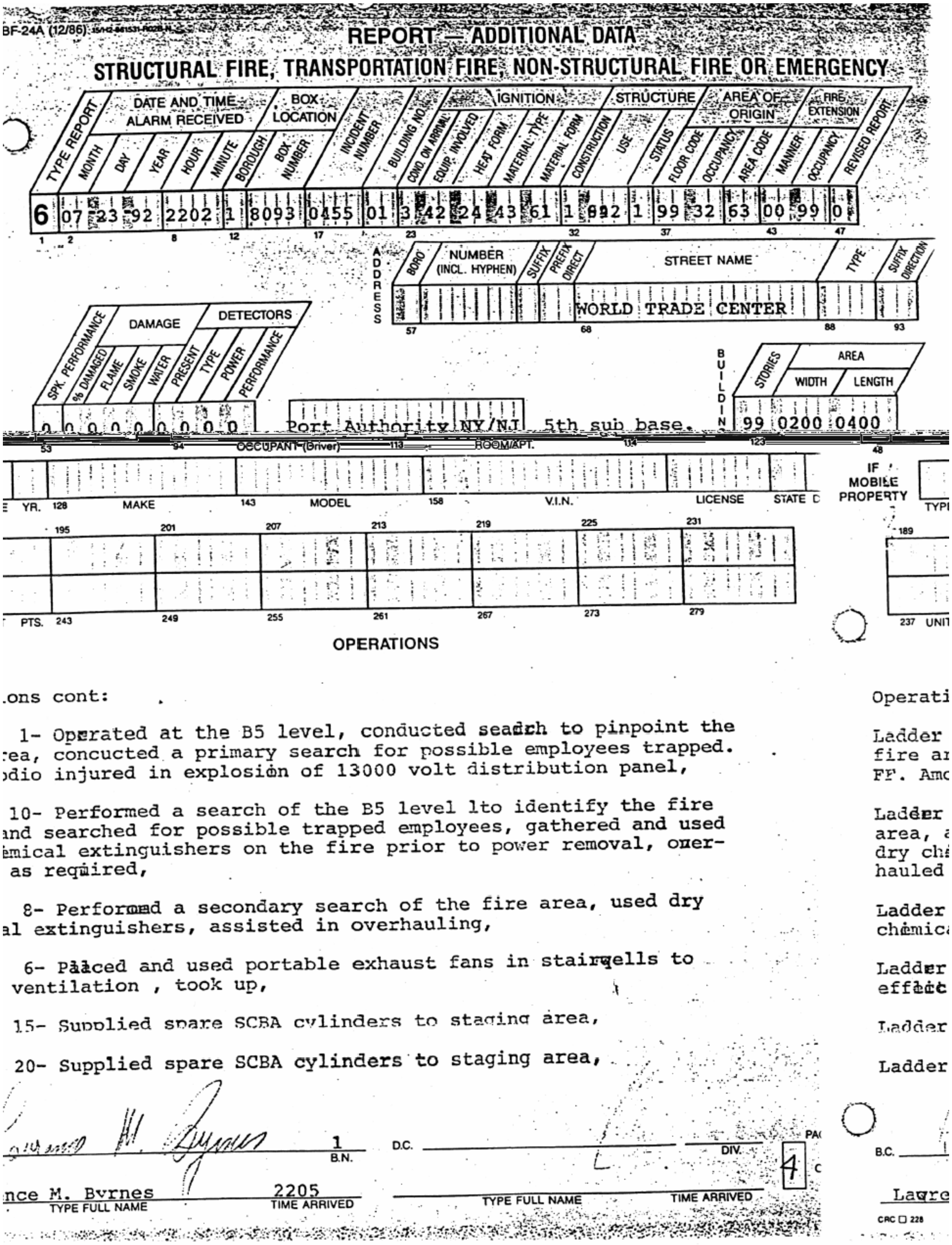
ROOM/APT.: 5th sub. base.

BUILDING		
STORIES	AREA	
	WIDTH	LENGTH
99	0200	0400
114		123

IF MOBILE PROPERTY

TYPE	YR.	128 MAKE	143 MODEL	158 V.I.N.	LICENSE	STATE

189	195	201	207	213	219	225	231



BF-24A (12/86)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NUMBER	INCIDENT NUMBER	BUILDING NO.	COND. ON ARRIVAL	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCTION	USE	STATUS	FLOOR CODE	OCCUPANCY	AREA CODE	MANNER	OCCUPANCY	REVISED REPORT
6	07	23	92	22	02	1	8093	0455	01	3	42	24	43	61	1	892	1	99	32	63	00	99	0

ADDRESS: STREET NAME: WORLD TRADE CENTER

DAMAGE / DETECTORS: 0 0 0 0 0 0 0 0 0

OCCUPANT (Driver): Port Authority NY/NJ

ROOM/APT.: 5th sub base.

BUILDING: STORIES 99 AREA WIDTH 0200 LENGTH 0400

OPERATIONS

.ons cont:

1- Operated at the B5 level, conducted search to pinpoint the :ea, concucted a primary search for possible employees trapped. ›dio injured in explosion of 13000 volt distribution panel,

10- Performed a search of the B5 level lto identify the fire ınd searched for possible trapped employees, gathered and used emical extinguishers on the fire prior to power removal, over- as required,

8- Performed a secondary search of the fire area, used dry al extinguishers, assisted in overhauling,

6- Placed and used portable exhaust fans in stairwells to ventilation , took up,

15- Supplied spare SCBA cylinders to staging area,

20- Supplied spare SCBA cylinders to staging area,

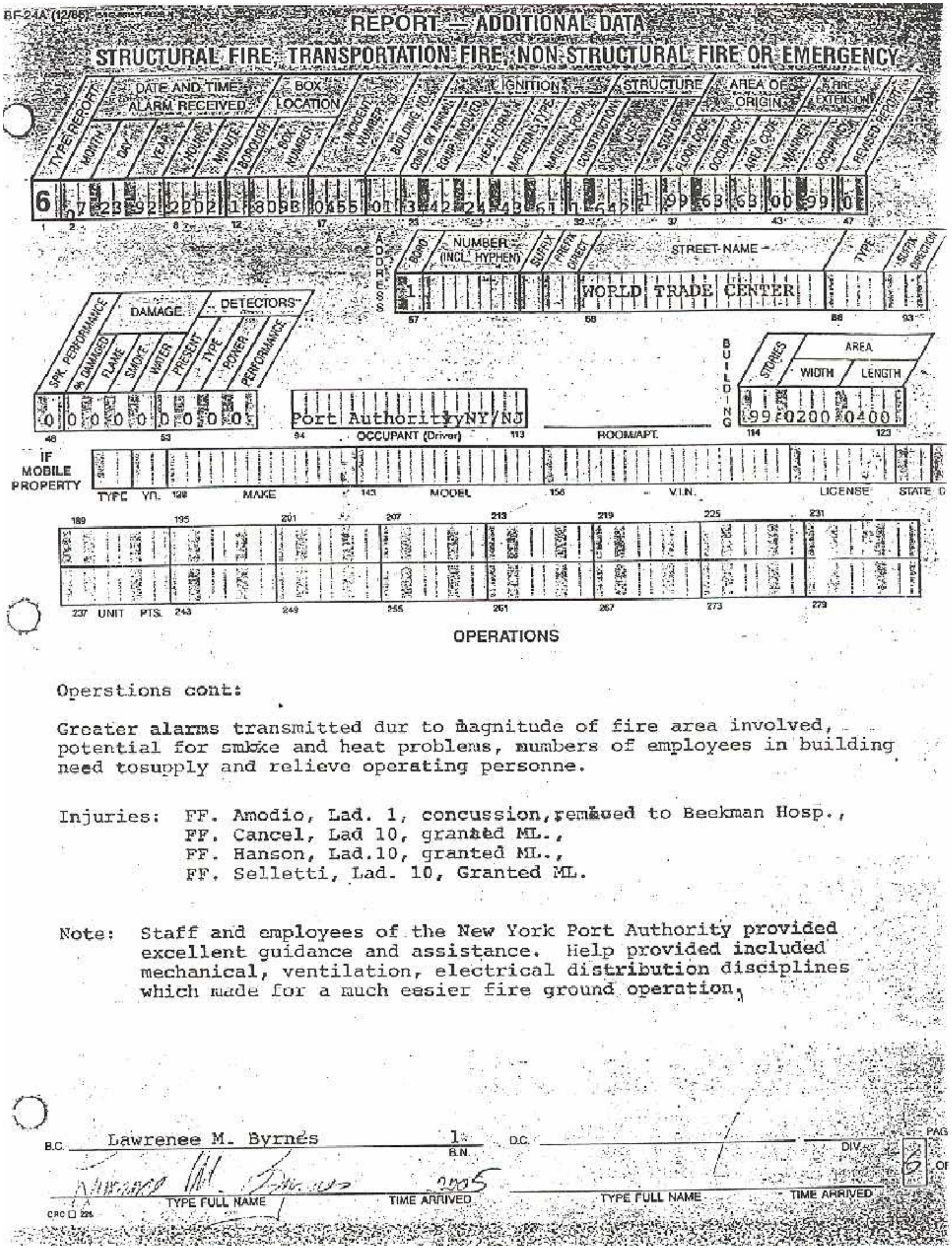
1 B.N. D.C. DIV. 4

nce M. Byrnes — TYPE FULL NAME — 2205 TIME ARRIVED — TYPE FULL NAME — TIME ARRIVED

Operati
Ladder
fire ar
FF. Amc
Ladder
area, a
dry ch
hauled
Ladder
chemica
Ladder
effect
Ladder
Ladder
B.C.
Lawre
CRC 228

BF-24A (12/86) [illegible]

REPORT — ADDITIONAL DATA



BF-24A (12/85)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT	DATE AND TIME ALARM RECEIVED	BOX LOCATION	INCIDENT NUMBER	BUILDING NO.
6	07 23 92 22 02	1 8098	0155	01

ADDRESS: BORO 1 — STREET NAME: WORLD TRADE CENTER

OCCUPANT (Driver): Port Authority NY/NJ

ROOM/APT.

DAMAGE / DETECTORS: 0 0 0 0 0 0 0 0 0

BUILDING — STORIES: 99 — AREA: WIDTH 0200, LENGTH 0400

IF MOBILE PROPERTY: TYPE, YR., MAKE, MODEL, V.I.N., LICENSE, STATE

UNIT, PTS.

OPERATIONS

Operstions cont:

Greater alarms transmitted dur to magnitude of fire area involved, potential for smoke and heat problems, numbers of employees in building need tosupply and relieve operating personne.

Injuries: FF. Amodio, Lad. 1, concussion, removed to Beekman Hosp.,
FF. Cancel, Lad 10, granted ML.,
FF. Hanson, Lad.10, granted ML.,
FF. Selletti, Lad. 10, Granted ML.

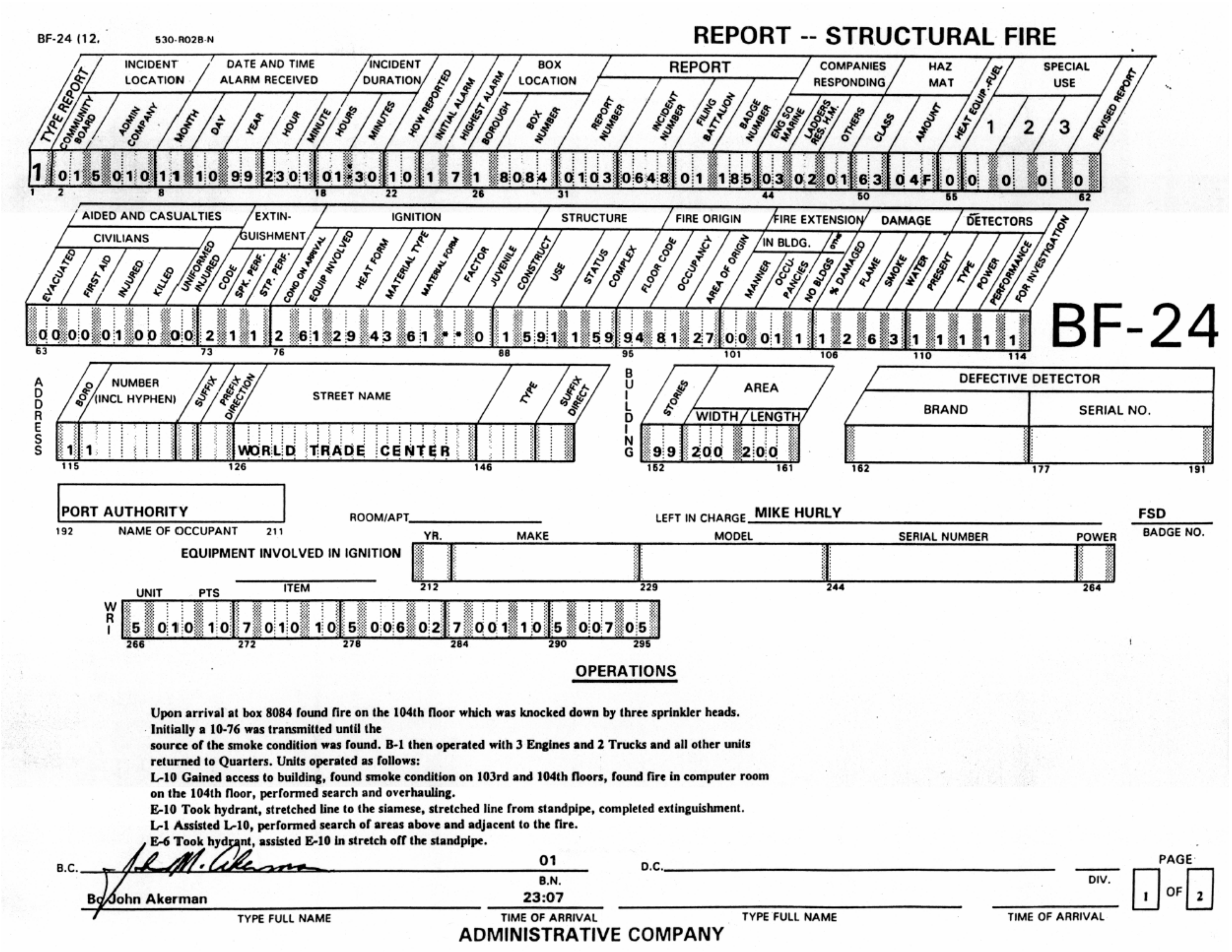
Note: Staff and employees of the New York Port Authority provided excellent guidance and assistance. Help provided included mechanical, ventilation, electrical distribution disciplines which made for a much easier fire ground operation.

B.C. Lawrence M. Byrnes — 1 B.N.

TYPE FULL NAME — TIME ARRIVED 2005

D.C. — TYPE FULL NAME — TIME ARRIVED — DIV. 6

PAG OF



BF-24 (12. 530-R02B-N

REPORT -- STRUCTURAL FIRE

TYPE REPORT / INCIDENT LOCATION: COMMUNITY BOARD, ADMIN COMPANY / DATE AND TIME ALARM RECEIVED: MONTH, DAY, YEAR, HOUR, MINUTE / INCIDENT DURATION: HOURS, MINUTES / HOW REPORTED / INITIAL ALARM / HIGHEST ALARM / BOX LOCATION: BOROUGH, BOX NUMBER / REPORT: REPORT NUMBER, INCIDENT NUMBER, FILING BATTALION, BADGE NUMBER / COMPANIES RESPONDING: ENG SQ MARINE, LADDERS RES. H.M., OTHERS / HAZ MAT: CLASS, AMOUNT / HEAT EQUIP.-FUEL / SPECIAL USE: 1, 2, 3 / REVISED REPORT

1 | 0 1 5 0 1 0 | 1 1 1 0 9 9 | 2 3 0 1 | 0 1 • 3 0 | 1 0 | 1 7 1 | 8 0 8 4 | 0 1 0 3 | 0 6 4 8 | 0 1 1 8 5 | 0 3 0 2 0 1 | 6 3 | 0 4 F | 0 | 0 0 0 0

1 2 8 18 22 26 31 44 50 55 62

AIDED AND CASUALTIES: CIVILIANS: EVACUATED, FIRST AID, INJURED, KILLED; UNIFORMED INJURED / EXTINGUISHMENT: CODE, SPK. PERF., STP. PERF. / IGNITION: COND ON ARRIVAL, EQUIP INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM, FACTOR, JUVENILE / STRUCTURE: CONSTRUCT, USE, STATUS, COMPLEX / FIRE ORIGIN: FLOOR CODE, OCCUPANCY, AREA OF ORIGIN / FIRE EXTENSION: IN BLDG.: MANNER, OCCUPANCIES; OTHER: NO BLDGS / DAMAGE: % DAMAGED, FLAME, SMOKE, WATER / DETECTORS: PRESENT, TYPE, POWER, PERFORMANCE, FOR INVESTIGATION

0 0 0 0 0 1 0 0 0 0 | 2 1 1 | 2 6 1 2 9 4 3 6 1 • • 0 | 1 5 9 1 1 5 9 | 9 4 8 1 2 7 | 0 0 0 1 1 | 1 2 6 3 | 1 1 1 1 1

63 73 76 88 95 101 106 110 114

BF-24

ADDRESS: BORO, NUMBER (INCL HYPHEN), SUFFIX, PREFIX DIRECTION, STREET NAME, TYPE, SUFFIX DIRECT

1 | 1 | | | WORLD TRADE CENTER | |

115 126 146

BUILDING: STORIES, AREA: WIDTH / LENGTH

9 9 | 2 0 0 | 2 0 0

152 161

DEFECTIVE DETECTOR: BRAND, SERIAL NO.

162 177 191

PORT AUTHORITY

192 NAME OF OCCUPANT 211

ROOM/APT________

LEFT IN CHARGE MIKE HURLY

FSD

BADGE NO.

EQUIPMENT INVOLVED IN IGNITION: YR., MAKE, MODEL, SERIAL NUMBER, POWER

ITEM

212 229 244 264

WRI: UNIT, PTS

5 0 1 0 1 0 | 7 0 1 0 1 0 | 5 0 0 6 0 2 | 7 0 0 1 1 0 | 5 0 0 7 0 5

266 272 278 284 290 295

OPERATIONS

Upon arrival at box 8084 found fire on the 104th floor which was knocked down by three sprinkler heads.
Initially a 10-76 was transmitted until the
source of the smoke condition was found. B-1 then operated with 3 Engines and 2 Trucks and all other units returned to Quarters. Units operated as follows:
L-10 Gained access to building, found smoke condition on 103rd and 104th floors, found fire in computer room on the 104th floor, performed search and overhauling.
E-10 Took hydrant, stretched line to the siamese, stretched line from standpipe, completed extinguishment.
L-1 Assisted L-10, performed search of areas above and adjacent to the fire.
E-6 Took hydrant, assisted E-10 in stretch off the standpipe.

B.C. J.M. Akerman 01 B.N.

BC John Akerman — TYPE FULL NAME

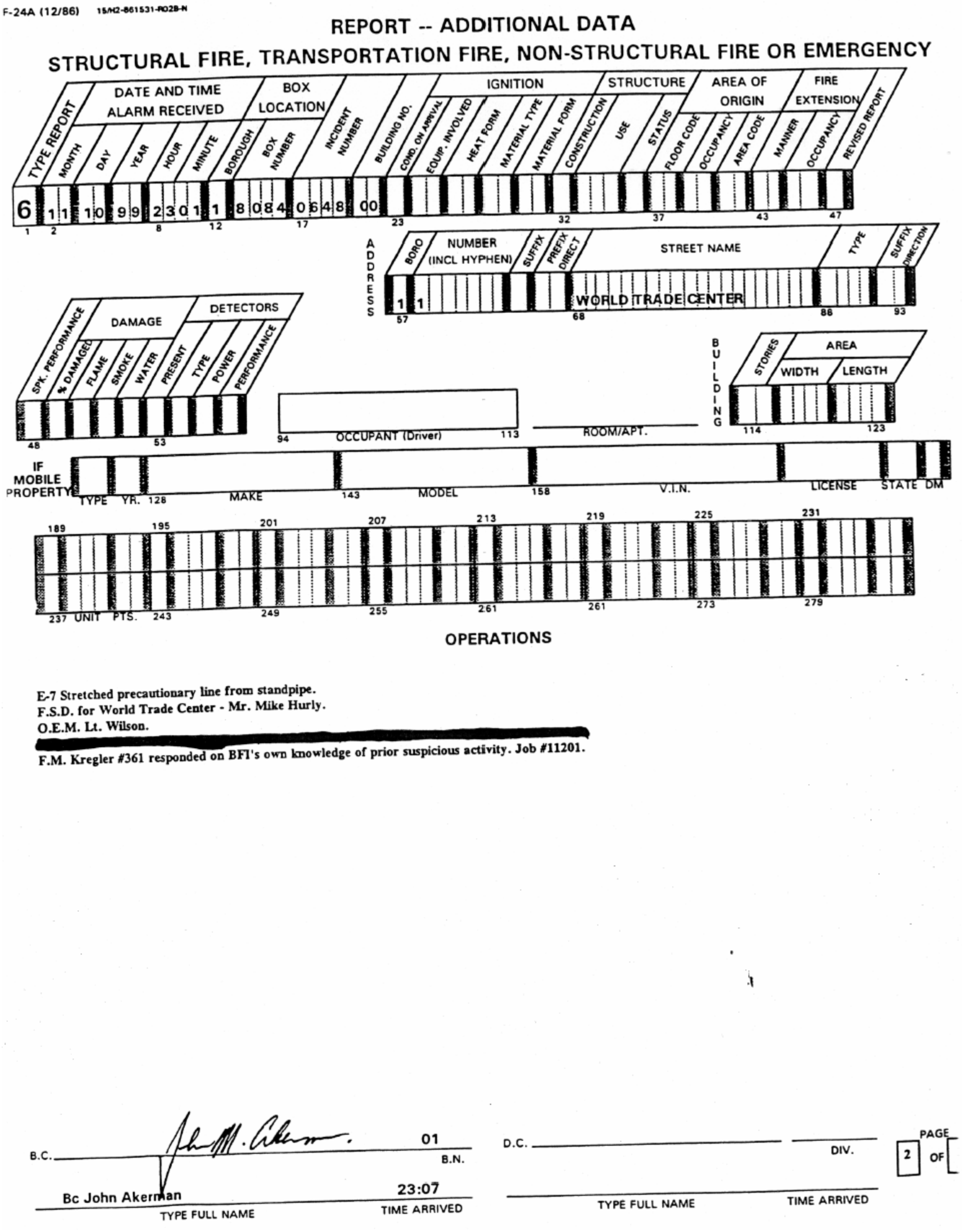
23:07 — TIME OF ARRIVAL

D.C.________ DIV.

TYPE FULL NAME — TIME OF ARRIVAL

ADMINISTRATIVE COMPANY

PAGE 1 OF 2



F-24A (12/86) 15/H2-861531-R02B-N

REPORT -- ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

	DATE AND TIME ALARM RECEIVED					BOX LOCATION					IGNITION				STRUCTURE			AREA OF ORIGIN			FIRE EXTENSION		
TYPE REPORT	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NUMBER	INCIDENT NUMBER	BUILDING NO.	COND. ON ARRIVAL	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCTION	USE	STATUS	FLOOR CODE	OCCUPANCY	AREA CODE	MANNER	OCCUPANCY	REVISED REPORT
6	11	10	99	23	01	1	8084	0648	00														

1 2 8 12 17 23 32 37 43 47

ADDRESS						
BORO	NUMBER (INCL HYPHEN)	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECTION
1 1				WORLD TRADE CENTER		

57 68 88 93

	DAMAGE				DETECTORS			
SPK. PERFORMANCE	% DAMAGED	FLAME	SMOKE	WATER	PRESENT	TYPE	POWER	PERFORMANCE

48 53

94 OCCUPANT (Driver) 113

ROOM/APT.

BUILDING	AREA	
STORIES	WIDTH	LENGTH

114 123

IF MOBILE PROPERTY								
TYPE	YR.	MAKE	MODEL	V.I.N.	LICENSE	STATE	DM

128 143 158

189 195 201 207 213 219 225 231

237 UNIT PTS. 243 249 255 261 261 273 279

OPERATIONS

E-7 Stretched precautionary line from standpipe.
F.S.D. for World Trade Center - Mr. Mike Hurly.
O.E.M. Lt. Wilson.
[redacted]
F.M. Kregler #361 responded on BFI's own knowledge of prior suspicious activity. Job #11201.

B.C. ______ 01 B.N.

Bc John Akerman 23:07
TYPE FULL NAME TIME ARRIVED

D.C. ______ ______ DIV.

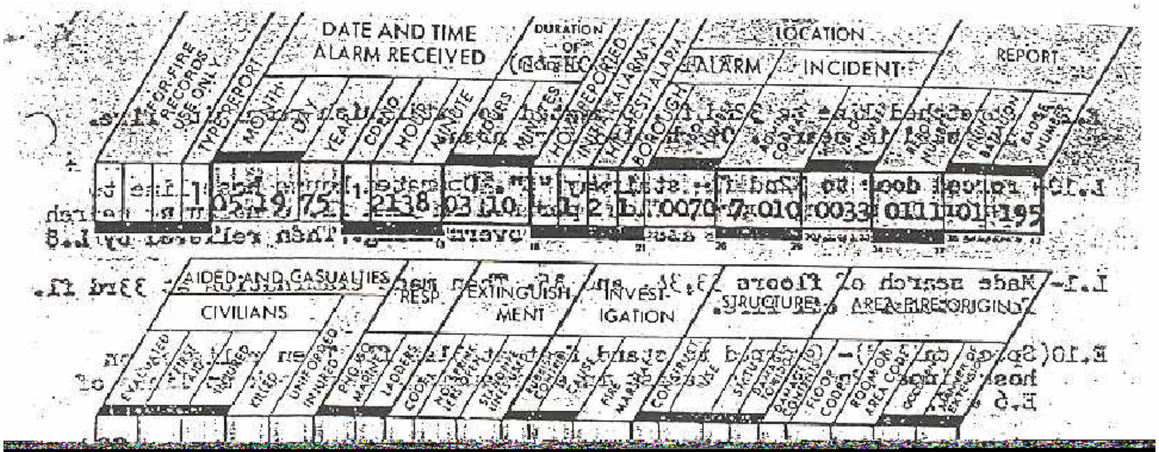
______ TYPE FULL NAME TIME ARRIVED

PAGE 2 OF

Appendix E
SIGNIFICANT FIRES IN WTC 2

Significant fire incidents occurring in WTC 2

Significant Fire	Incident Date	Fire Location	# Sprinklers Activated	# Standpipes Activated	Cause of Fire	Material Ignited
1	5/19/75	Floor 32	-	3	Incendiary	Trash/waste
2	4/12/77	Duct work over grill in restaurant on floor 107	2		None listed	Duct work
3	3/22/93	Fan motor room on floor 108	2		Mechanical failure	Not classified



FOR FIRE RECORDS USE ONLY

TYPE REPORT 1

DATE AND TIME ALARM RECEIVED

MONTH 05 | DAY 19 | YEAR 75 | CODE NO. 1 | HOUR 21 | MINUTE 38

DURATION OF (HOURS) 03 | MINUTES 10

HOW REPORTED | INITIAL ALARM 2 | HIGHEST ALARM 1

LOCATION

ALARM: BOROUGH | BOX NUMBER 0070

INCIDENT: 7 010 | 0033

REPORT: 011 | 101 | 195

AIDED AND CASUALTIES

CIVILIANS: EVACUATED | FIRST AID | INJURED | KILLED

UNIFORMED INJURED | PHYSICAL OR MARINE

RESP.: LADDERS | CODE

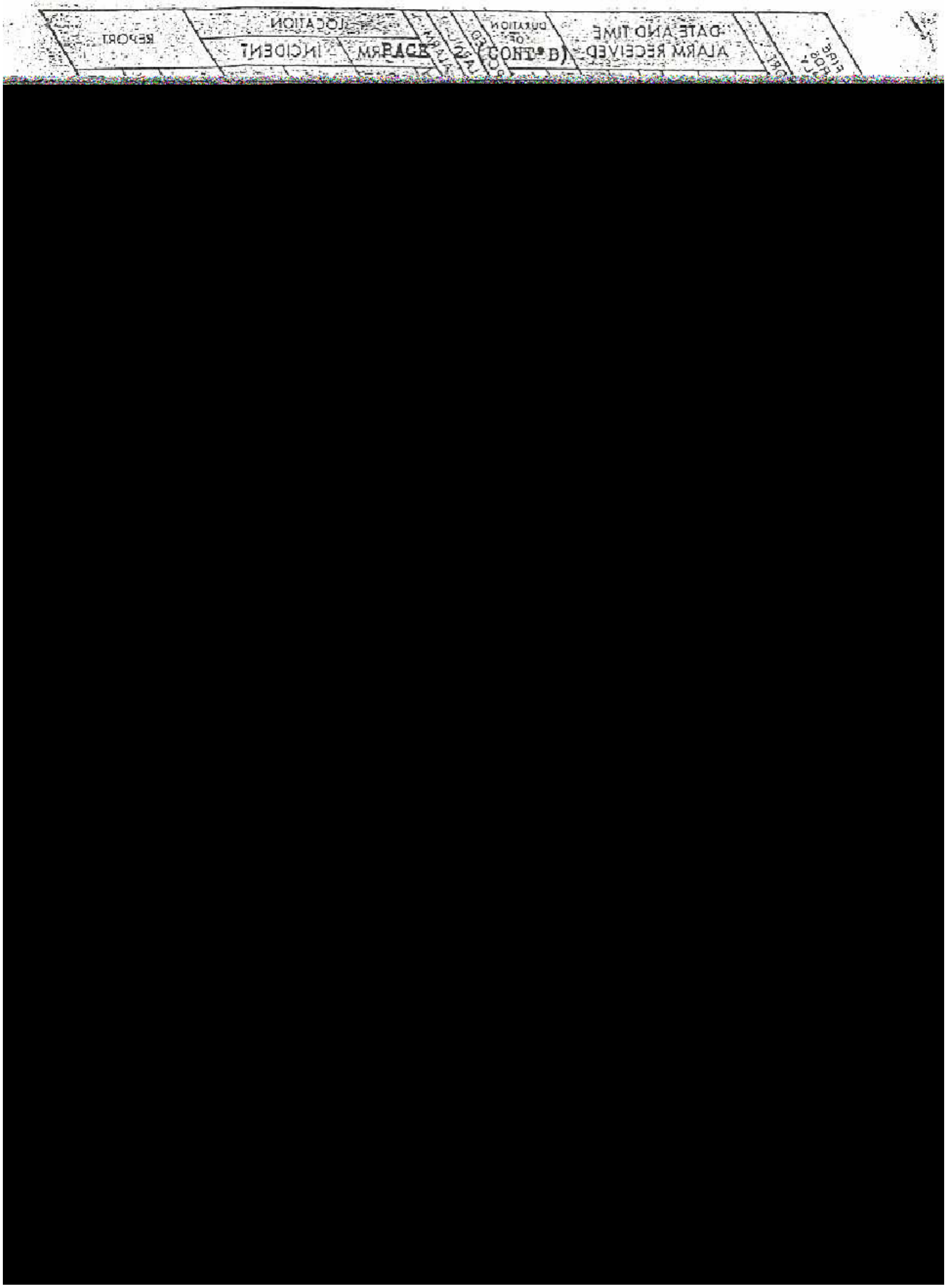
EXTINGUISHMENT: NO. SPRINKLERS OPEN | STANDPIPE UNITS USED

INVESTIGATION: RUBBISH CONTROL | CAUSE | FIRE MARSHAL

STRUCTURE: CONSTRUCT | USE | STATUS | DAMAGE (DOLLARS) | DAMAGE (CONTENTS)

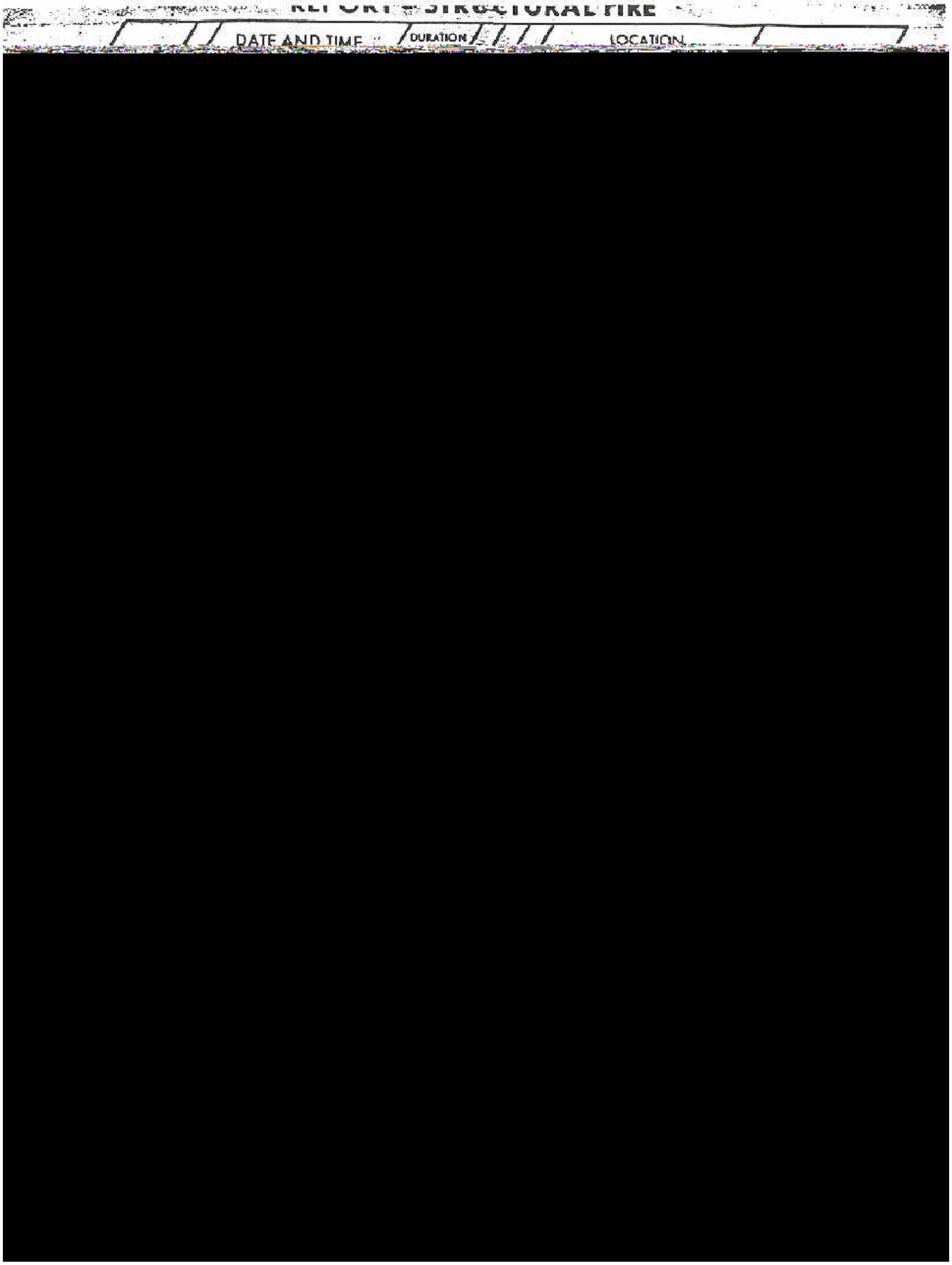
AREA FIRE ORIGIN: FLOOR CODE | ROOM OR AREA CODE | OCCUPANT | MANNER OF EXTENSION

[redacted]



PAGE 2 (CONT'D)

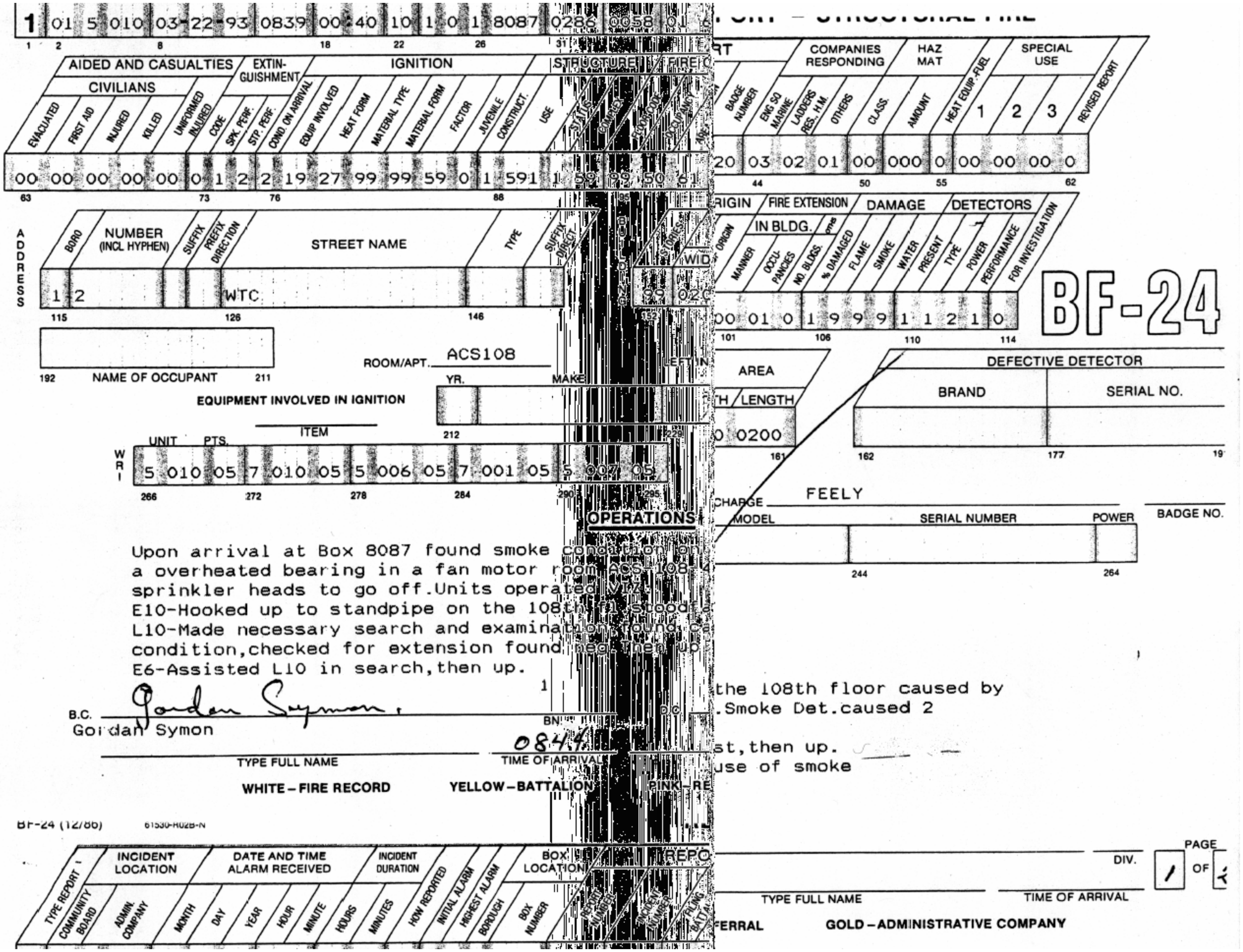
[redacted]



REPORT – STRUCTURAL FIRE

DATE AND TIME | DURATION | LOCATION

[redacted]



1 01 5 010 03-22-93 0839 00:40 10 1 0 1 8087 0286 0058 01

AIDED AND CASUALTIES — CIVILIANS: EVACUATED, FIRST AID, INJURED, KILLED; UNIFORMED INJURED

EXTINGUISHMENT: CODE, SPK. PERF., STP. PERF., COND. ON ARRIVAL

IGNITION: EQUIP. INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM, FACTOR, JUVENILE, CONSTRUCT., USE

STRUCTURE

FIRE

COMPANIES RESPONDING: BADGE NUMBER, ENG SQ MARINE, LADDERS RES. H.M., OTHERS

HAZ MAT: CLASS, AMOUNT, HEAT EQUIP.-FUEL

SPECIAL USE: 1, 2, 3

REVISED REPORT

00 00 00 00 00 0 1 2 2 19 27 99 99 59 0 1 591 1 59 99 50 61

20 03 02 01 00 000 0 00 00 00 0

ADDRESS: BORO 1; NUMBER (INCL HYPHEN) 2; SUFFIX; PREFIX DIRECTION; STREET NAME WTC; TYPE; SUFFIX DIRECT.

ORIGIN: MANNER, ORIGIN

FIRE EXTENSION — IN BLDG.: OCCUPANCIES, NO. BLDGS.

DAMAGE: % DAMAGED, FLAME, SMOKE, WATER

DETECTORS: PRESENT, TYPE, POWER, PERFORMANCE, FOR INVESTIGATION

00 01 0 1 9 9 9 1 1 2 1 0

BF-24

NAME OF OCCUPANT

ROOM/APT. ACS108

AREA — LENGTH: 0200

DEFECTIVE DETECTOR: BRAND, SERIAL NO.

EQUIPMENT INVOLVED IN IGNITION: ITEM, YR., MAKE, MODEL, SERIAL NUMBER, POWER

CHARGE FEELY

BADGE NO.

WRI — UNIT, PTS.: 5 010 05 7 010 05 5 006 05 7 001 05 5 007 05

OPERATIONS

Upon arrival at Box 8087 found smoke condition on [illegible] the 108th floor caused by

a overheated bearing in a fan motor room ACS 108 [illegible] .Smoke Det.caused 2

sprinkler heads to go off.Units operated viz. [illegible]

E10-Hooked up to standpipe on the 108th fl stood [illegible] st,then up.

L10-Made necessary search and examination found [illegible] use of smoke

condition,checked for extension found neg.then up [illegible]

E6-Assisted L10 in search,then up.

B.C. Gordan Symon

Gordan Symon

TYPE FULL NAME

BN.

TIME OF ARRIVAL 0844

TYPE FULL NAME

TIME OF ARRIVAL

DIV.

PAGE 1 OF

WHITE – FIRE RECORD

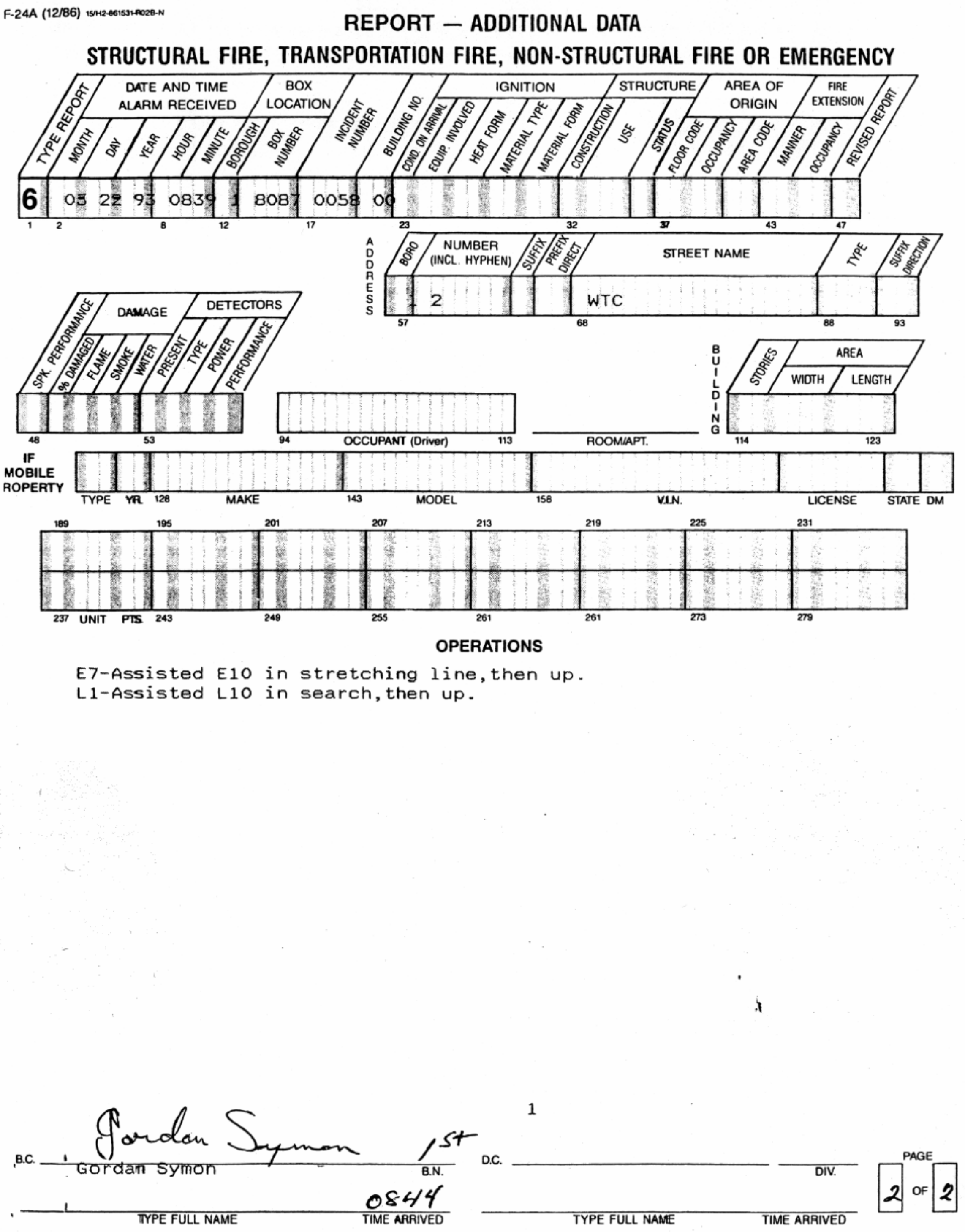
YELLOW – BATTALION

PINK – RE

GOLD – ADMINISTRATIVE COMPANY

BF-24 (12/86) 61530-H02B-N

TYPE REPORT; COMMUNITY BOARD; INCIDENT LOCATION: ADMIN. COMPANY; DATE AND TIME ALARM RECEIVED: MONTH, DAY, YEAR, HOUR, MINUTE; INCIDENT DURATION: HOURS, MINUTES; HOW REPORTED; INITIAL ALARM; HIGHEST ALARM; BOX LOCATION: BOROUGH, BOX NUMBER; REPORT NUMBER; INCIDENT NUMBER; FILING DATA



F-24A (12/86) 15/H2-861531-R02B-N

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NUMBER	INCIDENT NUMBER	BUILDING NO.
6	03	22	93	08	39	1	8087	0058	00

DATE AND TIME ALARM RECEIVED · BOX LOCATION · IGNITION: COND. ON ARRIVAL, EQUIP. INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM · STRUCTURE: CONSTRUCTION, USE, STATUS · AREA OF ORIGIN: FLOOR CODE, OCCUPANCY, AREA CODE · FIRE EXTENSION: MANNER, OCCUPANCY · REVISED REPORT

1 2 8 12 17 23 32 37 43 47

ADDRESS

BORO	NUMBER (INCL. HYPHEN)	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECTION
1	2			WTC		

57 68 88 93

SPK. PERFORMANCE · DAMAGE: % DAMAGED, FLAME, SMOKE, WATER · DETECTORS: PRESENT, TYPE, POWER, PERFORMANCE

48 53 94 OCCUPANT (Driver) 113 ROOM/APT.

BUILDING: STORIES · AREA: WIDTH, LENGTH

114 123

IF MOBILE ROPERTY: TYPE YR. 128 MAKE 143 MODEL 158 V.I.N. LICENSE STATE DM

189 195 201 207 213 219 225 231

237 UNIT PTS. 243 249 255 261 261 273 279

OPERATIONS

E7-Assisted E10 in stretching line,then up.
L1-Assisted L10 in search,then up.

1

B.C. Gordon Symon 1st
Gordan Symon

TYPE FULL NAME

B.N.

0844

TIME ARRIVED

D.C. ____ DIV. ____

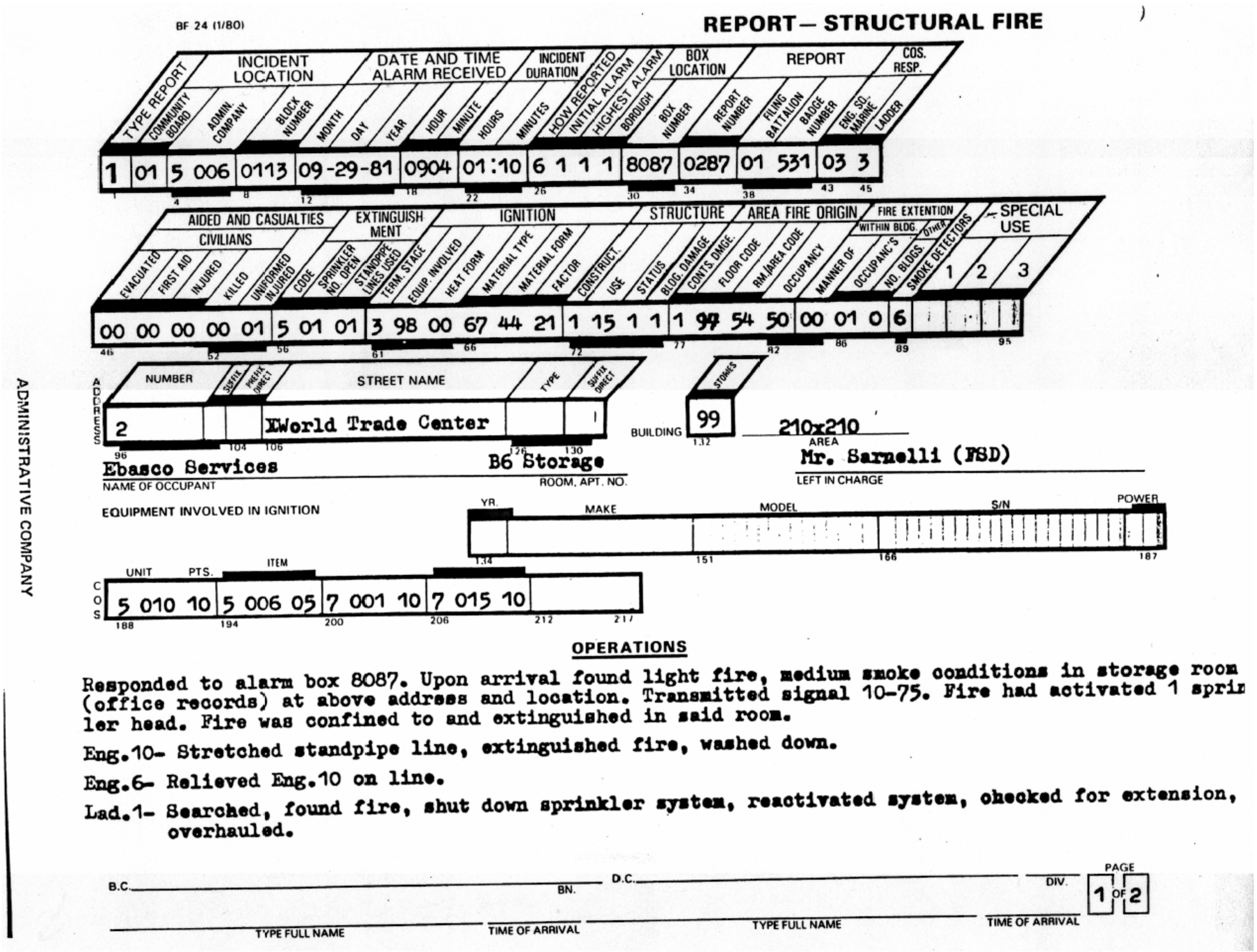
TYPE FULL NAME ____ TIME ARRIVED ____

PAGE 2 OF 2

Appendix F
FIRES WITH STANDPIPES AND SPRINKLERS IN WTC 1 AND WTC 2

Additional fire incidents involving the deployment of standpipe lines in WTC 1 and WTC 2:

- Fires involving the use of one standpipe line and the activation of one sprinkler (4 in total)



BF 24 (1/80)

REPORT — STRUCTURAL FIRE

TYPE REPORT	INCIDENT LOCATION: COMMUNITY BOARD	ADMIN. COMPANY	BLOCK NUMBER	DATE AND TIME ALARM RECEIVED: MONTH / DAY / YEAR	HOUR / MINUTE	INCIDENT DURATION: HOURS / MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOX LOCATION: BOROUGH	BOX NUMBER	REPORT NUMBER	REPORT: FILING BATTALION	BADGE NUMBER	COS. RESP.: ENG. SQ. MARINE	LADDER
1	01	5 006	0113	09-29-81	0904	01:10	6	1	1	1	8087	0287	01	531	03	3

1 4 8 12 18 22 26 30 34 38 43 45

AIDED AND CASUALTIES, CIVILIANS: EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	EXTINGUISHMENT: CODE	SPRINKLER NO. OPEN	STANDPIPE LINES USED	TERM. STAGE	IGNITION: EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	FACTOR	STRUCTURE: CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	AREA FIRE ORIGIN: FLOOR CODE	RM./AREA CODE	OCCUPANCY	FIRE EXTENTION WITHIN BLDG.: MANNER OF	OCCUPANC'S	OTHER: NO. BLDGS.	SMOKE DETECTORS	SPECIAL USE: 1	2	3
00	00	00	00	01	5	01	01	3	98	00	67	44	21	1	15	1	1	1	97	54	50	00	01	0	6			

46 52 56 61 66 72 77 82 86 89 95

ADDRESS: NUMBER	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECT
2			World Trade Center		1

96 104 106 126 130

BUILDING: STORIES 99 (132)

210x210
AREA

Ebasco Services
NAME OF OCCUPANT

B6 Storage
ROOM, APT. NO.

Mr. Sarnelli (FSD)
LEFT IN CHARGE

EQUIPMENT INVOLVED IN IGNITION

YR.	MAKE	MODEL	S/N	POWER

134 151 166 187

COS: UNIT	PTS.	ITEM			
5 010 10	5 006 05	7 001 10	7 015 10		

188 194 200 206 212 217

OPERATIONS

Responded to alarm box 8087. Upon arrival found light fire, medium smoke conditions in storage room (office records) at above address and location. Transmitted signal 10-75. Fire had activated 1 sprin ler head. Fire was confined to and extinguished in said room.

Eng.10- Stretched standpipe line, extinguished fire, washed down.

Eng.6- Relieved Eng.10 on line.

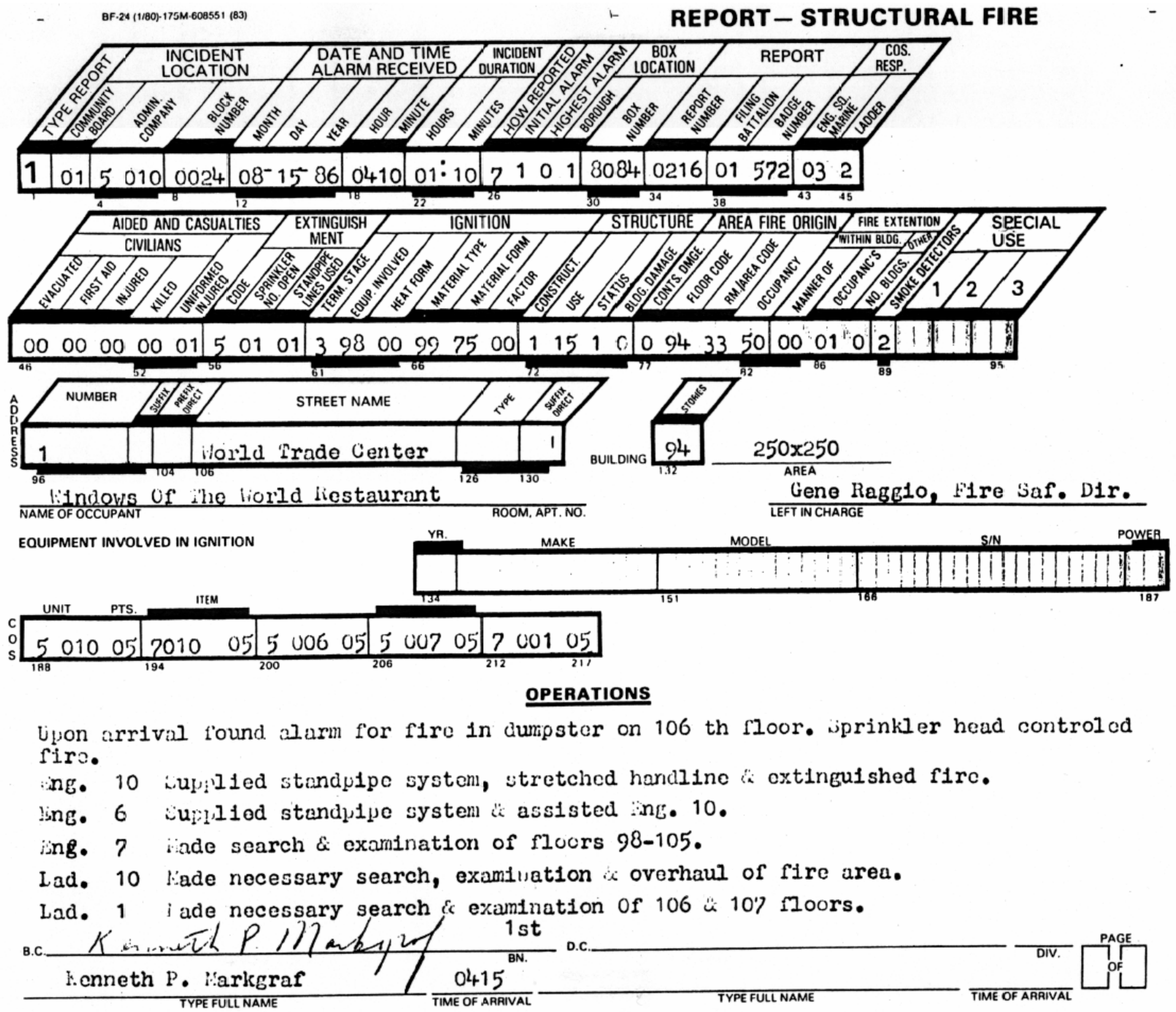
Lad.1- Searched, found fire, shut down sprinkler system, reactivated system, checked for extension, overhauled.

B.C. ____________ BN. ____________ D.C. ____________ DIV. ____

TYPE FULL NAME ____ TIME OF ARRIVAL ____ TYPE FULL NAME ____ TIME OF ARRIVAL ____

PAGE 1 OF 2

ADMINISTRATIVE COMPANY



BF-24 (1/80)-175M-608551 (83)

REPORT — STRUCTURAL FIRE

TYPE REPORT	INCIDENT LOCATION: COMMUNITY BOARD	INCIDENT LOCATION: ADMIN. COMPANY	INCIDENT LOCATION: BLOCK NUMBER	DATE AND TIME ALARM RECEIVED: MONTH / DAY / YEAR	DATE AND TIME ALARM RECEIVED: HOUR / MINUTE	INCIDENT DURATION: HOURS / MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOX LOCATION: BOROUGH	BOX LOCATION: BOX NUMBER	REPORT: REPORT NUMBER	REPORT: FILING BATTALION / BADGE NUMBER	COS. RESP.: ENG. SQ. MARINE / LADDER
1	01	5 010	0024	08-15-86	0410	01:10	7	1	0	1	8084	0216	01 572	03 2

AIDED AND CASUALTIES, CIVILIANS: EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	EXTINGUISHMENT: CODE	SPRINKLER NO. OPEN	STANDPIPE LINES USED	IGNITION: TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	FACTOR
00	00	00	00	01	5	01	01	3	98	00	99	75	00

STRUCTURE: CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	AREA FIRE ORIGIN: FLOOR CODE	RM./AREA CODE	OCCUPANCY	FIRE EXTENTION WITHIN BLDG.: MANNER OF	OCCUPANC'S	OTHER: NO. BLDGS.	SMOKE DETECTORS	SPECIAL USE 1	2	3
1	15	1	0	0	94	33	50	00	01	0	2			

ADDRESS: NUMBER	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECT
1			World Trade Center		1

BUILDING: STORIES 94

AREA: 250x250

NAME OF OCCUPANT: Windows Of The World Restaurant

ROOM, APT. NO.:

LEFT IN CHARGE: Gene Raggio, Fire Saf. Dir.

EQUIPMENT INVOLVED IN IGNITION

YR.	MAKE	MODEL	S/N	POWER

COS	UNIT	PTS.
	5 010	05
	7010	05
	5 006	05
	5 007	05
	7 001	05

OPERATIONS

Upon arrival found alarm for fire in dumpster on 106 th floor. Sprinkler head controled fire.

Eng. 10 Supplied standpipe system, stretched handline & extinguished fire.

Eng. 6 Supplied standpipe system & assisted Eng. 10.

Eng. 7 Made search & examination of floors 98-105.

Lad. 10 Made necessary search, examination & overhaul of fire area.

Lad. 1 Made necessary search & examination Of 106 & 107 floors.

B.C. Kenneth P. Markgraf BN. 1st D.C. ______ DIV. ______ PAGE ☐ OF ☐

Kenneth P. Markgraf — TYPE FULL NAME

0415 — TIME OF ARRIVAL

TYPE FULL NAME ______ TIME OF ARRIVAL ______

F-24

SERIAL NO.

BADGE NO.

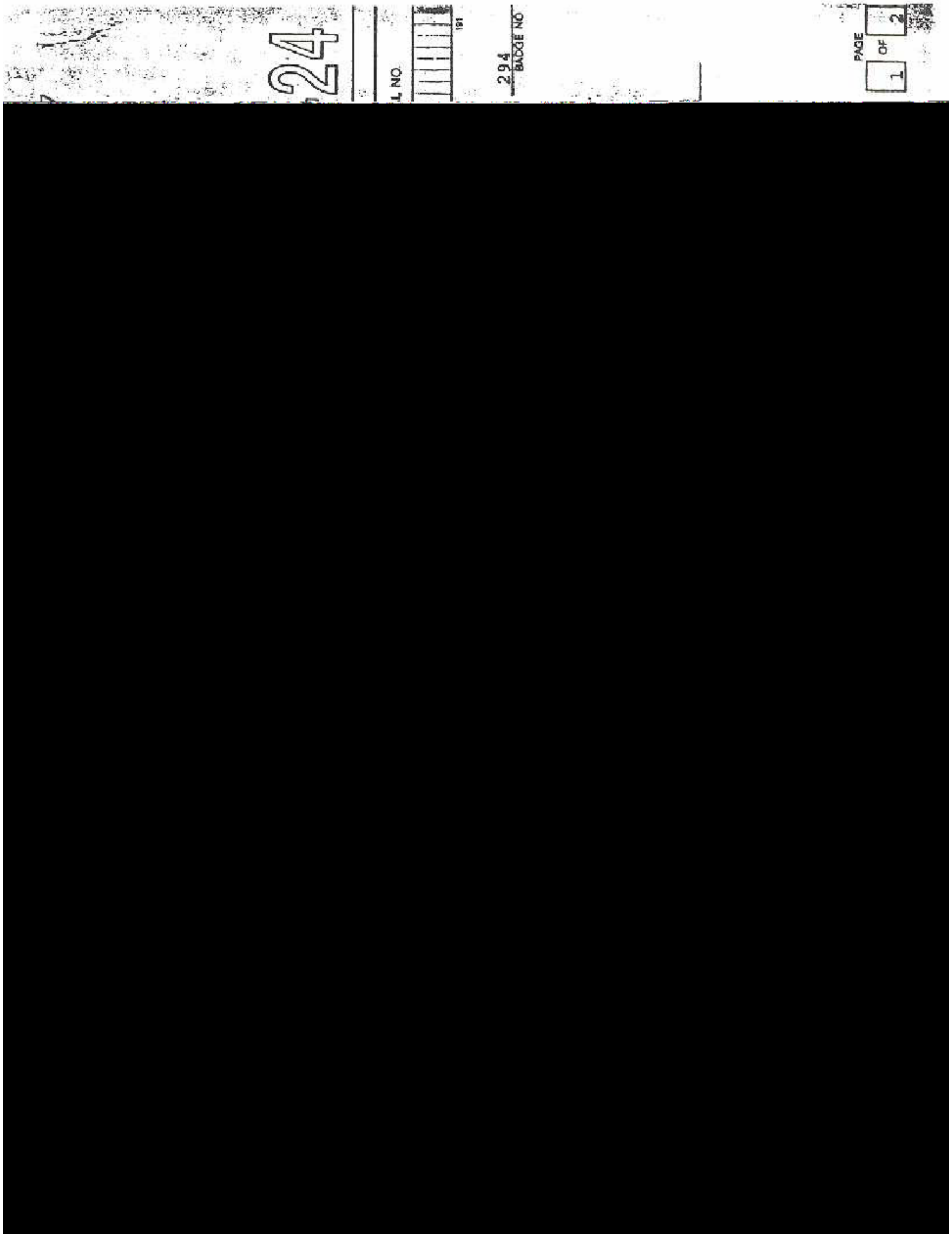
POWER

PAGE ☐ OF ☐

DIV.

ARRIVAL

[redacted]



24

L NO

191

294
BADGE NO

PAGE 1 OF 2

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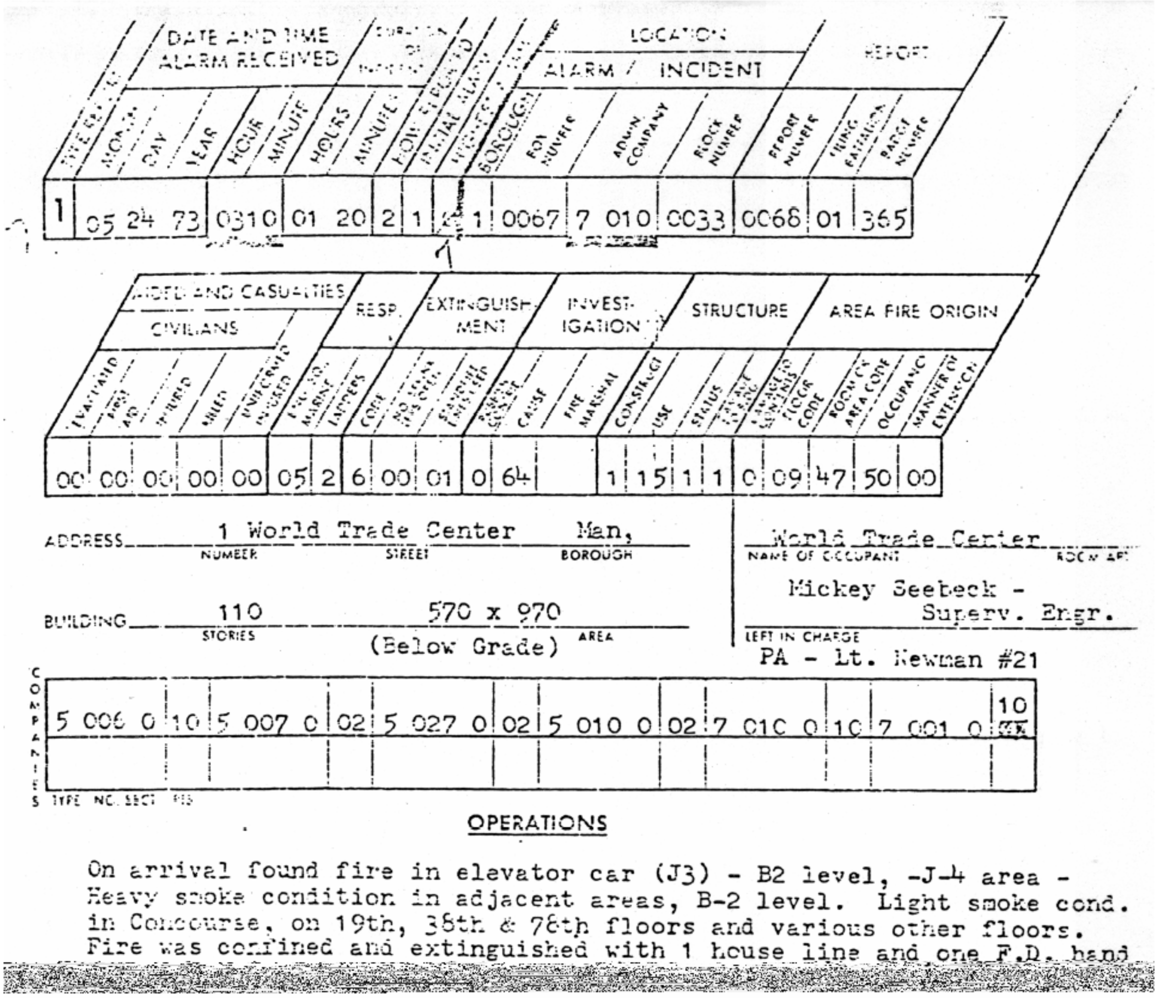
Appendix G
FIRES WITH STANDPIPES IN WTC 1 AND WTC 2

Additional fire incidents involving the deployment of standpipe lines in WTC 1 and WTC 2:

- Fires involving the use of one standpipe line (27 in total)



	DATE AND TIME ALARM RECEIVED					DURATION OF INCIDENT					LOCATION ALARM / INCIDENT				REPORT		
TYPE [illegible]	MONTH	DAY	YEAR	HOUR	MINUTE	HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	[illegible]	BOROUGH	BOX NUMBER	ADMIN. COMPANY	BLOCK NUMBER	REPORT NUMBER	FIRING BATTALION	BADGE NUMBER
1	05	24	73	03	10	01	20	2	1	4	1	0067	7 010	0033	0068	01	365

AIDED AND CASUALTIES							RESP.	EXTINGUISHMENT		INVESTIGATION			STRUCTURE				AREA FIRE ORIGIN				
CIVILIANS																					
EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	[illegible]	LADDERS	CODE	[illegible]	[illegible]	[illegible]	CAUSE	FIRE MARSHAL	CONSTRUCT.	USE	STATUS	[illegible]	DAMAGE TO CONTENTS	FLOOR CODE	ROOM OR AREA CODE	OCCUPANCY	MANNER OF EXTENSION
00	00	00	00	00	05	2	6	00	01	0	64		1	15	1	1	0	09	47	50	00

ADDRESS 1 World Trade Center Man,
NUMBER STREET BOROUGH

World Trade Center
NAME OF OCCUPANT ROOM APT.

BUILDING 110 570 x 970 (Below Grade)
STORIES AREA

Mickey Seebeck - Superv. Engr.
LEFT IN CHARGE
PA - Lt. Newman #21

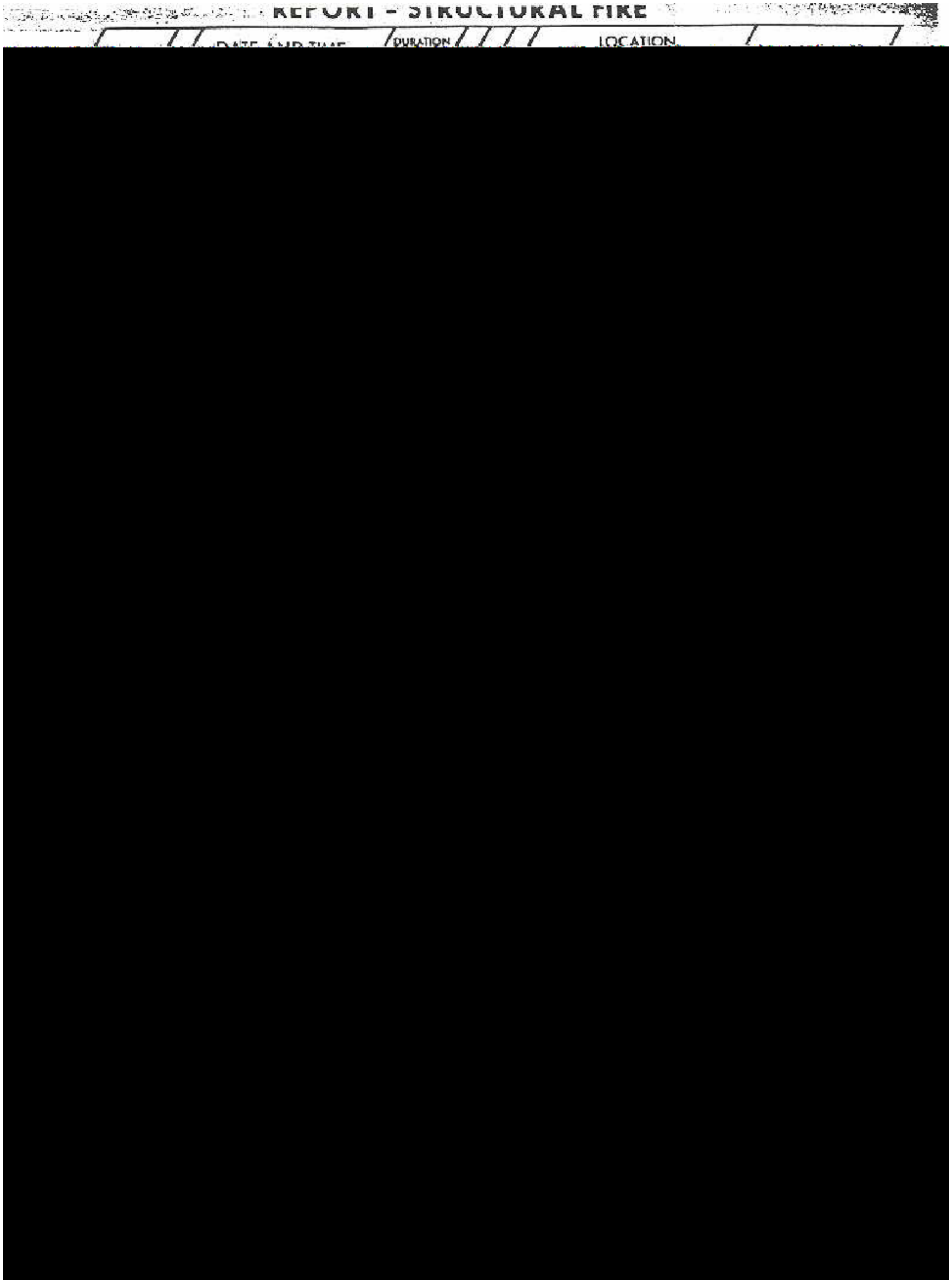
COMPANIES

5 006 0	10	5 007 0	02	5 027 0	02	5 010 0	02	7 010 0	10	7 001 0	10

TYPE NO. SECT. FIS

OPERATIONS

On arrival found fire in elevator car (J3) - B2 level, -J-4 area - Heavy smoke condition in adjacent areas, B-2 level. Light smoke cond. in Concourse, on 19th, 38th & 78th floors and various other floors. Fire was confined and extinguished with 1 house line and one F.D. hand



REPORT – STRUCTURAL FIRE

DATE AND TIME

DURATION

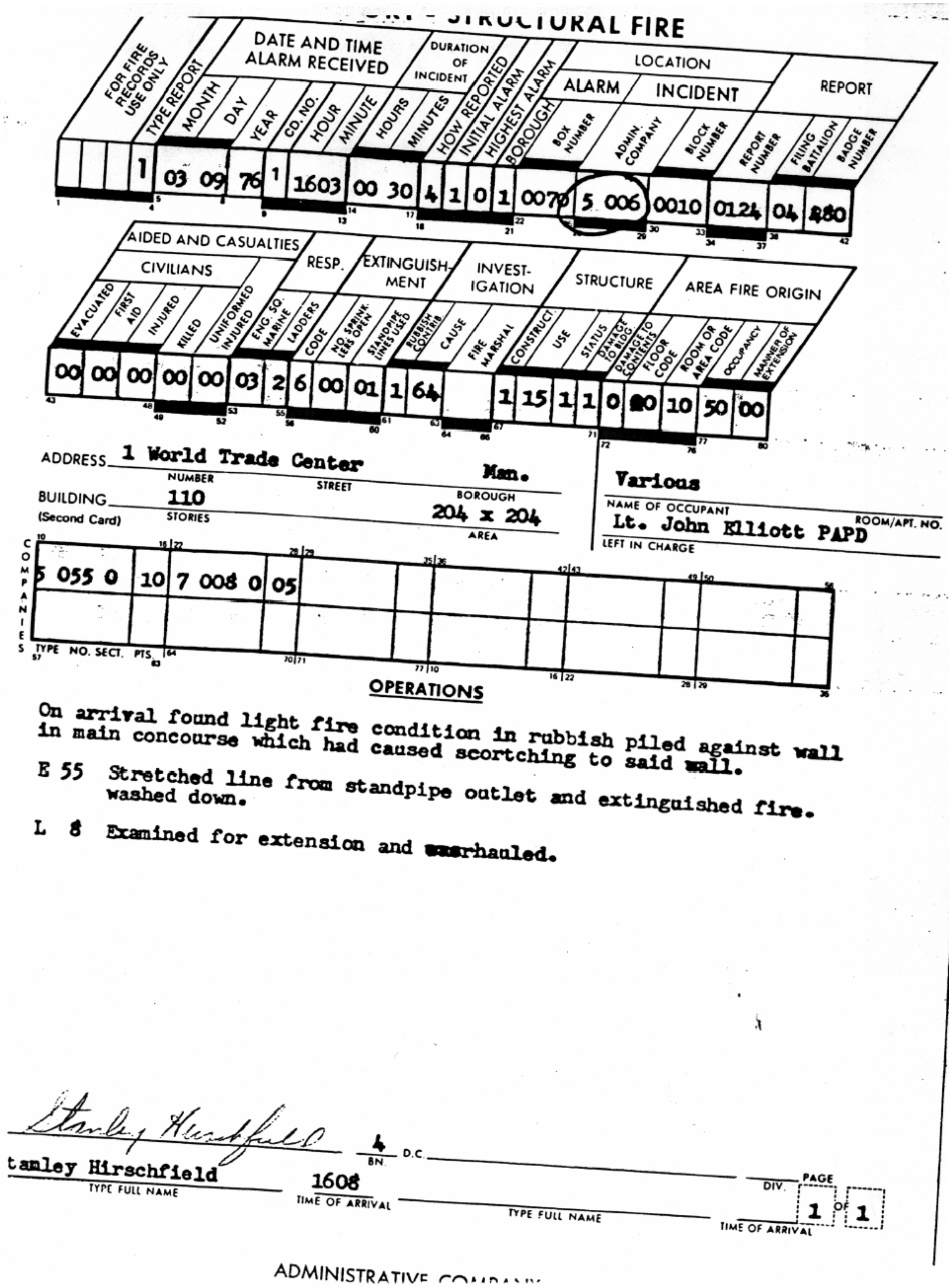
LOCATION

[redacted]

(6/72)

REPORT - STRUCTURAL FIRE

DATE AND TIME	DURATION OF	LOCATION	REPORT



STRUCTURAL FIRE

FOR FIRE RECORDS USE ONLY			TYPE REPORT	MONTH	DAY	YEAR	CD. NO.	HOUR MINUTE	HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	BOX NUMBER	ADMIN. COMPANY	BLOCK NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER
				DATE AND TIME ALARM RECEIVED					DURATION OF INCIDENT						LOCATION ALARM	LOCATION INCIDENT		REPORT		
			1	03	09	76	1	1603	00	30	4	1	0	1	0070	5 006	0010	0124	04	880

AIDED AND CASUALTIES CIVILIANS						RESP.		EXTINGUISHMENT				INVESTIGATION		STRUCTURE					AREA FIRE ORIGIN			
EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	ENG. SQ. MARINE	LADDERS	CODE	NO SPRINKLERS OPEN	STANDPIPE LINES USED	RUBBISH CONTRIB.	CAUSE	FIRE MARSHAL	CONSTRUCT.	USE	STATUS	DAMAGE TO BLDG.	DAMAGE TO CONTENTS	FLOOR CODE	ROOM OR AREA CODE	OCCUPANCY	MANNER OF EXTENSION
00	00	00	00	00	03	2	6	00	01	1	64		1	15	1	1	0	80	10	50	00

ADDRESS 1 World Trade Center (NUMBER, STREET) Man. (BOROUGH)

BUILDING (Second Card) 110 (STORIES) 204 x 204 (AREA)

Various
NAME OF OCCUPANT

Lt. John Elliott PAPD
LEFT IN CHARGE

ROOM/APT. NO.

COMPANIES

TYPE NO. SECT.	PTS.							
5 055 0	10	7 008 0	05					

OPERATIONS

On arrival found light fire condition in rubbish piled against wall in main concourse which had caused scortching to said wall.

E 55 Stretched line from standpipe outlet and extinguished fire. washed down.

L 8 Examined for extension and overhauled.

Stanley Hirschfield

tanley Hirschfield
TYPE FULL NAME

4
BN.

D.C.

1608
TIME OF ARRIVAL

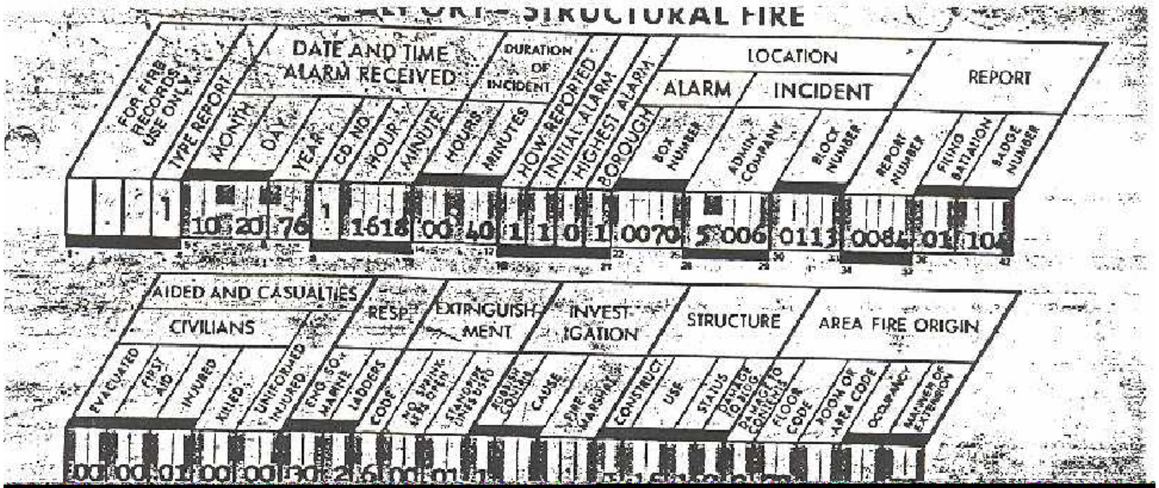
TYPE FULL NAME

DIV.

TIME OF ARRIVAL

PAGE 1 OF 1

ADMINISTRATIVE

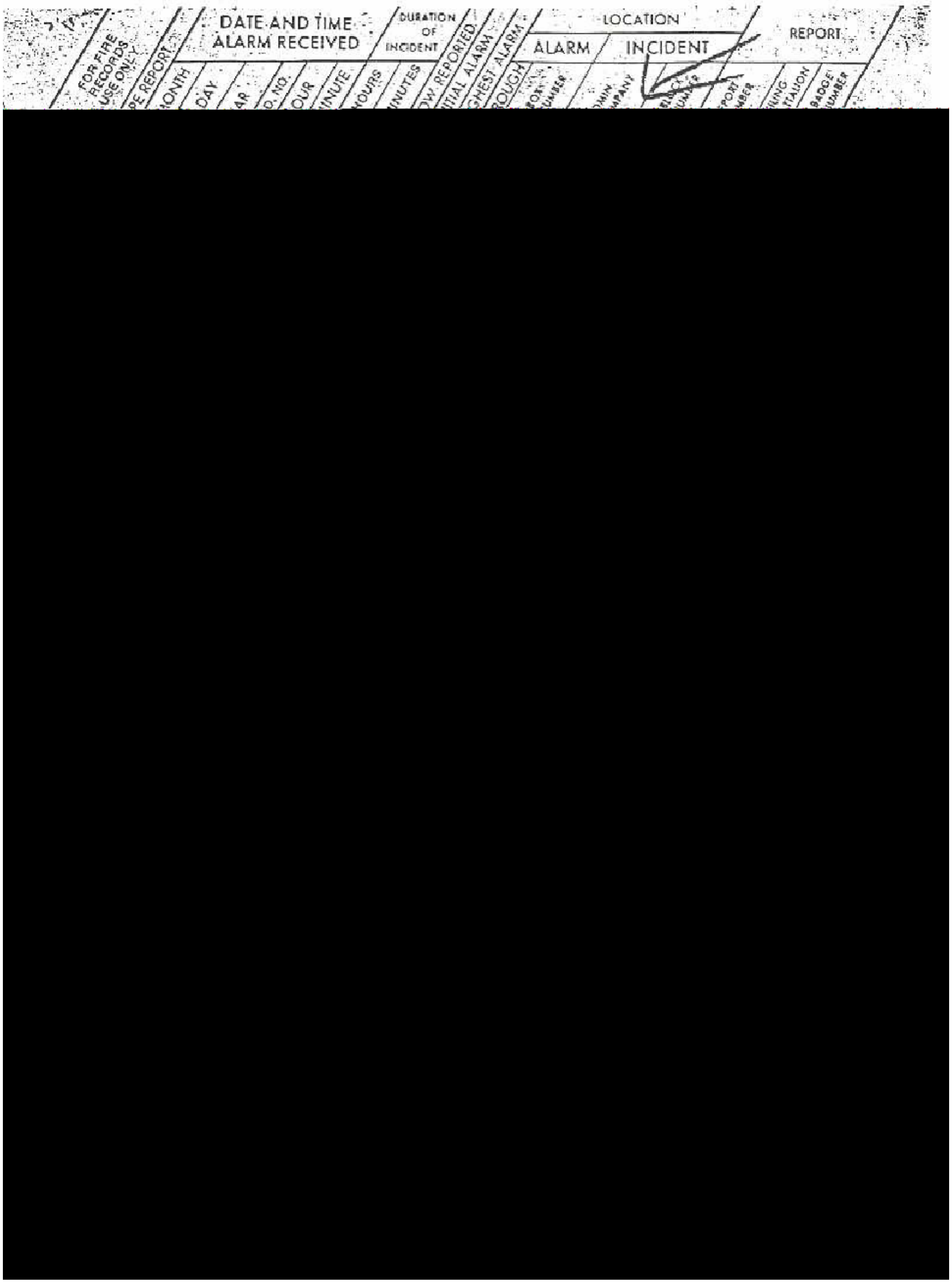


STRUCTURAL FIRE

FOR FIRE RECORDS USE ONLY	TYPE REPORT	DATE AND TIME ALARM RECEIVED: MONTH	DAY	YEAR	CD. NO.	HOUR	MINUTE	DURATION OF INCIDENT: HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	LOCATION: ALARM: BOX NUMBER	INCIDENT: ADMIN. COMPANY	BLOCK NUMBER	REPORT: REPORT NUMBER	FIRING BATTALION	BADGE NUMBER
	1	10	20	76	1	16	18	00	40	1	1	0	1	0070	5 006	0113	0084	01	104

AIDED AND CASUALTIES: CIVILIANS: EVACUATED, FIRST AID, INJURED, KILLED; UNIFORMED INJURED; RESP.: ENG. SQ. MARINE, LADDERS; EXTINGUISHMENT: CODE, NO. SPRINK. HDS OPEN, STANDPIPE LINES USED, RUBBISH CONTAINER; INVESTIGATION: CAUSE, FIRE MARSHAL; STRUCTURE: CONSTRUCT., USE, STATUS, DAMAGE TO BLDG, DAMAGE TO CONTENTS; AREA FIRE ORIGIN: FLOOR CODE, ROOM OR AREA CODE, OCCUPANCY, MANNER OF EXTENSION

[redacted]



FOR FIRE RECORDS USE ONLY

PE REPORT

ONTH

DAY

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O. NO.

OUR

INUTE

DATE AND TIME ALARM RECEIVED

HOURS

INUTES

DURATION OF INCIDENT

OW REPORTED

ITIAL ALARM

GHEST ALARM

OUGH

LOCATION

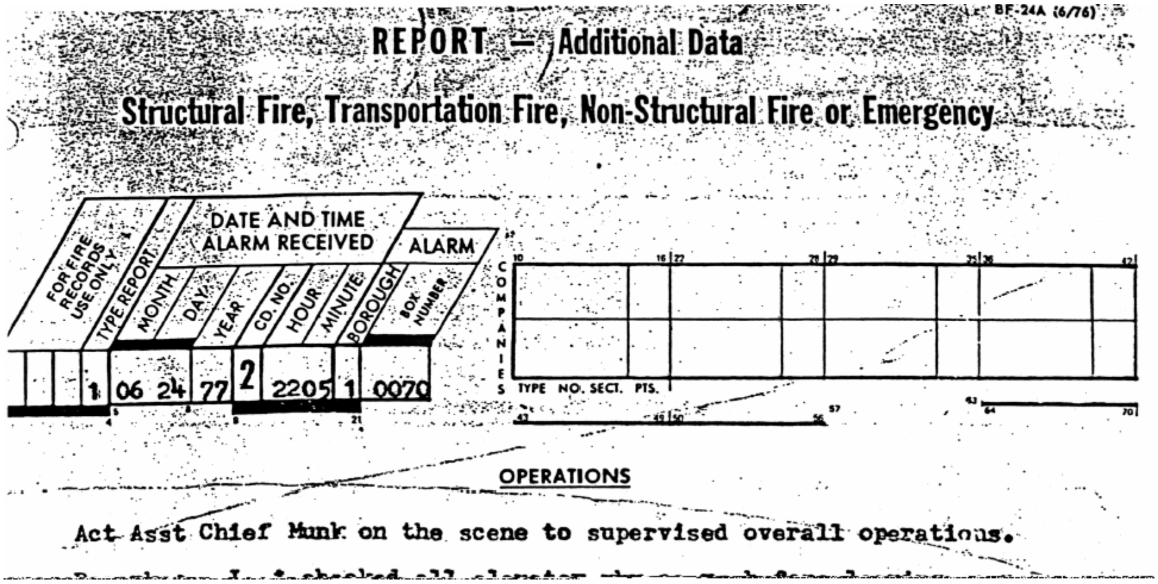
ALARM

INCIDENT

REPORT

[redacted]

BF-24A (6/76)



BF-24A (6/76)

REPORT — Additional Data

Structural Fire, Transportation Fire, Non-Structural Fire or Emergency

FOR FIRE RECORDS USE ONLY	TYPE REPORT	MONTH	DAY	YEAR	CD. NO.	HOUR	MINUTE	BOROUGH	BOX NUMBER
	1	06	24	77	2	22	05	1	0070

DATE AND TIME ALARM RECEIVED

ALARM

COMPANIES

TYPE NO. SECT. PTS.

OPERATIONS

Act Asst Chief Munk on the scene to supervised overall operations.

BF-24 (6/73)-50M-121973(75)

REPORT

DATE AND TIME ALARM RECEIVED

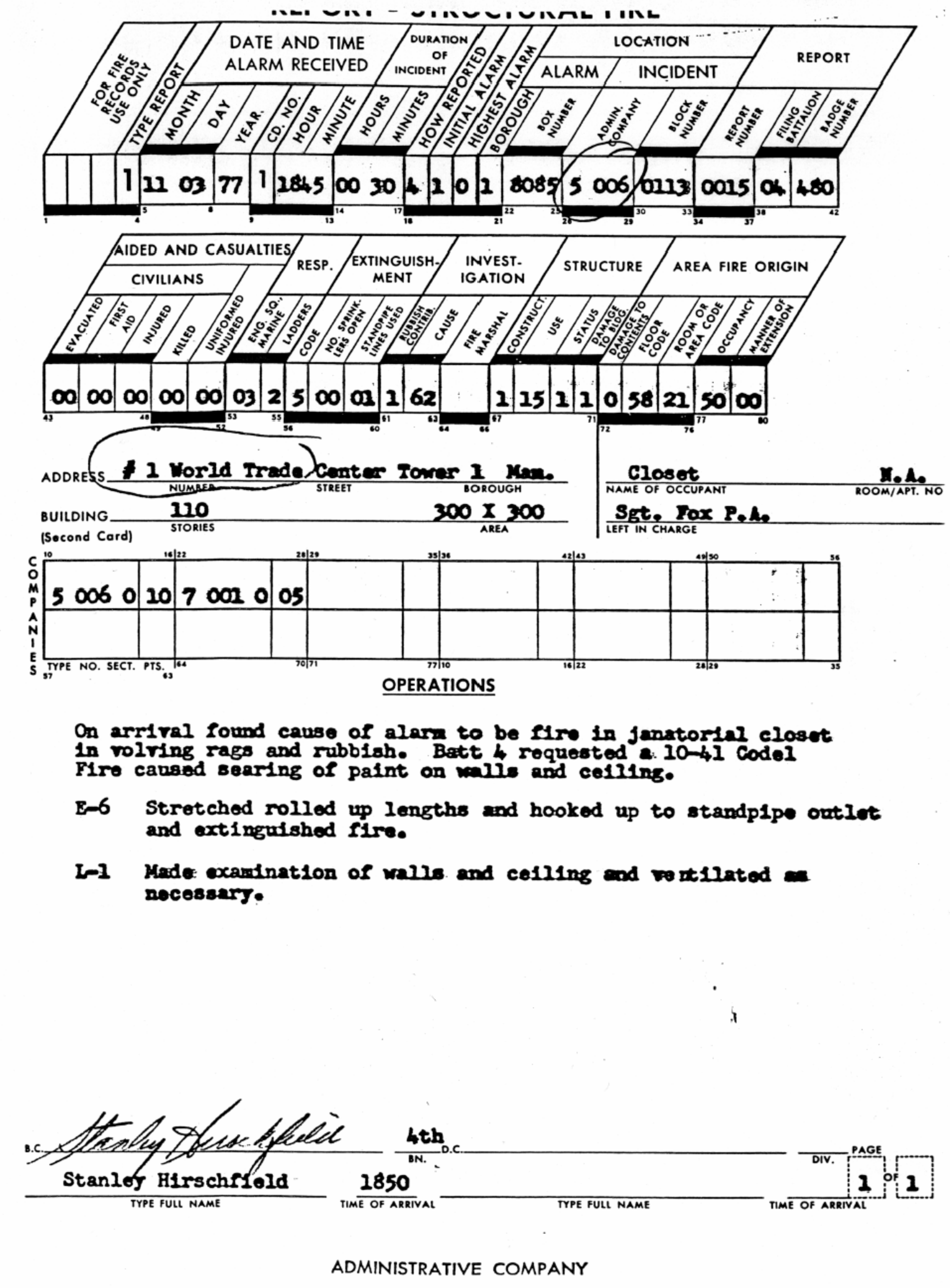
DURATION OF INCIDENT

ALARM

BOX NUMBER

ADMIN. COMPANY

[redacted]



REPORT - STRUCTURAL FIRE

FOR FIRE RECORDS USE ONLY			TYPE REPORT	DATE AND TIME ALARM RECEIVED						DURATION OF INCIDENT		HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	LOCATION ALARM	LOCATION INCIDENT		REPORT		
				MONTH	DAY	YEAR	CD. NO.	HOUR	MINUTE	HOURS	MINUTES					BOX NUMBER	ADMIN. COMPANY	BLOCK NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER
			1	11	03	77	1	18	45	00	30	4	1	0	1	8085	5 006	0113	0015	04	480

AIDED AND CASUALTIES CIVILIANS					RESP.		EXTINGUISHMENT				INVESTIGATION		STRUCTURE					AREA FIRE ORIGIN			
EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	ENG. SQ., MARINE	LADDERS	CODE	NO. SPRINKLERS OPEN	STANDPIPE LINES USED	RUBBISH CONTRIB.	CAUSE	FIRE MARSHAL	CONSTRUCT.	USE	STATUS	DAMAGE TO BLDG.	DAMAGE TO CONTENTS	FLOOR CODE	ROOM OR AREA CODE	OCCUPANCY	MANNER OF EXTENSION
00	00	00	00	00	03	2	5	00	01	1	62		1	15	1	1	0	58	21	50	00

ADDRESS # 1 World Trade Center Tower 1 Man.
NUMBER STREET BOROUGH

Closet N.A.
NAME OF OCCUPANT ROOM/APT. NO

BUILDING 110 300 X 300
STORIES AREA
(Second Card)

Sgt. Fox P.A.
LEFT IN CHARGE

COMPANIES

TYPE NO. SECT. PTS.							
5 006 0 10	7 001 0 05						

OPERATIONS

On arrival found cause of alarm to be fire in janatorial closet in volving rags and rubbish. Batt 4 requested a 10-41 Code1 Fire caused searing of paint on walls and ceiling.

E-6 Stretched rolled up lengths and hooked up to standpipe outlet and extinguished fire.

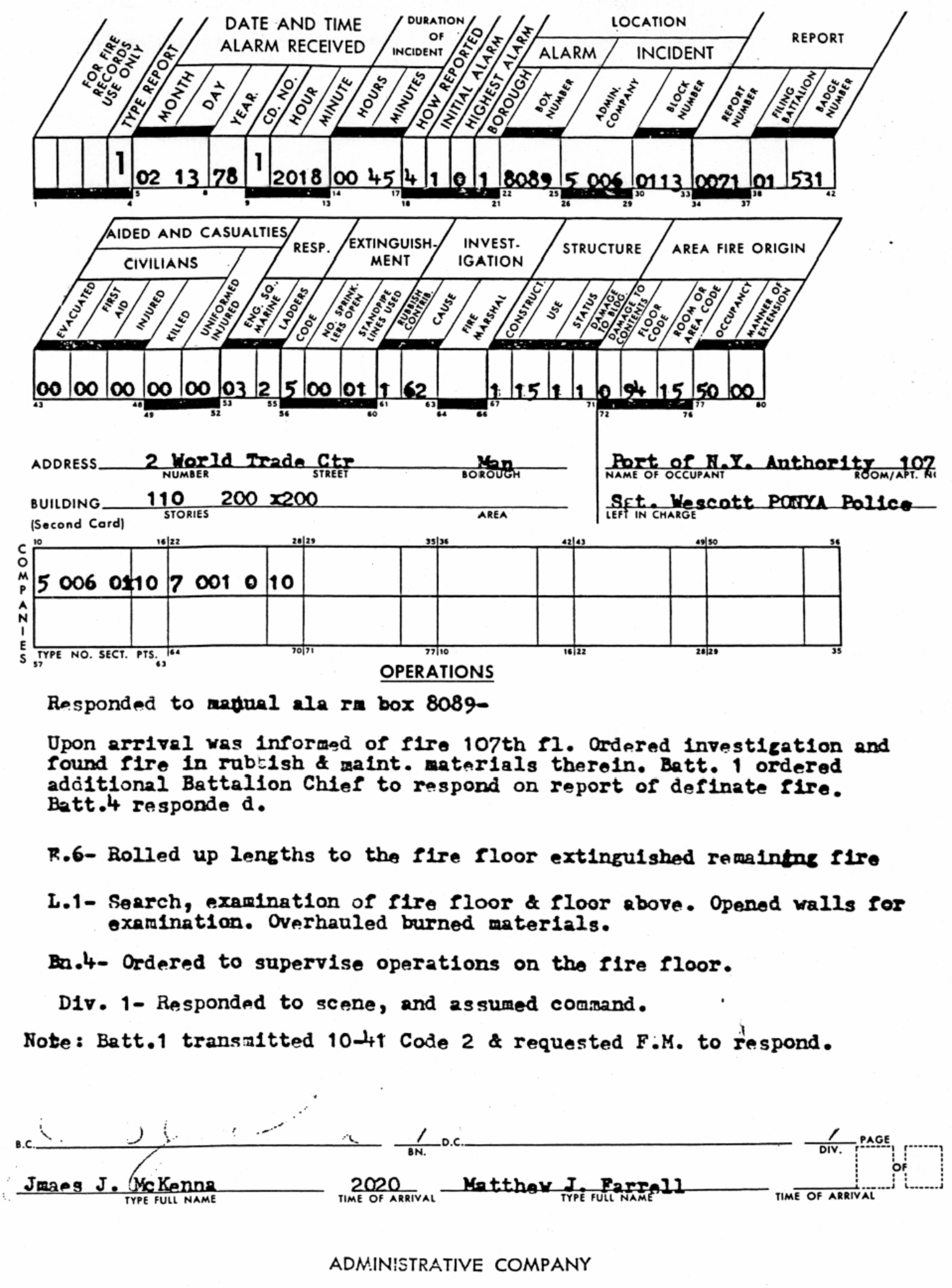
L-1 Made examination of walls and ceiling and ventilated as necessary.

B.C. Stanley Hirschfield 4th BN. D.C. DIV.

Stanley Hirschfield 1850
TYPE FULL NAME TIME OF ARRIVAL TYPE FULL NAME TIME OF ARRIVAL

PAGE 1 OF 1

ADMINISTRATIVE COMPANY



FOR FIRE RECORDS USE ONLY			TYPE REPORT	MONTH	DAY	YEAR	CD. NO.	HOUR	MINUTE	HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	BOX NUMBER	ADMIN. COMPANY	BLOCK NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER
			1	02	13	78	1	20	18	00	45	4	1	0	1	8089	5 006	0113	0071	01	531

DATE AND TIME ALARM RECEIVED / DURATION OF INCIDENT / LOCATION: ALARM, INCIDENT / REPORT

EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	ENG. SQ., MARINE	LADDERS	CODE	NO. SPRINKLERS OPEN	STANDPIPE LINES USED	RUBBISH CONTRIB.	CAUSE	FIRE MARSHAL	CONSTRUCT.	USE	STATUS	DAMAGE TO BLDG.	DAMAGE TO CONTENTS	FLOOR CODE	ROOM OR AREA CODE	OCCUPANCY	MANNER OF EXTENSION
00	00	00	00	00	03	2	5	00	01	1	62		1	15	1	1	0	94	15	50	00

AIDED AND CASUALTIES: CIVILIANS / RESP. / EXTINGUISHMENT / INVESTIGATION / STRUCTURE / AREA FIRE ORIGIN

ADDRESS 2 World Trade Ctr (NUMBER, STREET) Man (BOROUGH)

Port of N.Y. Anthority 107 (NAME OF OCCUPANT, ROOM/APT. NO.)

BUILDING 110 (STORIES) 200 x200 (AREA)

Sgt. Wescott PONYA Police (LEFT IN CHARGE)

(Second Card)

COMPANIES: 5 006 0110 7 001 0 10

TYPE NO. SECT. PTS.

OPERATIONS

Responded to manual ala rm box 8089-

Upon arrival was informed of fire 107th fl. Ordered investigation and found fire in rubbish & maint. materials therein. Batt. 1 ordered additional Battalion Chief to respond on report of definate fire. Batt.4 responde d.

E.6- Rolled up lengths to the fire floor extinguished remaining fire

L.1- Search, examination of fire floor & floor above. Opened walls for examination. Overhauled burned materials.

Bn.4- Ordered to supervise operations on the fire floor.

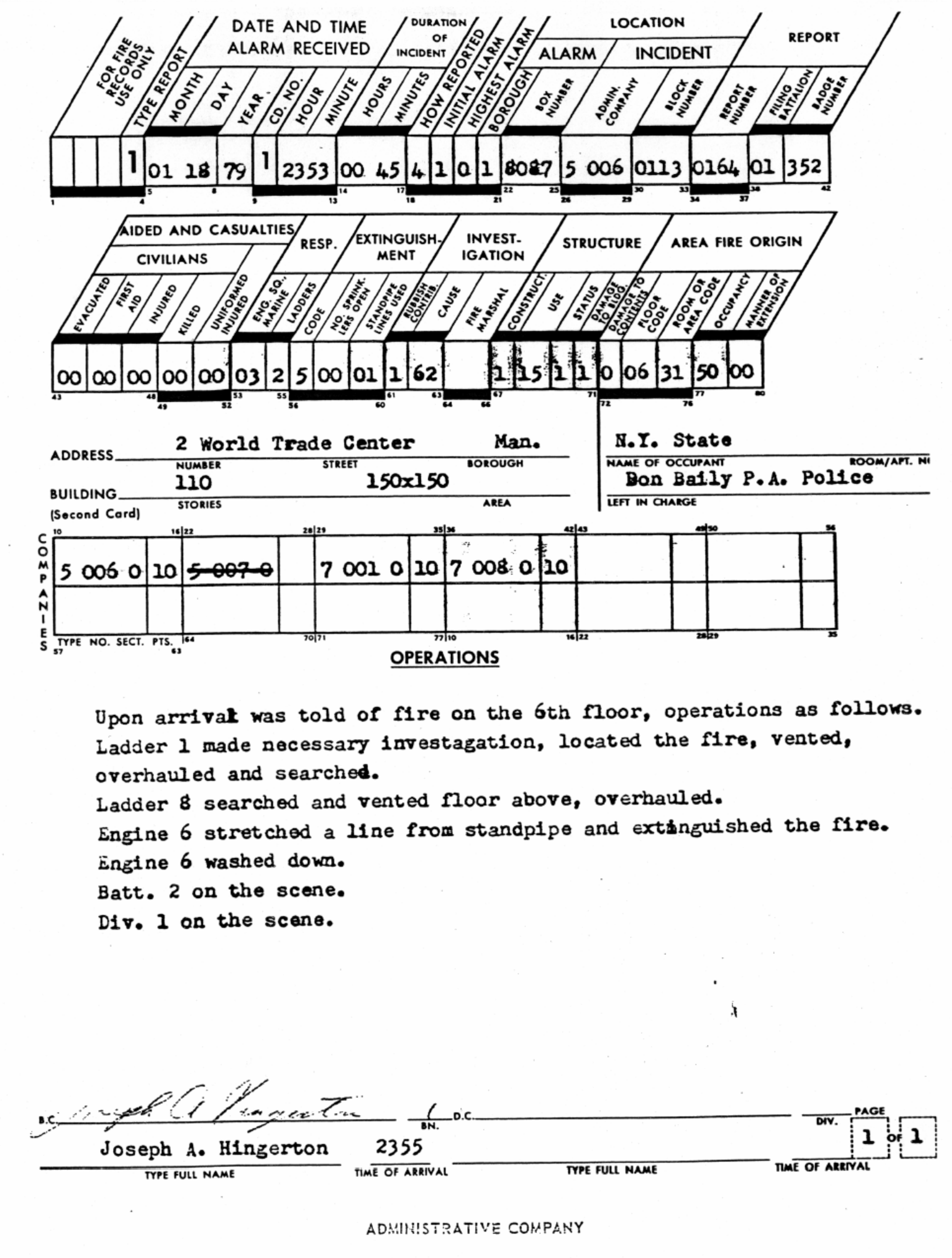
Div. 1- Responded to scene, and assumed command.

Note: Batt.1 transmitted 10-41 Code 2 & requested F.M. to respond.

B.C. ______ 1 BN. D.C. ______ 1 DIV. PAGE ☐ OF ☐

Jmaes J. McKenna (TYPE FULL NAME) 2020 (TIME OF ARRIVAL) Matthew J. Farrell (TYPE FULL NAME) ______ (TIME OF ARRIVAL)

ADMINISTRATIVE COMPANY



FOR FIRE RECORDS USE ONLY			TYPE REPORT	MONTH	DAY	YEAR	CD. NO.	HOUR	MINUTE	HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	BOX NUMBER	ADMIN. COMPANY	BLOCK NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER
			1	01	18	79	1	23	53	00	45	4	1	0	1	8087	5 006	0113	0164	01	352

DATE AND TIME ALARM RECEIVED — DURATION OF INCIDENT — LOCATION: ALARM, INCIDENT — REPORT

EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	ENG. SQ., MARINE	LADDERS	CODE	NO. SPRINKLERS OPEN	STANDPIPE LINES USED	RUBBISH CONTRIB.	CAUSE	FIRE MARSHAL	CONSTRUCT.	USE	STATUS	DAMAGE TO BLDG.	DAMAGE TO CONTENTS	FLOOR CODE	ROOM OR AREA CODE	OCCUPANCY	MANNER OF EXTENSION
00	00	00	00	00	03	2	5	00	01	1	62		1	15	1	1	0	06	31	50	00

AIDED AND CASUALTIES: CIVILIANS — RESP. — EXTINGUISHMENT — INVESTIGATION — STRUCTURE — AREA FIRE ORIGIN

ADDRESS 2 World Trade Center Man.
NUMBER STREET BOROUGH

N.Y. State
NAME OF OCCUPANT ROOM/APT. NO.

BUILDING 110 150x150
(Second Card)
STORIES AREA

Bon Baily P.A. Police
LEFT IN CHARGE

COMPANIES

5 006 0	10	~~5 007 0~~		7 001 0	10	7 008 0	10				

TYPE NO. SECT. PTS.

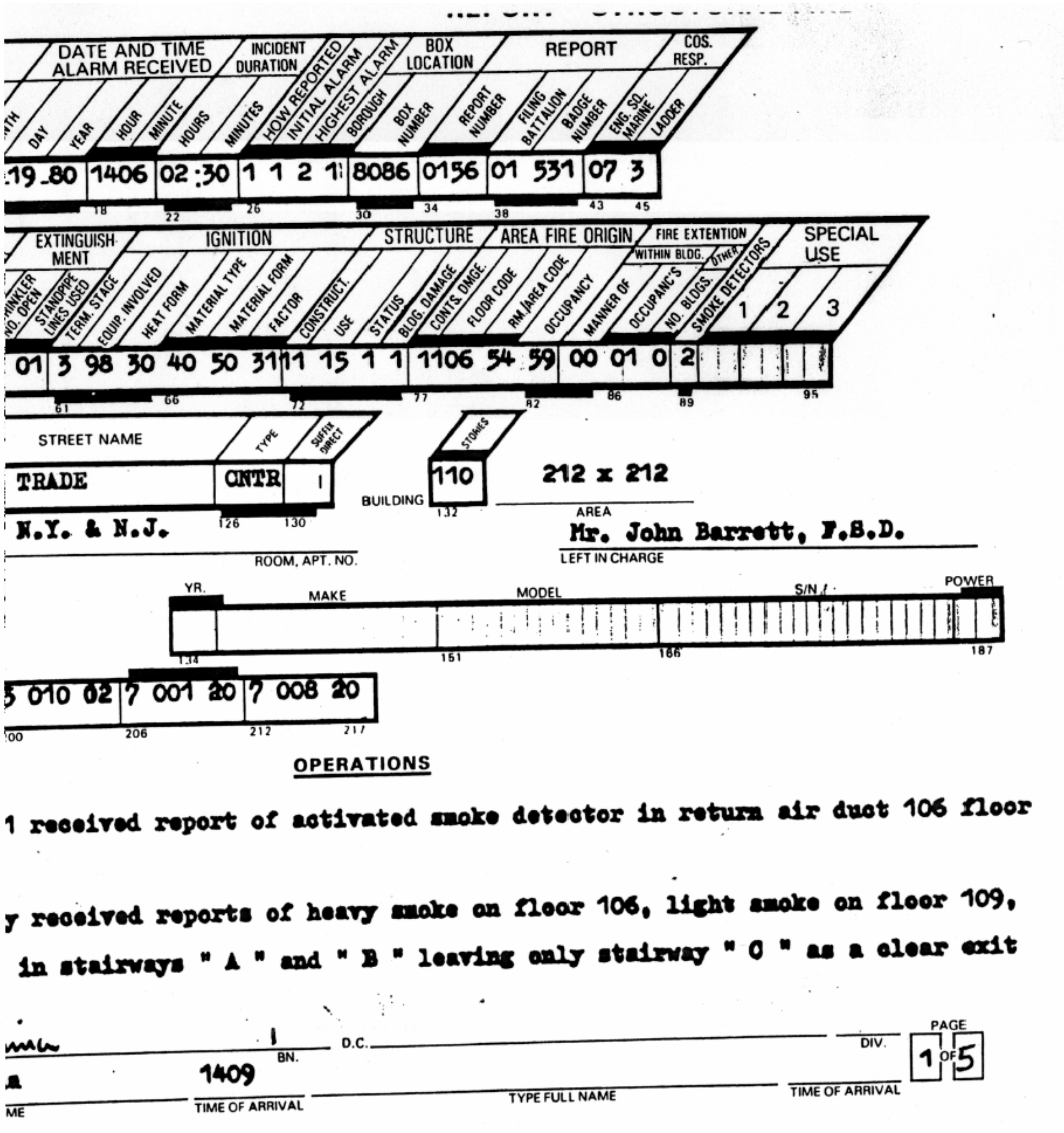
OPERATIONS

Upon arrival was told of fire on the 6th floor, operations as follows.
Ladder 1 made necessary investagation, located the fire, vented, overhauled and searched.
Ladder 8 searched and vented floor above, overhauled.
Engine 6 stretched a line from standpipe and extinguished the fire.
Engine 6 washed down.
Batt. 2 on the scene.
Div. 1 on the scene.

B.C. Joseph A Hingerton 1 BN. D.C. DIV. PAGE 1 OF 1

Joseph A. Hingerton 2355
TYPE FULL NAME — TIME OF ARRIVAL — TYPE FULL NAME — TIME OF ARRIVAL

ADMINISTRATIVE COMPANY



DATE AND TIME ALARM RECEIVED: …TH / DAY / YEAR / HOUR / MINUTE — INCIDENT DURATION: HOURS / MINUTES — HOW REPORTED / INITIAL ALARM / HIGHEST ALARM / BOROUGH — BOX LOCATION: BOX NUMBER — REPORT: REPORT NUMBER / FILING BATTALION / BADGE NUMBER — COS. RESP.: ENG. SQ. MARINE / LADDER

:19 .80 | 1406 | 02 :30 | 1 1 2 1 | 8086 | 0156 | 01 531 | 07 3

18 22 26 30 34 38 43 45

EXTINGUISHMENT: …INKLER NO. OPEN / STANDPIPE LINES USED / TERM. STAGE — IGNITION: EQUIP. INVOLVED / HEAT FORM / MATERIAL TYPE / MATERIAL FORM / FACTOR — STRUCTURE: CONSTRUCT. / USE / STATUS / BLDG. DAMAGE / CONTS. DMGE. — AREA FIRE ORIGIN: FLOOR CODE / RM./AREA CODE / OCCUPANCY / MANNER OF — FIRE EXTENTION: WITHIN BLDG. OCCUPANC'S / OTHER NO. BLDGS. — SMOKE DETECTORS — SPECIAL USE: 1 / 2 / 3

01 | 3 98 30 40 50 31 | 11 15 1 1 | 1106 54 59 | 00 01 0 | 2

61 66 72 77 82 86 89 95

STREET NAME: TRADE — TYPE: CNTR — SUFFIX DIRECT: I

126 130

BUILDING — STORIES: 110

132

AREA: 212 x 212

N.Y. & N.J.

ROOM, APT. NO.

LEFT IN CHARGE: Mr. John Barrett, F.S.D.

YR. — MAKE — MODEL — S/N — POWER

134 151 186 187

5 010 02 | 7 001 20 | 7 008 20

00 206 212 217

OPERATIONS

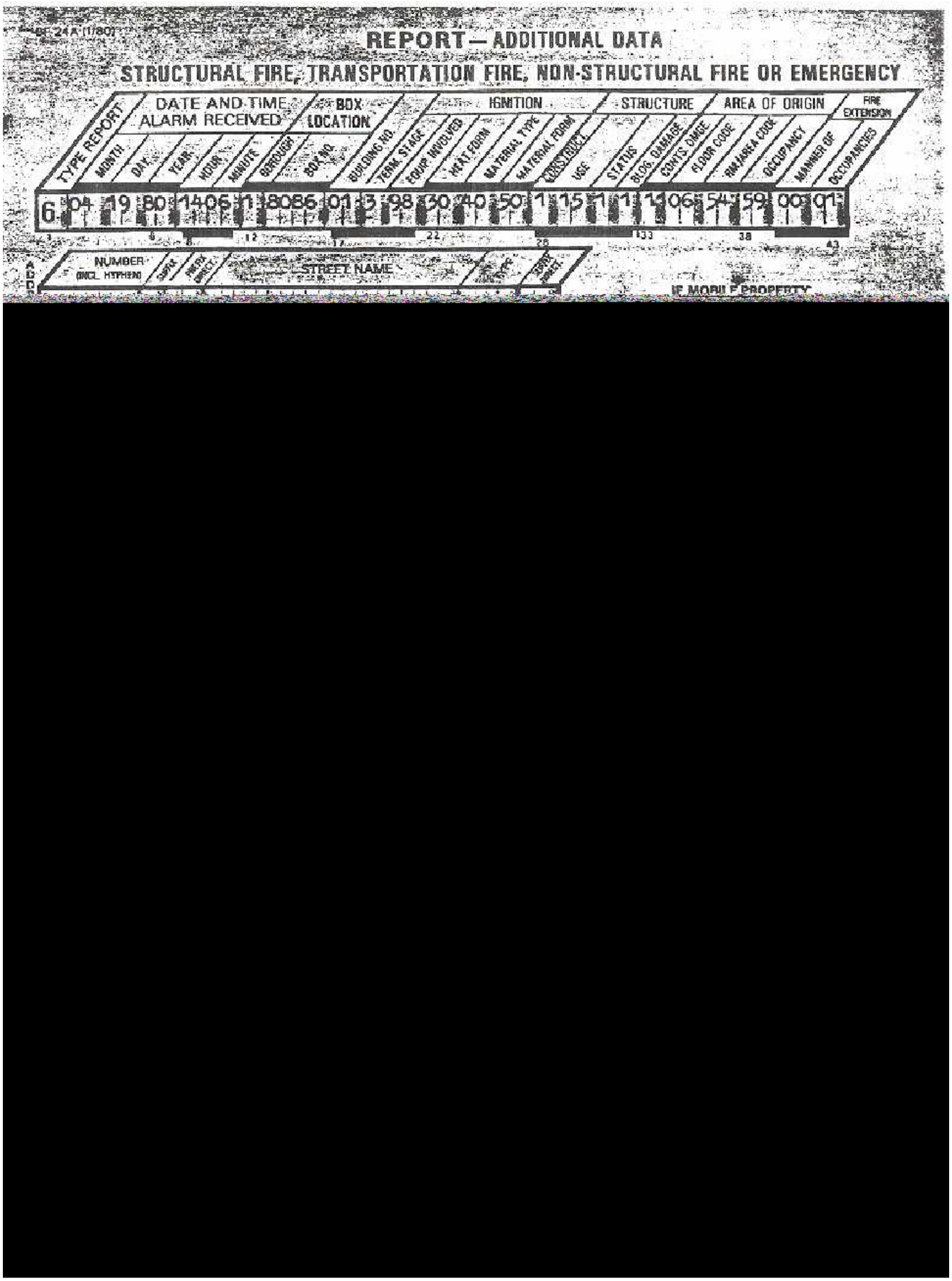
1 received report of activated smoke detector in return air duct 106 floor

y received reports of heavy smoke on floor 106, light smoke on floor 109, in stairways " A " and " B " leaving only stairway " C " as a clear exit

a — 1409 — BN. 1 — D.C. — DIV.

ME — TIME OF ARRIVAL — TYPE FULL NAME — TIME OF ARRIVAL

PAGE 1 OF 5



BF 24A (1/80)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

	DATE AND TIME ALARM RECEIVED					BOX LOCATION				IGNITION						STRUCTURE		AREA OF ORIGIN				FIRE EXTENSION	
TYPE REPORT	MONTH	DAY	YEAR	HOUR	MINUTE	BOROUGH	BOX NO.	BUILDING NO.	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE	FLOOR CODE	RM/AREA CODE	OCCUPANCY	MANNER OF	OCCUPANCIES
6	04	19	80	14	06	1	8086	01	3	98	30	40	50	1	15	1	1	1	06	54	59	00	01

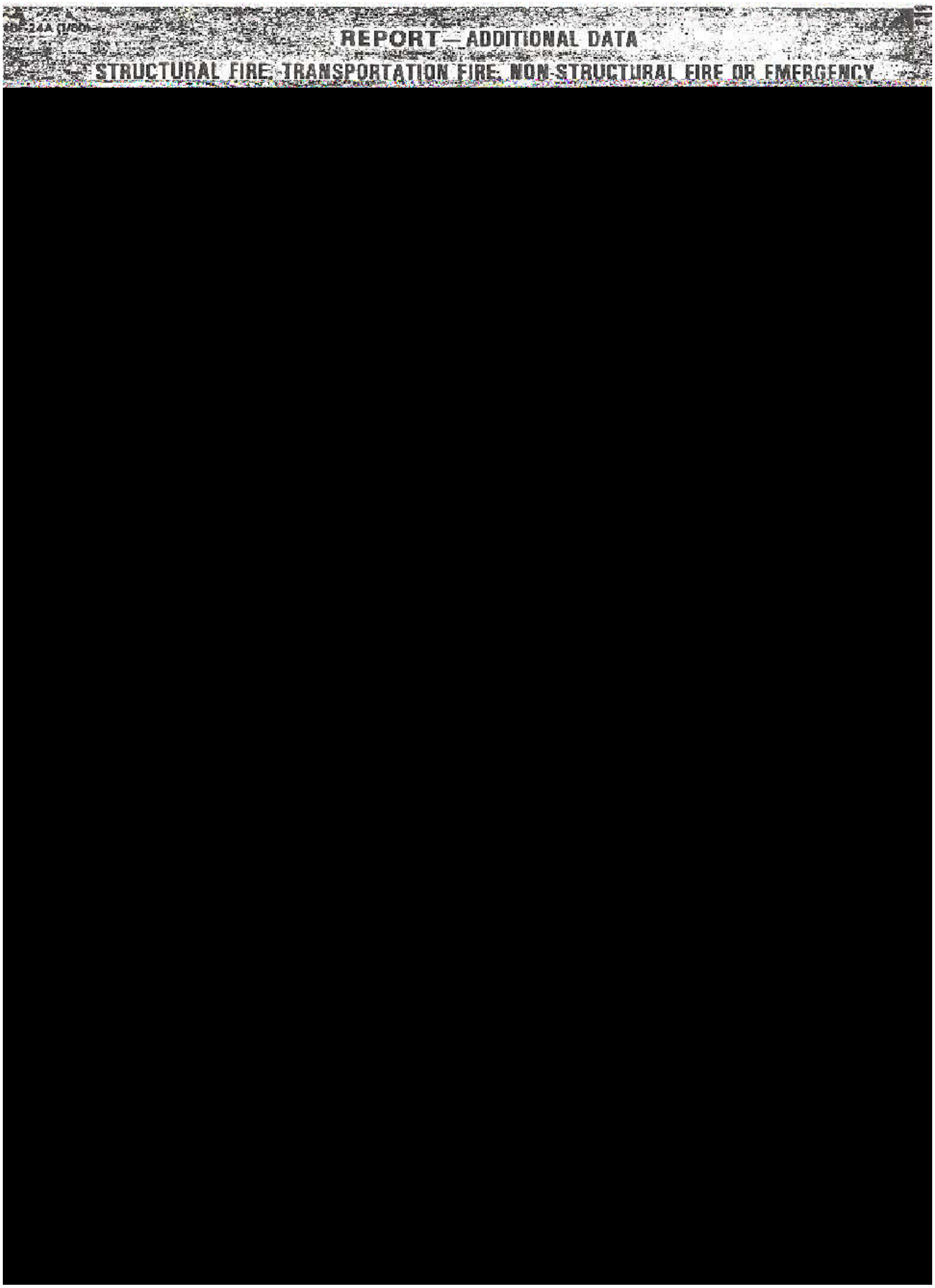
3 6 8 12 17 22 28 33 38 43

ADDR

NUMBER (INCL. HYPHEN)	SUFFIX	PREFIX DIRECT.	STREET NAME	TYPE	SUFFIX DIRECT.

IF MOBILE PROPERTY

[redacted]



-24A (1/80)

REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

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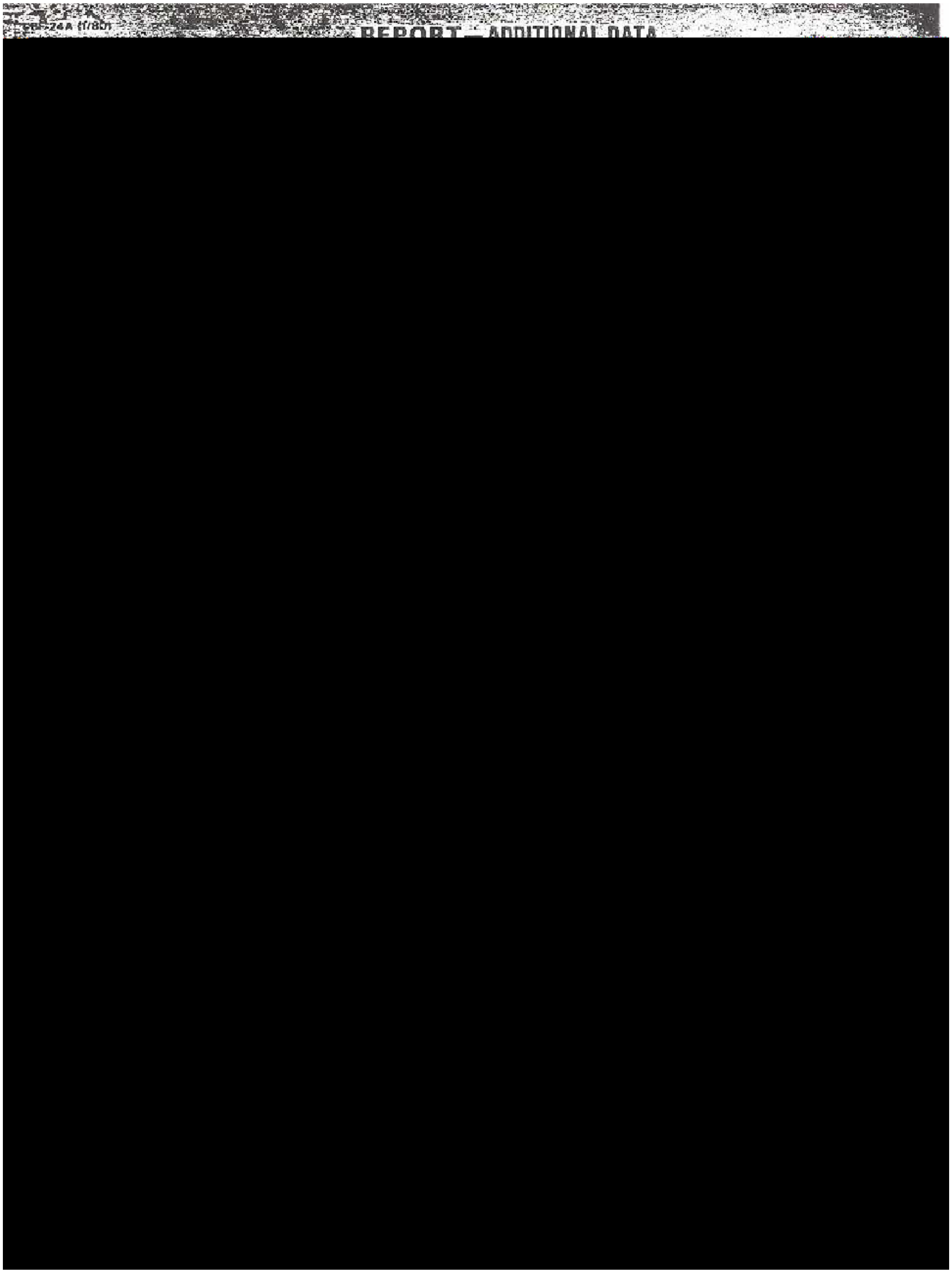

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REPORT—ADDITIONAL DATA

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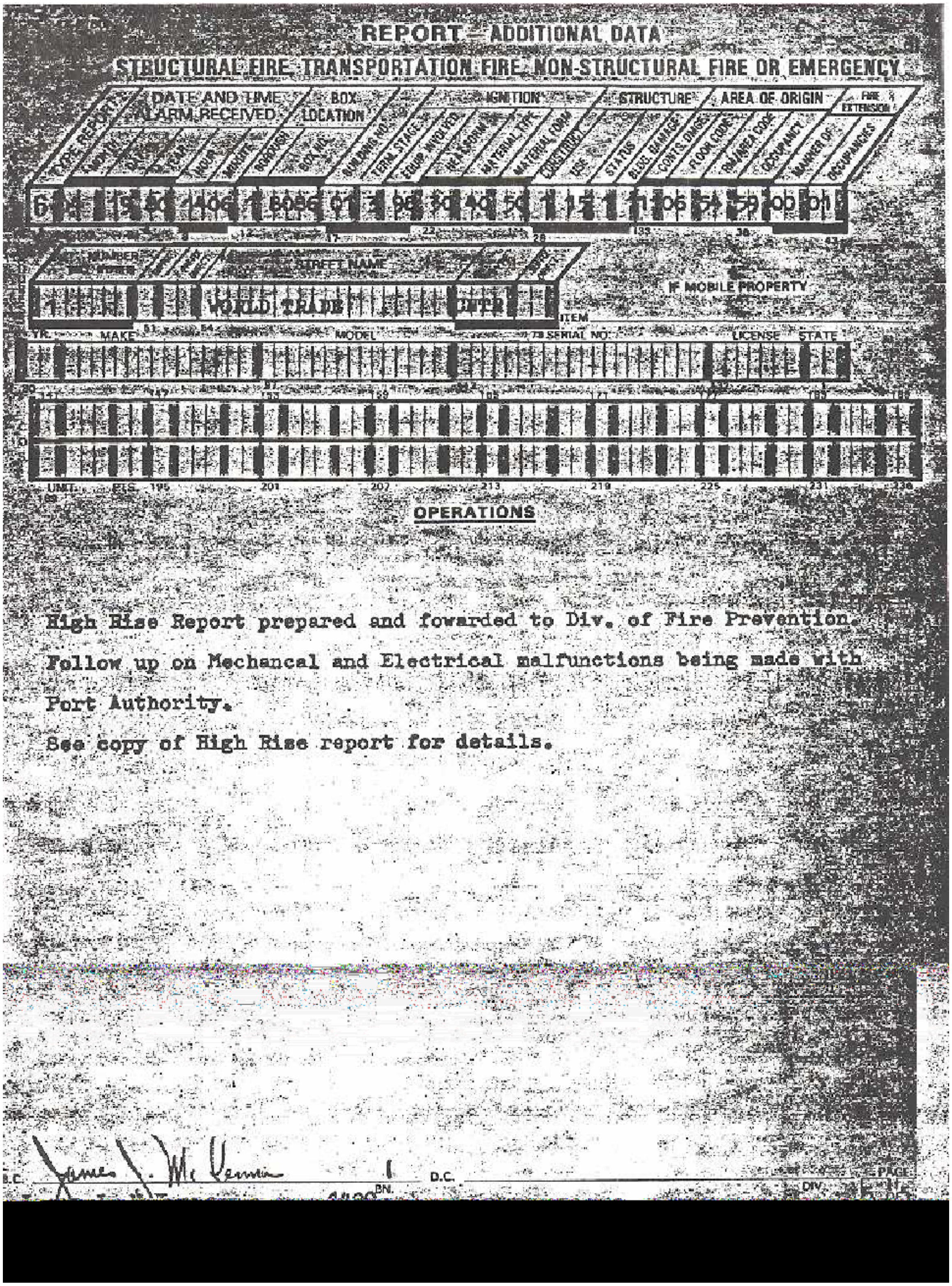


REPORT — ADDITIONAL DATA

STRUCTURAL FIRE, TRANSPORTATION FIRE, NON-STRUCTURAL FIRE OR EMERGENCY

TYPE REPORT | DATE AND TIME ALARM RECEIVED: MONTH, DAY, YEAR, HOUR, MINUTE | BOX LOCATION: BOROUGH, BOX NO. | IGNITION: BUILDING NO., TERM. STAGE, EQUIP. INVOLVED, HEAT FORM, MATERIAL TYPE, MATERIAL FORM | CONSTRUCT. | USE | STRUCTURE: STATUS, BLDG. DAMAGE, CONTS. DAMGE | AREA OF ORIGIN: FLOOR CODE, RM/AREA CODE, OCCUPANCY | FIRE EXTENSION: MANNER OF, OCCUPANCIES

6 04 15 40 1406 1 8086 01 3 96 30 40 50 1 1 5 1 1 1 06 54 59 00 01

STREET NAME: WORLD TRADE CNTR

IF MOBILE PROPERTY

ITEM

YR. MAKE MODEL SERIAL NO. LICENSE STATE

UNIT PTS.

OPERATIONS

High Rise Report prepared and fowarded to Div. of Fire Prevention.

Follow up on Mechancal and Electrical malfunctions being made with Port Authority.

See copy of High Rise report for details.

B.C. James J. Mc Vernon BN. D.C. DIV. PAGE

[redacted]

RAL FIRE

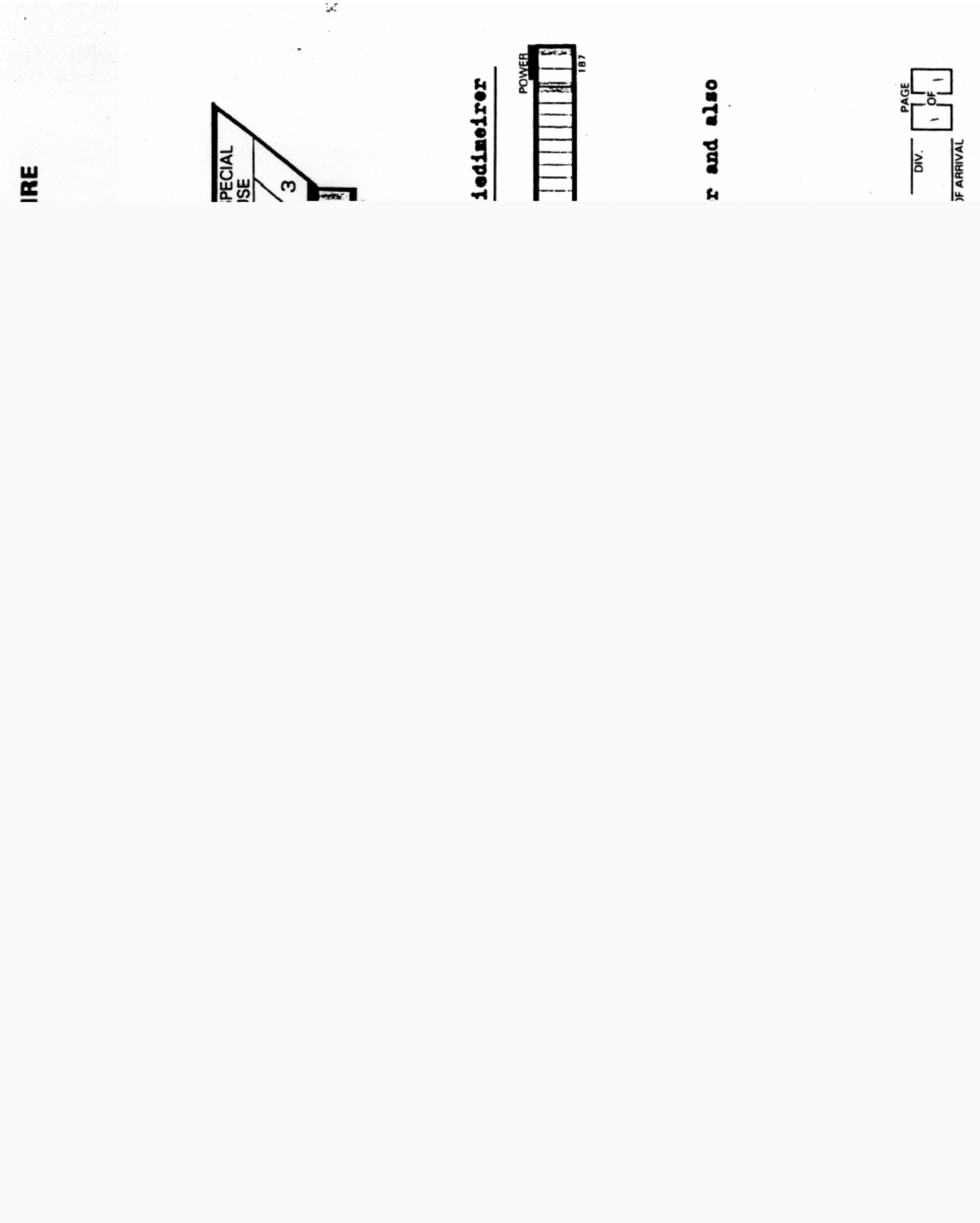
ON
ECTORS
SPECIAL USE
1 2 3
95

ho Fire Safety director

S/N
POWER
187

ported heavy smoke

DIV.
TIME OF ARRIVAL
PAGE
OF



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3

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POWER
187

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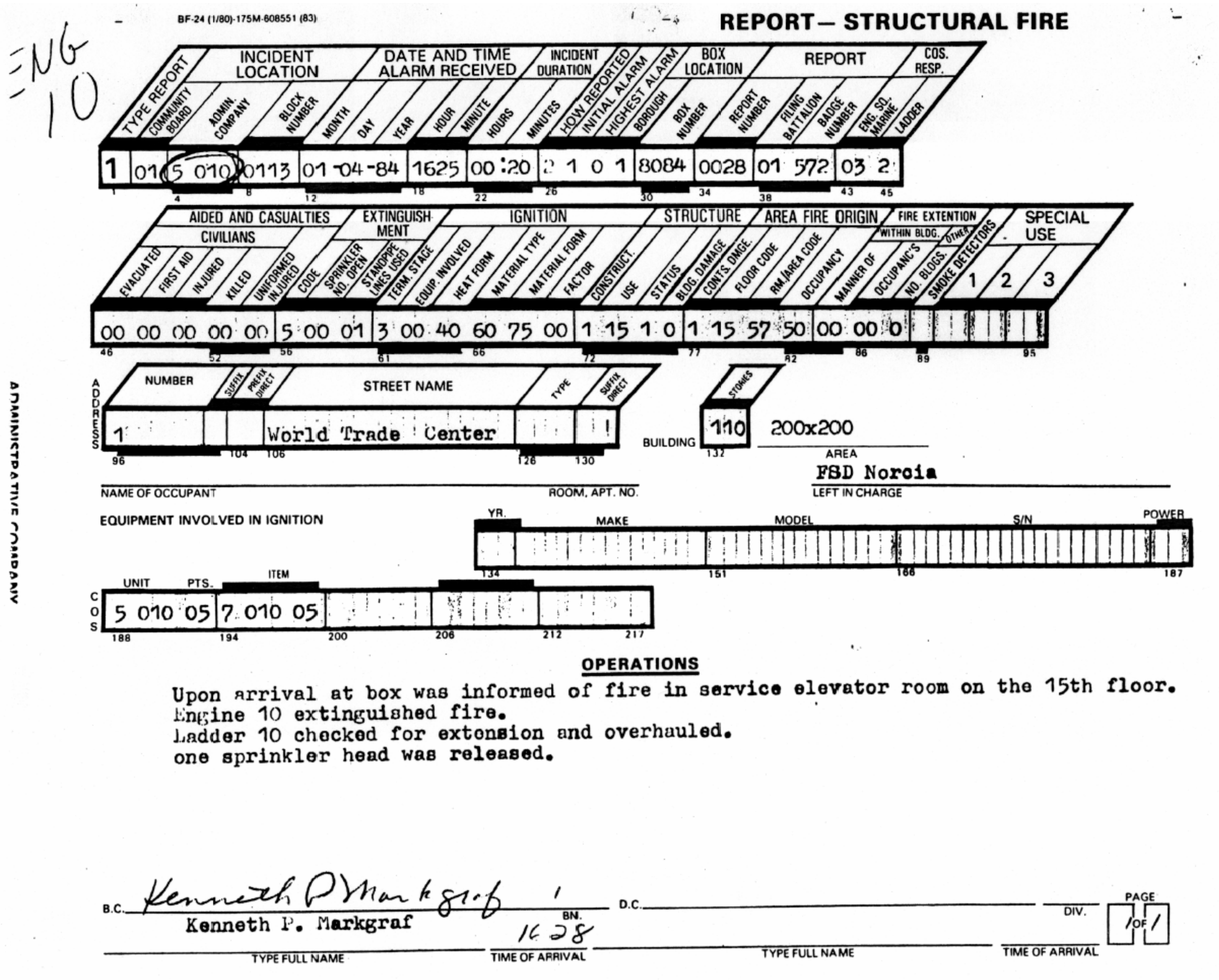
DIV.
F ARRIVAL

PAGE 1 OF 1



ENG 10

BF-24 (1/80)-175M-608551 (83)

REPORT — STRUCTURAL FIRE

TYPE REPORT	INCIDENT LOCATION			DATE AND TIME ALARM RECEIVED					INCIDENT DURATION						BOX LOCATION		REPORT			COS. RESP.	
	COMMUNITY BOARD	ADMIN. COMPANY	BLOCK NUMBER	MONTH	DAY	YEAR	HOUR	MINUTE	HOURS	MINUTES	HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOROUGH	BOX NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER		ENG. SQ. MARINE	LADDER
1	01	5 010	0113	01	04	84	16	25	00	20	2	1	0	1	8084	0028	01	572		03	2

1 4 8 12 18 22 26 30 34 38 43 45

AIDED AND CASUALTIES					EXTINGUISHMENT			IGNITION						STRUCTURE				AREA FIRE ORIGIN					FIRE EXTENTION			SPECIAL USE		
CIVILIANS																							WITHIN BLDG.	OTHER				
EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	CODE	SPRINKLER NO. OPEN	STANDPIPE LINES USED	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	FACTOR	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	FLOOR CODE	RM./AREA CODE	OCCUPANCY	MANNER OF	OCCUPANC'S	NO. BLDGS.	SMOKE DETECTORS	1	2	3
00	00	00	00	00	5	00	01	3	00	40	60	75	00	1	15	1	0	1	15	57	50	00	00	0				

46 52 56 61 66 72 77 82 86 89 95

ADDRESS NUMBER	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECT
1			World Trade Center		

96 104 106 126 130

BUILDING STORIES	AREA
110	200x200

132

NAME OF OCCUPANT

ROOM, APT. NO.

LEFT IN CHARGE: FSD Norcia

EQUIPMENT INVOLVED IN IGNITION

YR.	MAKE	MODEL	S/N	POWER

134 151 166 187

COS UNIT	PTS.	ITEM			
5 010	05	7 010 05			

188 194 200 206 212 217

OPERATIONS

Upon arrival at box was informed of fire in service elevator room on the 15th floor.
Engine 10 extinguished fire.
Ladder 10 checked for extension and overhauled.
one sprinkler head was released.

B.C. Kenneth P Markgraf
Kenneth P. Markgraf
TYPE FULL NAME

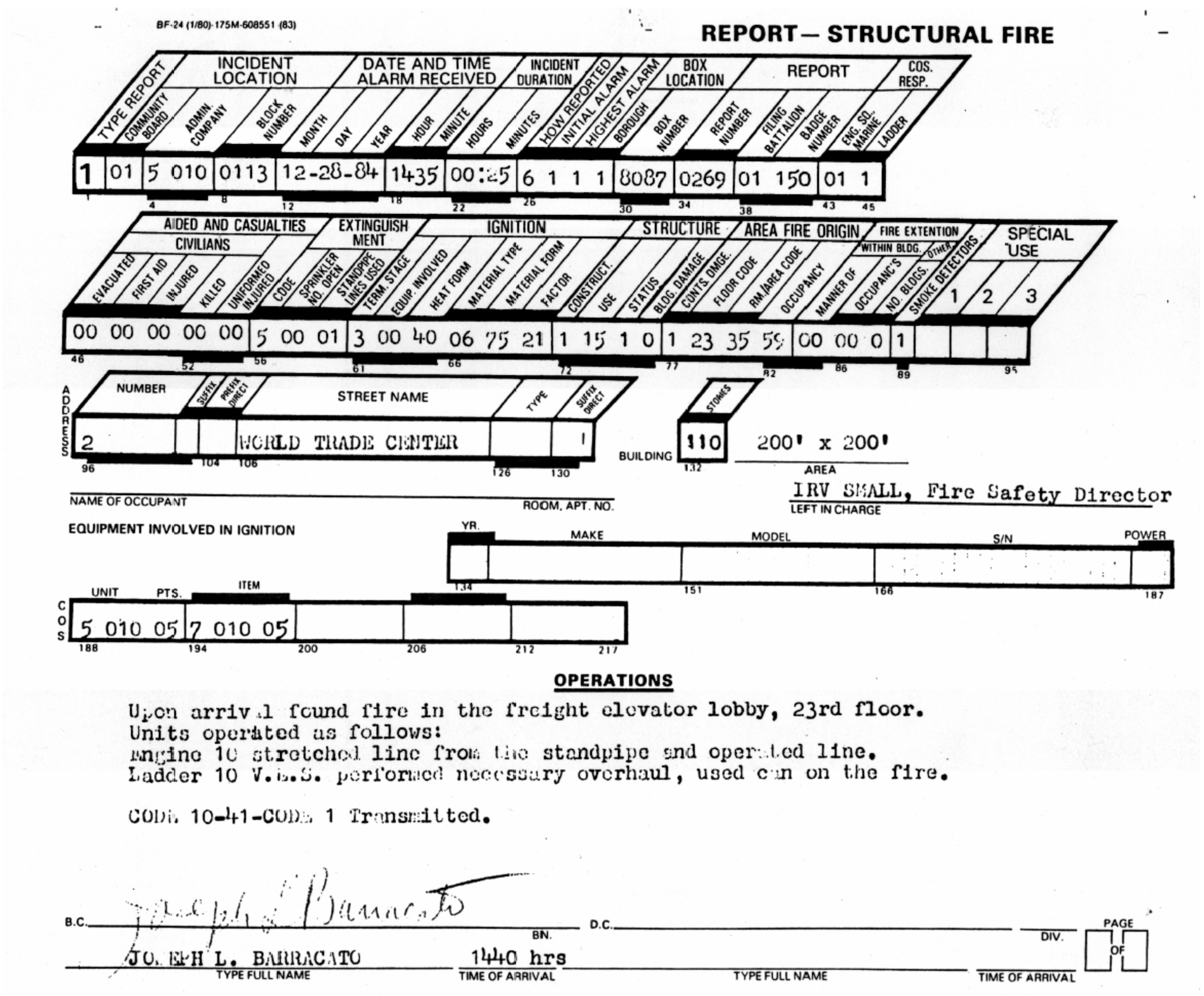
BN. 1
TIME OF ARRIVAL 1628

D.C.
TYPE FULL NAME

DIV.
TIME OF ARRIVAL

PAGE 1 OF 1

ADMINISTRATIVE COMPANY



BF-24 (1/80)-175M-608551 (83)

REPORT — STRUCTURAL FIRE

TYPE REPORT	INCIDENT LOCATION			DATE AND TIME ALARM RECEIVED					INCIDENT DURATION		HOW REPORTED	INITIAL ALARM	HIGHEST ALARM	BOX LOCATION		REPORT			COS. RESP.	
	COMMUNITY BOARD	ADMIN. COMPANY	BLOCK NUMBER	MONTH	DAY	YEAR	HOUR	MINUTE	HOURS	MINUTES				BOROUGH	BOX NUMBER	REPORT NUMBER	FILING BATTALION	BADGE NUMBER	ENG. SQ. MARINE	LADDER
1	01	5 010	0113	12-	28-	84	14	35	00:	25	6	1	1	1	8087	0269	01	150	01	1

AIDED AND CASUALTIES					EXTINGUISHMENT				IGNITION					STRUCTURE					AREA FIRE ORIGIN			FIRE EXTENTION				SPECIAL USE		
CIVILIANS																						WITHIN BLDG.		OTHER				
EVACUATED	FIRST AID	INJURED	KILLED	UNIFORMED INJURED	CODE	SPRINKLER NO. OPEN	STANDPIPE LINES USED	TERM. STAGE	EQUIP. INVOLVED	HEAT FORM	MATERIAL TYPE	MATERIAL FORM	FACTOR	CONSTRUCT.	USE	STATUS	BLDG. DAMAGE	CONTS. DMGE.	FLOOR CODE	RM./AREA CODE	OCCUPANCY	MANNER OF	OCCUPANC'S	NO. BLDGS.	SMOKE DETECTORS	1	2	3
00	00	00	00	00	5	00	01	3	00	40	06	75	21	1	15	1	0	1	23	35	59	00	00	0	1			

ADDRESS

NUMBER	SUFFIX	PREFIX DIRECT	STREET NAME	TYPE	SUFFIX DIRECT
2			WORLD TRADE CENTER		1

BUILDING

STORIES
110

AREA: 200' x 200'

NAME OF OCCUPANT:

ROOM, APT. NO.:

LEFT IN CHARGE: IRV SMALL, Fire Safety Director

EQUIPMENT INVOLVED IN IGNITION

YR.	MAKE	MODEL	S/N	POWER

COS

UNIT	PTS.	ITEM			
5 010 05	7 010 05				

OPERATIONS

Upon arrival found fire in the freight elevator lobby, 23rd floor.
Units operated as follows:
Engine 10 stretched line from the standpipe and operated line.
Ladder 10 V.E.S. performed necessary overhaul, used can on the fire.

CODE 10-41-CODE 1 Transmitted.

B.C. Joseph L Barracato

JOSEPH L. BARRACATO — TYPE FULL NAME

BN.

1440 hrs — TIME OF ARRIVAL

D.C.

TYPE FULL NAME

DIV.

TIME OF ARRIVAL

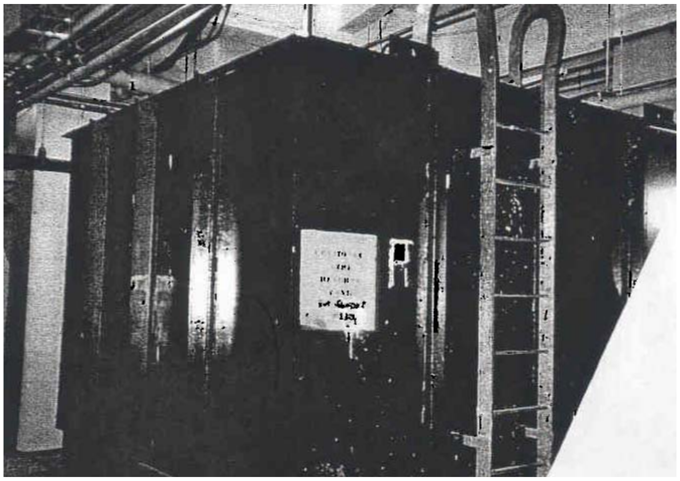
PAGE ☐ OF ☐

The exception to this arrangement were the high zone hose stations located on the 110th floor, which were supplied with water from a combination sprinkler and standpipe system booster pump located on the 108th floor (PANYNJ 1972, 1987a).

Reserve water supply tanks were located in the mechanical equipment room (MER) floor levels of both towers. In most cases, the MER levels were two stories in height. The MER levels were located at the following elevations:

- Floor levels 7 and 8
- Floor levels 41 and 42
- Floor levels 75 and 76
- Floor levels 108 and 109
- Bulkhead deck 110

Four reserve water storage tanks were provided in WTC 1 to supply the standpipes. Each tank had a holding capacity of 5,000 gal for a total of 20,000 gal of water dedicated for manual fire suppression. These tanks were located on floors 20, 41, 75, and 110. The tanks were designated FSP storage tank No. 20A, FSP storage tank No. 41A, FSP storage tank No. 75A, and FSP storage tank No. 110A, respectively (PANYNJ 1987a). Figure 5–2 illustrates a typical water storage tank (Merritt & Harris Inc. 2000).



Source: Merritt & Harris Inc. 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–2. Typical 5,000 gal water storage tank, WTC 1 and WTC 2.

The water storage tank located on the 20th floor of WTC 1 supplied water to the sub-grade loops and the low zone standpipes in both towers. A similar tank was not provided in WTC 2.

Three reserve water storage tanks were provided in WTC 2 to supply the standpipes. These tanks were located on floors 42, 76, and 110. The tanks were designated FSP storage tank No. 41B, FSP storage tank

No. 75B, and FSP storage tank No. 110B respectively. Similar to WTC 1, each of the tanks had a holding capacity of 5,000 gal of water. The total holding capacity of the tanks in WTC 2 was 15,000 gal (PANYNJ 1987).

Two parallel 5,000 gal water storage tanks were provided on the 110th floor in each of the towers. These tanks provided a dedicated water supply of 10,000 gal for the high and mid-level zone sprinkler systems. The 5,000 gal standpipe reserve water storage tank on the 110th floor level also served as a secondary automatic water supply for the high and mid-level automatic fire sprinkler systems. Figure B–1[2] is a riser diagram of the WTC 1 and WTC 2 tower sprinkler and standpipe systems. Figure B–1 illustrates the interconnection of the standpipe and sprinkler systems within the towers. Figures 5–3 and 5–4 depict the configuration of the sprinkler system reserve storage tanks for the high and mid-level zone sprinkler systems.

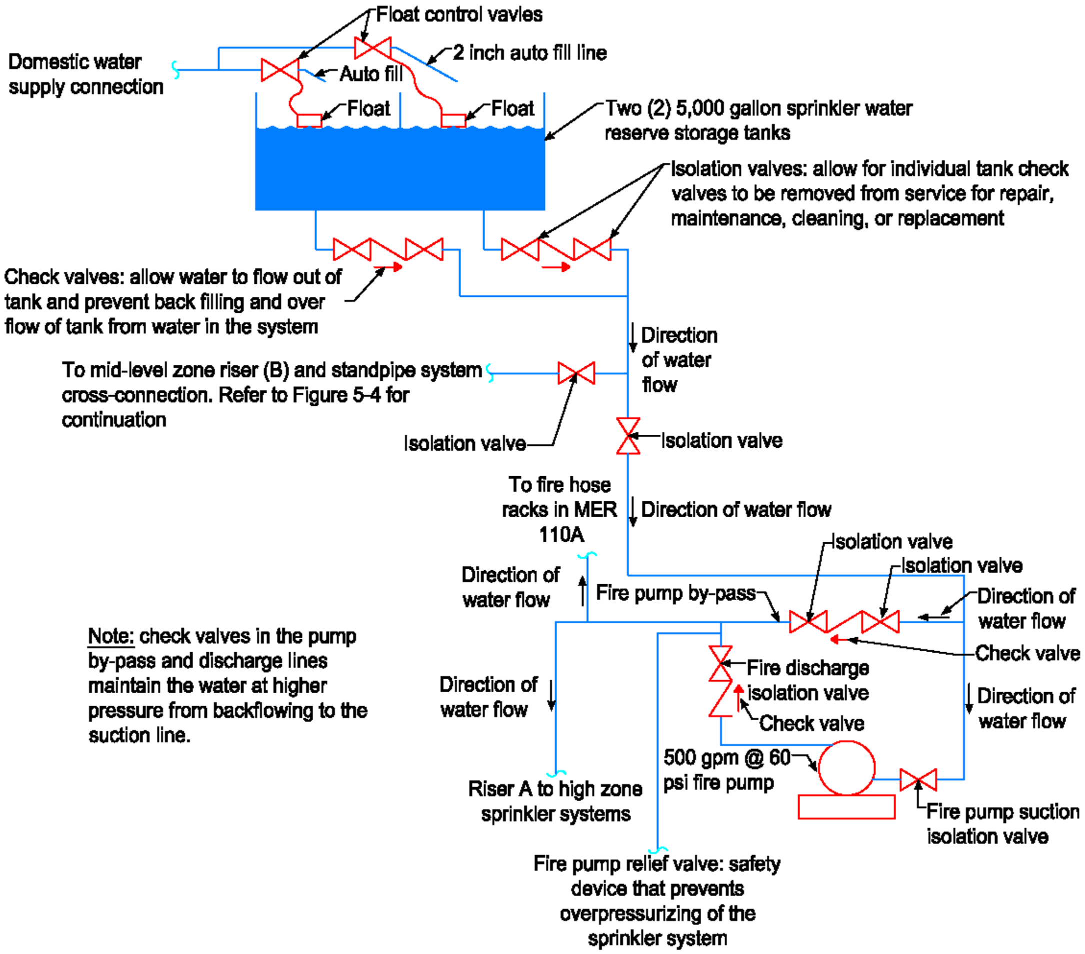


Figure 5–3. Water storage tanks, high zone sprinkler systems.

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[2] Refer to Appendix B for detailed figures.

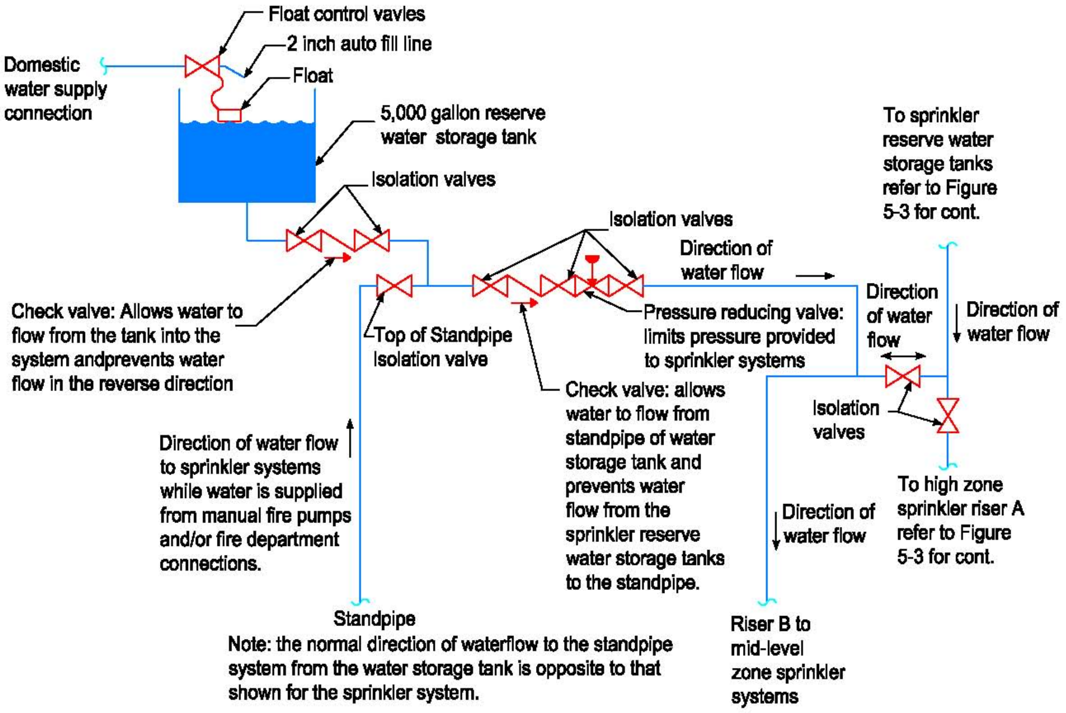


Figure 5–4. Water storage tanks, mid-level zone sprinkler systems.

The 5,000 gal water storage tanks located in the 41st floor level mechanical rooms were arranged to provide the primary water supply for the low zone sprinkler systems and the standpipe system zone serving floors 8 through 31. Therefore, a minimum of 5,000 gal was provided for the standpipe and sprinkler systems in each tower. Since each tank was also equipped with a 2 in. diameter automatic fill line supplied by the domestic water system, the volume of water in the tank would be partially replenished as the water was depleted from the tank.

The domestic plumbing system was provided with a separate and independent connection to the NYC water distribution system from the fire service connections. Water was supplied to the water storage tanks through the domestic plumbing system. This is identified on the plumbing system design documents as the fire make-up system. The water for the domestic system was supplied by an 8 in. connection to the distribution system with multiple, staged high pressure domestic pumps capable of delivering water to the tanks as well as serving the domestic demand requirements for the building. Each tank was equipped with a float control valve that automatically filled the tank through a 2 in. fill line (PANYNJ 1972, 1983, 1987a).

Fire Pumps

The WTC complex was provided with 12 fire pumps and a single vertical turbine jockey pump PANYNJ 1972, 1987a). Table 5–1 provides a summary of the fire pump locations for the WTC 1 and 2 sprinkler and standpipe systems.

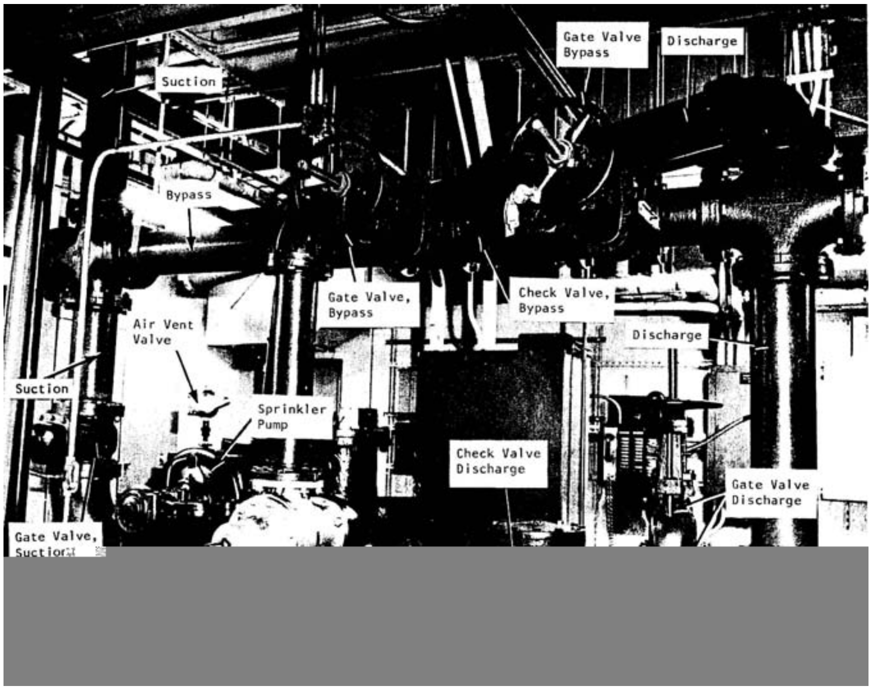
Table 5–1. Fire pumps, WTC 1 and WTC 2.

Tower		Fire Pump	Size	Location	System	Operation
WTC 1	1	Standpipe Pump 294A	750 gpm @ 360 psi (831 ft)	B1 level	Standpipe	Manual
	2	Sprinkler Pump 294A	1,500 gpm @ 100 psi (231 ft)	B1 level	Sprinkler	Manual
		Jockey Pump		B1 level	Sprinkler	Automatic
	3	Pump 7A	750 gpm @ 346 psi (800 ft)	7th floor	Standpipe	Manual
	4	Pump 41A	750 gpm @ 360 psi (831 ft)	41st floor	Standpipe	Manual
	5	Pump 75A	750 gpm @ 228 psi (527 ft)	75th floor	Standpipe	Manual
	6	Pump 108A	500 gpm @ 60 psi (139 ft)	108th floor	Sprinkler	Automatic
WTC 2	7	Standpipe Pump 294B	750 gpm @ 360 psi (831 ft)	B1 level	Standpipe	Manual
	8	Sprinkler Pump 294B	1,500 gpm @ 100 psi (231 ft)	B1 level	Sprinkler	Manual
	9	Pump 7B	750 gpm @ 346 psi (800 ft)	7th floor	Standpipe	Manual
	10	Pump 41B	750 gpm @ 360 psi (831 ft)	41st floor	Standpipe	Manual
	11	Pump 75B	750 gpm @ 228 psi (527 ft)	75th floor	Standpipe	Manual
	12	Pump 108B	500 gpm @ 60 psi (139 ft)	108th floor	Sprinkler	Automatic

Two manual fire pumps were used to supply water to the B1 and concourse level loops for the automatic fire sprinkler systems. These 1,500 gpm pumps were located on the B1 sub-grade level. Sprinkler pump 294A and the jockey pump were located in WTC 1, and sprinkler pump 294B was located in WTC 2. The jockey pump was used to maintain the sub-grade sprinkler loops at 155 psi. These two pumps supplied water to the sub-grade sprinkler loops and throughout the WTC complex but did not supply water to the sprinkler systems in the WTC 1 and WTC 2 towers (PANYNJ 1972, 1987b).

Two parallel 750 gpm manual standpipe fire pumps, designated 294A and 294B, were installed for the standpipe system sub-grade loops. The B1 level fire pumps for the sprinkler and standpipe systems were provided with separate 8 in. fire service connections to a centralized 12 in. main connected to the NYC water distribution system at two locations. Figure 5–5 is a photograph of standpipe fire pump 294A taken from the Operation and Maintenance (O&M) manual (PANYNJ 1972, 1987b).

The standpipe system infrastructures in WTC 1 and WTC 2 included three additional 750 gpm staged, manually operated fire pumps at the 7th, 41st, and 75th MER floor levels (PANYNJ 1972). The initial operating mode for the standpipe systems relied on gravity pressure supplied by the reserve water storage tanks to supply water for manual fire fighting and automatic sprinkler system activities prior to the operation of the manual fire pumps in the tower. The reserve water storage tanks were also intended to be used as an initial water supply for the manually operated fire pumps serving the higher standpipe system zones and upper level fire pumps. As water was supplied from the fire department connections or lower level tanks, the need for water supplied from the reserve water storage tanks would be reduced.



Source: PANYNJ 1987a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–5. Manual standpipe fire pump 294A, WTC 1.

The standpipe system reserve storage tanks located on the 75th and 41st floor mechanical rooms were configured to serve as secondary manual water supplies for the high and mid-level zone automatic sprinkler systems. The use of these storage tanks required the manual operation of the fire pumps to lift the water to the 110th floor level. Any two manual fire pumps operating in series were capable of providing adequate capacity and pressure to supply the fire protection (suppression) systems within the high or mid-level sprinkler or standpipe systems.

A single fire (booster) pump was provided in each tower at the 108th floor level for the high zone sprinkler systems and the hose connections located on the 110th floor level. The suction line for each of the fire pumps received water from the sprinkler and standpipe reserve water storage tanks located in the mechanical rooms on the 110th floor. The 15,000 gal combined water capacity within the tanks was capable of supplying water to the booster pump at a flow rate of 500 gpm, the 100 percent capacity of the fire pump, for a minimum duration of 30 min without any supplemental water being supplied by the domestic water system. This duration would be reduced to 20 min if the pump was operating at 750 gpm (the 150 percent capacity of the fire pump), which is the maximum required flow rate for a 500 gpm pump.

Fire Department Connections

The WTC complex was provided with 14 separate fire department connection (FDC) stations, with a total of 32 fire department (siamese) connections. Figure B–2 provides an overview of the layout for the fire department connections at the WTC complex (PANYNJ 1972, 1987a).

All of the FDC stations included a two-barrel siamese connection for the WTC complex sub-grade sprinkler loops and a separate siamese connection for the WTC complex standpipe systems. Any of the standpipe system FDC stations could be used to supply water to the WTC 1 and WTC 2 standpipe systems. The standpipe FDC connections could also be used to supply water to the sprinkler systems above the 31st floors in the WTC 1 and 2 towers. Any standpipe FDC and a single manual fire pump were able to supply water to any floor in the respective tower where the fire pump was located (PANYNJ 1972, 1987a).

Two additional high-pressure siamese connections were provided at the north and south sides of the complex at Vesey and Liberty Streets, respectively. These high-pressure connections permitted the fire department to use a high-pressure pumper to supply water to the standpipe systems at any floor in the towers. They were also used to supply water to the sprinkler systems above the 31st floor in either tower. The high-pressure pumpers have a third stage that can supply 500 gpm at 700 psi (Syska & Hennessy 1984; PANYNJ 1972, 1987a; FDNY 1990).

The two final siamese connections were provided for the tower low zone sprinkler systems, floors 1–31 of WTC 1 and WTC 2. These were located at Liberty and West Streets (PANYNJ 1972).

The FDNY high-rise office buildings firefighting procedures and fire operations manual provides recommended pump pressures to support manual fire suppression efforts in high-rise office buildings (FDNY 1990). Table 5–2 provides a summary of the recommended pump pressures.

Table 5–2. FDNY recommended FDC pump pressures.

Floors	Controlling Nozzle Pressure (psi)	Fog Nozzle Pressure (psi)
1 to 10	150	200
11 to 20	200	250
21 to 30	250	300
31 to 40	300	350
41 to 50	350	400
51 to 60	400	450
61 to 70	450	500
71 to 80	500	550
81 to 90	550	600
91 to 100	600	650
101 to 110	650	700

5.2.2 Standpipe and Pre-Connected Hose Systems

The standpipe systems for the WTC 1 and WTC 2 towers were provided with two separate infrastructures, one for the sub-grade levels and one for the towers. Figure B–3 illustrates the WTC 1 and WTC 2 tower standpipe system risers. Figures B–4 and B–5 illustrate the standpipe and parallel sprinkler loops on the concourse and B1 levels respectively. A separate standpipe system with multiple vertical water supply zones was provided in WTC 1 and WTC 2. The standpipe systems were composed of an automatic water supply, distribution piping, fittings, control valves, check valves, standpipe risers, hose valves, hose stations, hose cabinets, fire department connections, and a secondary water supply (PANYNJ 1972).

Standpipe Risers

Each tower contained three separate standpipe risers to supply water to the hose stations located on floors 1 through 110. One standpipe riser was provided in each exit stair enclosure. Table 5–3 provides a summary of the standpipe designations and locations.

Table 5–3. Standpipe designations and locations, WTC 1 and WTC 2.

Tower	Stair Enclosure	Standpipe Riser Designations	Location of Stair Enclosure
WTC 1 (A)	Stairway B (3)	FS-F1	South
	Stairway C (2)	FS-F2	Northwest
	Stairway A (1)	FS-F3	Northeast
WTC 2 (B)	Stairway B (3)	FS-F1	East
	Stairway C (2)	FS-F2	Southwest
	Stairway A (1)	FS-F3	Northwest

Standpipe risers FS-F1, FS-F2 and FS-F3 were located within and supplied water to pre-connected hose racks located in each respective stair enclosure. Figure B–6 shows a typical hose rack arrangement with a typical intermediate isolation valve. Standpipe riser FS-F1 also supplied water to auxiliary hose cabinets located in the corridors and tenant areas of both buildings (PANYNJ 1972, 2000b).

The design documents for the towers indicated that the standpipes included six separate pipe and fitting zones within the towers. Since the working pressure within the standpipe systems varied as a function of elevation, the construction of the standpipe risers also varied as a function of elevation. Table 5–4 provides a summary of the standpipe system component specifications (PANYNJ 1972, 1987b, 2000b).

Table 5–4. Typical tower pipe and fitting zones.

Zone	Pipe Specification	Fitting Specification	Lower Floor (Elevation)	Upper Floor (Elevation)
1	Standard weight, Schedule 40, black steel	350 # WWP threaded, cast iron Class 250	102 (1,552 ft)	Roof (1,673 ft)
2	Standard weight, Schedule 40, black steel	350 # WWP threaded, cast iron Class 250	89 (1,396 ft)	101 (1,540 ft)
3	Standard weight, Schedule 40, black steel	350 # WWP threaded, cast iron Class 250	76 (1,236 ft)	88 (1,384 ft)
4	Extra strong, Schedule 80, black steel	500 # WWP threaded, malleable iron Class 300	58 (1,012 ft)	75 (1,222 ft)
5	Extra strong, Schedule 80, black steel	800 # WWP threaded, malleable iron Class 300	20 (546 ft)	57 (1,000 ft)
6	Extra strong, Schedule 80, black steel	1,000 # WWP threaded, malleable iron Class 300	B6 (242 ft)	19 (534 ft)

Vertical Supply Zones

The standpipe systems within each tower were installed with four vertical water supply zones (PANYNJ 1987a):

1. High (upper)
2. Upper mid-level
3. Lower mid-level
4. Low

Table 5–5 provides a summary of the zones.

Table 5–5. Standpipe system zones, WTC 1 and WTC 2.

	Zone	Description	Lower Floor	Upper Floor	Notes
WTC 1 (A)	1	High	77	110	Floor 75 was occupied by a 2-story MER
	2	Upper mid-level	42	76	Hose rack on FS-F1 only
	3	Lower mid-level	9	41	Floor 41 was occupied by a 2-story MER
	4	Low	1	8	Floor 7 was occupied by a 2-story MER
WTC 2 (B)	1	High	77	110	Floor 75 was occupied by a 2-story MER
	2	Upper mid-level	42	76	Hose rack on FS-F1 only
	3	Lower mid-level	9	41	Floor 41 was occupied by a 2-story MER
	4	Low	1	8	Floor 7 was occupied by a 2-story MER

The terminology for the vertical water supply zones was established for the purpose of describing the standpipe systems within this report. In the initial operating mode with water supplied from the water storage tanks only, each of these standpipe system zones functioned separately from the other zones. A series of check valves were installed between zones that prevented water from flowing downward from one zone to the next. In other operating modes, water was permitted to flow upward from one zone to the next. The manual fire pumps were used to supply water from the NYC water distribution system to all floors within either tower. The fire department connections were also used by the FDNY to supply water to the standpipe systems from the ground level (FDNY 1988; PANYNJ 1972, 1987a).

High Zone

The high zone in both WTC 1 and WTC 2 included three standpipe risers spanning all floors between the 77th and 110th floors. Figure B–7 shows the configuration of the WTC 1 high zone standpipe system with notations of the differences in the WTC 2 system. A single standpipe riser was provided in each of the three exit stair enclosures of both towers. As previously described, the standpipe risers were identified as FS-F1, FS-F2 and FS-F3 as shown in Fig. B–7. The high zone standpipes were interconnected near the top on the 109th floor and at the bottom on the 76th floor. Standpipe hose racks were provided at floors 77 through 109 in each stair enclosure. The high zone standpipe systems also contained a single hose valve manifold on the 110th floor of each tower that included three 6 by 2 ½ in. outlets (PANYNJ 1972, 1987a).

A single 5,000 gal water storage tank, FSP 110A, located on the 110th floor, was the primary water supply for the high zone standpipe system in WTC 1. The tank was equipped with an automatic re-fill connection, which was controlled by a float valve and supplied by the domestic water system. The domestic water supply was provided with a separate water service connection to the NYC water distribution system. Other than supplying the water storage tanks, the domestic water system was completely independent from the fire suppression systems. The reserve water storage tanks were intended to allow manual fire suppression efforts to begin before the manual fire pumps were turned on. The tanks were capable of supplying 500 gpm for 10 min without any additional water supply from the domestic water supply system. During this period, it was expected that the manual fire pumps would be placed into operation (PANYNJ 1972, 1983, 1987a).

A similar 5,000 gal tank, FSP 110B was located on the 110th floor of WTC 2. All of the water storage tanks in both buildings were equipped with a check valve centered between two isolation valves at the discharge outlet from the tank. The check valves prevented water pressure in the standpipe system from backfilling or overflowing water from the tanks.

High zone riser FS-F1 in WTC 1 was a 6 in. standpipe with Class III style hose racks and hose cabinets used for manual fire suppression activities. This standpipe was located in stairway B (3) at the center of the south side of the core area. This standpipe contained hose racks on every floor level between floor 77 and 107. This standpipe also supplied hose cabinets in corridors and tenant spaces on floors 89 through 91 and floors 80 and 81. Sectional isolation valves were provided at the base of the standpipe riser at floor level 76, at the top of the risers at floor level 109, and at two intermediate locations at floor levels 88 and 99 (PANYNJ 19872a, 2000).

Riser FS-F1 was configured to provide bi-directional flow in the upward and downward directions. Initially, water flowed downward from tank FSP 110 A. However, once the manual fire pumps were started, the direction of water flow changed. In the normal operating mode, water was initially gravity supplied from the 5,000 gal standpipe reserve storage tank on the 110th floor to the three standpipes. Water was supplied to the top of standpipe riser FS-F1 in the downward direction and to the other two standpipes from the bottom up. Although the standpipes were interconnected on the 109th floor, check valves prevented water from being supplied directly from the tank to standpipes FS-F2 and FS-F3. After the manual fire pumps were started, water was supplied upward through all three standpipes (PANYNJ 1987a, 2000).

Riser FS-F1 in WTC 2 was similar to the one in WTC 1, except that this riser was located at the center of the east side of the core area in stairway B (3) of WTC 2. The riser supplied water from tank FSP 110 B to all three risers allowing bi-directional flow and had isolation valves at the same locations. This riser also supplied a hose rack on floor 110 but did not supply additional hose cabinets on floors 80, 81, or 89 through 91 (PANYNJ 1972, 1987a).

Riser FS-F3 was configured the same in both towers. This standpipe was located at the northeast corner of the core area in WTC 1 and the northwest corner of the core area in WTC 2. The risers were configured to permit flow in the upward direction only. Riser FS-F3 was a 6 in. standpipe with Class III style hose racks at every floor level between 77 and 110. A check valve located at the top of the riser prevented water from flowing in the downward direction. Similar to riser FS-F1, sectional isolation valves were provided at the base of the risers at floor level 76, at the top of the risers at floor level 109, and at two intermediate locations at floor levels 88 and 99 (PANYNJ 1972, 1987a).

Riser FS-F2 in WTC 2 was identical to riser FS-F3 and was located at the southwest corner of the core area. This riser was located in the northwest corner of the WTC 1 core area. Riser FS-F2 in WTC 1 was similar, except that this riser also supplied a hose cabinet on the 82nd floor level.

Based on available information, it appears that hose racks were located in all stair enclosures at approximately 4 ½ ft above the finished floor level of the primary stair landing. This arrangement allowed the fire department to access the standpipe valve without having to traverse a half flight of stairs. Potter-Roemer 2700 series hose rack assemblies were specified for use throughout both towers. Adjustable pressure restricting devices were installed for the hose racks on floors 77 through 94 (PANYNJ 1972, 1987a, 2000b).

The typical hose rack arrangement included a 2 ½ in. standpipe valve, a 2 ½ by 1 ½ in. reducer coupling, and a hose station or hose cabinet containing 125 ft of fire hose and a nozzle. This arrangement allowed the fire department or fire brigade to stage manual fire suppression efforts using the 1 ½ in. hose line without having to carry fire hoses from the ground floor level to the upper levels of the building.

Additional hose stations were provided at the 110th floor level in each tower. These hose stations were supplied with water from automatic fire (booster) pumps located on the 108th floor level and were combined with the high zone sprinkler systems.

Upper Mid-Level Zone

The upper mid-level zone in each tower included floors 42 through 76. As with the high zone, three standpipe risers were provided, such that a single standpipe riser was provided in each of the three exit stair enclosures. The standpipes were interconnected near the top and bottom of the upper mid-level zone on floor levels 75 and 42, respectively. As with the high zone, the standpipe risers were identified as FS-F1, FS-F2 and FS-F3. Figure B–8 illustrates the configuration of the high mid-zone standpipe systems. The diagram shows the configuration of the system in WTC 1 with references to the differences in WTC 2 (PANYNJ 1987a, 2000b).

A 5,000 gal storage tank, FSP 75A, located in the MER on floors 75 and 76, was the primary water supply for the upper mid-level zone standpipe system in WTC 1. A similar 5,000 gal tank, FSP 75B was located in WTC 2. Check valves were installed within the tank discharge outlets to prevent backflow into the tanks from high pressure or surges in the standpipe system. These tanks were also equipped with automatic re-fill connections supplied by the domestic water system.

The tanks also served as intermediate water supply stages for the high zone standpipe systems. Manual fire pumps were installed to boost pressure in the system in order to provide sufficient energy to counteract the effects of gravity and lift the water to the 110th floor level. Check valves were provided within the pump discharge and by-pass piping to prevent water from the high zone from flowing down into the lower zones below.

As with the high zone, riser FS-F1 was a 6 in. standpipe located in stairway B (3) (PANYNJ 1972, 1987a). Water was supplied to this riser from the reserve water storage tank on the MER on the 75th floor level. This riser was configured to permit bi-directional water flow and was used to supply water to the other two standpipes. Sectional isolation valves were provided at the base of the riser at floor level 42, at the top of the riser at floor level 76, and at two intermediate locations at floor levels 54 and 65.

Class III style hose racks were provided at all floor levels between 42 and 75. Riser FS-F1 of WTC 1 also supplied a hose cabinet on floor 50; the riser in WTC 2 did not, however.

Risers FS-F2 and FS-F3 in WTC 2 were similar; both standpipes contained check valves at the top, allowing water to flow through the standpipe in the upward direction only. Although the location of the standpipes varied laterally within the stair enclosures, these risers were all similar. Each standpipe supplied hose racks on all floor levels between 43 and 74. Riser FS-F2 supplied an additional hose rack at the 75th floor level. Adjustable pressure restricting devices were installed for the hose racks on all three risers for floors 59 through 42.

The risers in WTC 1 also supplied hose cabinets. These risers all contained intermediate sectional isolation valves at floor levels 54 and 65. Riser FS-F2 supplied a hose cabinet on the 44th floor. Riser FS-F3 supplied a hose cabinet on the 48th floor (PANYNJ 1972, 1987a, 2000b).

Lower Mid-Level Zone

The standpipes in this zone were also interconnected near the top and bottom at floors 41 and 8, respectively. As with the two zones above, these risers were identified as FS-F1, FS-F2 and FS-F3. Figure B–9 shows the configuration of the low mid-zone standpipe system in WTC 1 with reference to the differences in the WTC 2 system.

The water supplies for lower mid-level zones included 5,000 gal reserve storage tanks, FSP 41A and FSP 41B, located on the 41st MERs. These tanks were also used as intermediate water supply stages for the standpipe system zones above. Manual fire pumps were installed with check valves in the discharge and by-pass piping to prevent backflow of water from the zones above.

As with the higher zones, riser FS-F1 in WTC 1 was a 6 in. standpipe located in stairway B (3). Water was supplied to this riser from the reserve water storage tank in the 41st floor MER and was used to supply water to the other two standpipes within the zone. The riser in WTC 2 was also located in stairway B (3) and functioned the same. This riser was configured to permit bi-directional water flow. Sectional isolation valves were provided at the base of the riser at floor level 8, at the top of the riser at floor level 41, and at two intermediate locations at floor levels 21 and 32. Class III style hose racks were provided at all floor levels between 9 and 41. Riser FS-F1 of WTC 1 also supplied hose cabinets on floors 10 through 15, 18, 19, 21 through 26, 29 through 31, 33 through 35, 39 and 40. The standpipe system in WTC 2 did not include these additional hose cabinets.

Risers FS-F2 and FS-F3 in WTC 2 and WTC 1 were all similar; these standpipes contained check valves at the top, allowing water to flow through the standpipe in the upward direction only. Each standpipe supplied hose racks on all floor levels between 9 and 41. These risers all contained intermediate sectional isolation valves at floor levels 21 and 32. Adjustable pressure restricting devices were installed for the hose racks on all three risers for floors 9 through 25 (PANYNJ 1972, 1987a, 2000b).

Low Zone

The low zone standpipe systems included floors one through seven in each of the WTC 1 and WTC 2 towers. Figure B–10 shows the configuration of the low zone standpipe systems. These systems were also interconnected with the high zone standpipe systems above in each individual tower. The two systems were also interconnected with each other and the two distribution loops that supplied water throughout the WTC complex. The primary water supply for the low zone standpipe systems in both towers was provided by a single 5,000 gal storage tank, FSP storage tank 20A, located on the 20th floor of WTC 1. A similar tank was not provided in WTC 2.

Water was supplied from tank FSP 20A through a single 6 in. riser in WTC 1 to the 8 in. distribution loop on the B1 level. This distribution loop was interconnected at two locations with a second 8 in. loop located on the concourse level. These distribution loops interconnected the standpipe systems for the six buildings in the main WTC complex, including WTC 1 through WTC 6. The loops also distributed water to the sub-grade standpipe systems. Figures B–4 and B–5 illustrate the configuration of the two loops.

Similar to the higher zones of the standpipe systems, three 6 in. risers were used to supply hose stations throughout the low zone. Again each tower was provided with risers FS-F1, FS-F2, and FS-F3, which were interconnected at the bottom and top of the zone. All of the risers included control valves at the tops and bottoms at floors 7 and the B1 levels, respectively. However, the low zone risers FS-F2 and FS-F3 were not equipped with check valves at the top. Therefore, all three of the standpipe risers allowed for bi-directional water flow. The low zone systems were similar but did not supply hose racks at all floor levels. Therefore, these risers will be discussed individually by tower (PANYNJ 1972).

Riser FS-F1 of WTC 1 supplied hose racks in stair B on the third, sixth, and seventh floors. In addition, this riser supplied a remote hose rack located on the first floor level. A hose cabinet located at the first floor level was supplied by a separate 4 in. main attached to the sub-grade level standpipe system riser in stair B. Riser FS-F2 included hose racks in stair C on the second and seventh floor levels only. A hose cabinet located in stair C on the first floor level was equipped with a separate 4 in. main connected to the sub-grade level standpipe system. Riser FS-F3 supplied hose racks in stair A on the second and seventh floors only (PANYNJ 1972, 1987a).

Riser FS-F2 of WTC 2 supplied hose racks at the first, second, and seventh floor levels in stair B. An additional hose rack was supplied at the first floor level of stair B by a separate 4 in. main attached to the sub-grade level standpipe system riser. Riser FS-F2 supplied hose racks on the second and seventh floor levels. A hose cabinet was provided at the first floor level, however, it was supplied by a separate 4 in. main attached to the sub-grade level system. Riser FS-F3 supplied hose racks in stair A on the third through seventh floor levels. Two additional remote hose stations on the first floor level were provided with separate 4 in. risers attached to the sub-grade level standpipe systems (PANYNJ 1972, 1987a).

5.2.3 Automatic Fire Sprinkler Systems

The automatic fire sprinkler systems for the towers were configured with two distinctly separate infrastructures, one for the sub-grade levels and another for the towers, similar to the arrangement for the standpipe systems (PANYNJ 1972, 1987a). The system infrastructure associated with the sub-grade levels was also used to supply automatic fire sprinkler systems in the WTC 4 and WTC 5 buildings (PANYNJ 1987a). Although a brief description of the sub-grade level sprinkler systems is provided in this report, the primary focus was directed at describing the tower sprinkler systems. Figures B–4 and B–5 illustrate the configuration of the sprinkler system loops on the concourse and B1 levels.

The sprinkler systems for the sub-grade levels were equipped with two separate and independent connections to the NYC water distribution systems (PANYNJ 1972, 1987a). This configuration provided two redundant water supply connections for the sub-grade sprinkler systems. Two fire pumps were used to supply water to the sprinkler systems on the sub-grade levels. Similar to the configuration of the standpipe systems on the sub-grade levels, two loops were provided for the sprinkler systems, one loop on the B1 level and a second loop on the concourse level. This sprinkler system infrastructure was completely separate from the standpipe systems (PANYNJ 1972, 1987a). However, the sprinkler system infrastructure for the towers was supplied with water from the standpipe systems.

The sprinkler systems for the towers were configured such that each floor level was provided with an independent sprinkler system. Figure B–11 provides a representation of the tower sprinkler systems. These sprinkler systems were supplied with water from a single shared sprinkler riser within the vertical water supply zones. The primary “automatic” water supply for each zone was provided from a series of gravity supplied water storage tanks dedicated to the automatic sprinkler systems or combined with the standpipe systems.

Separate sprinkler and standpipe risers were provided, even though the two systems shared the standpipe system infrastructure to provide water in addition to the initial reserve water supply stored in the gravity tanks. These systems were unlike most typical “combined systems” that have both sprinkler system floor control valve assemblies and standpipe hose valves directly connected to the same risers. In this case, the standpipe systems served as the secondary or tertiary water supplies for the sprinkler systems depending on the riser. Both the fire department connections and manual pumps could be used simultaneously to supply water to the standpipes and automatic fire sprinkler systems (PANYNJ 1972, 1987a).

Installation Schedule

The automatic fire sprinkler systems in the WTC 1 and WTC 2 towers were retrofit after the buildings were constructed. The initial base building installation included the standpipe system and the sprinkler systems throughout the sub-grade levels. The retrofit sprinkler systems were installed in the towers in two phases in response to the enactment of Local Law 5. The first phase was completed in 1976 and consisted of the installation of the sprinkler system infrastructure within the towers. This phase included the installation of the sprinkler system risers, cross-mains, and sprinklers throughout the core areas and in select tenant spaces operated by the PANYNJ. The second phase included the installation of sprinkler systems throughout the tenant areas. This phase occurred from 1983 through early 2001 (FDNY 1993b; PACO 2002; GC Engineering 1998).

Design Basis and Associated Criteria

In 2001, the buildings were equipped throughout with sprinklers in all areas, except mechanical and electrical rooms. The designs of the sprinkler systems in WTC 1 and WTC 2 were based on the PANYNJ guideline specifications, which required all tenant spaces to be provided with automatic fire sprinklers. The core areas, PANYNJ spaces, and select tenant spaces were equipped throughout with automatic fire sprinklers in 1976 as part of the first phase of the tower retrofit installations.

New tenants were required to install automatic fire sprinkler protection throughout (PANYNJ 2000b). Existing tenant spaces were required to install or modify sprinkler systems to comply with the partition layout if the spaces were renovated (PANYNJ 2000b). These systems were designed and installed from 1983 to 2001, during the final phase of the sprinkler systems installations (GC Engineering 1998). All sprinkler systems were designed in accordance with the requirements of the BCNYC, NFPA 13, and the PANYNJ/World Trade Division (PANYNJ 1987a, 2000a). The designs for all sprinkler systems were based on the occupancy hazard fire control approach and were hydraulically calculated. Other referenced standards were used for specialized hazards.

Modifications to existing sprinkler systems during renovations were permitted to use the pipe schedule method, an alternative to the hydraulic calculation method (PANYNJ 2000a). However, except for minor renovations that required relocations of sprinklers without adding sprinklers, the designs were hydraulically calculated (PACO 2002). Modifications to sprinkler systems in tenant spaces that resulted in the same number of sprinklers before and after completion used the pipe schedule method. All tenant spaces were provided with temporary sprinkler protection during renovations (PACO 2002).

The design guidelines and associated drawings indicated that wet-pipe sprinkler systems were designed and installed throughout, using the hydraulic calculation method as follows:

- All tenant spaces, lobbies, public spaces, and restaurant seating areas
    - Wet-pipe sprinkler system based on NFPA 13 and RS-17 Light Hazard Occupancy requirements with a density of 0.10 gpm/ft^2 over 1,500 ft^2
- Mechanical equipment rooms, mechanical spaces, janitor closets, and mail room, restaurant services areas
    - Wet-pipe sprinkler system based on NFPA 13 and RS-17 Ordinary Hazard Group 1 requirements with a density of 0.16 gpm/ft^2 over 1,500 ft^2
- Commercial and storage spaces
    - Wet-pipe sprinkler system based on Special Hazard in accordance with NFPA 13, NFPA 15, NFPA 16, NFPA 231, or NFPA 231C

The PANYNJ design criteria paralleled NFPA 13 criteria regarding the omission of sprinklers from spaces containing energized electrical equipment. The following four specific criteria were required for omission (PACO 2002):

1. The closet had to be dedicated to electrical equipment only and was not used for storage.
2. A 2 h fire resistance rated enclosure was provided, penetrations were protected with through penetration fire-stop systems, and opening protectives were used.
3. A smoke detector connected to the base building fire alarm system had to be installed in the closet.
4. Only dry type electrical equipment was used.

Sprinklers were installed in electric closets, communicating closets, telephone closets, emergency generator spaces, transformer and switchgear spaces, and telephone equipment rooms, unless the room configuration and contents met the screening criteria outlined above for omission (PACO 2002).

Pre-action sprinkler systems were specified for some computer rooms in place of wet-pipe sprinkler systems. In other computer rooms, clean agent total flooding fire suppression systems were specified instead of automatic fire sprinklers. The Operations and Maintenance (O&M) manuals document that these types of systems were installed. However, the actual locations where pre-action sprinkler systems and clean agent suppression systems were installed could not be verified based on the information available at this time.

Water curtains were installed for the protection of internal open staircases. The design approach closely resembled the design option outlined in the “special design approaches” section of NFPA 13. A draft stop was installed around the perimeter of the opening and closely spaced sprinklers (6 ft on center) were positioned 12 in. from the opening (PACO 2002).

Sprinkler System Risers

Existing documentation refers to the tower sprinkler systems as two separate zones with three risers (PANYNJ 1987a, 1972). The zones are identified as the high zone and the low zone. However, the high zone was separated into two different sub-sections using two separate risers. Therefore, the towers were actually separated into three vertical water supply zones. These zones are referred to as the high, mid-level, and low zones in this report. Each zone was provided with a separate sprinkler system riser as identified in Table 5–6. Figure B–11 illustrates the configuration of the risers within both towers. In all cases, the primary direction of water flow was downward from the top of the riser to the sprinkler systems. However, the low zone risers were arranged to allow water to flow upward while using a secondary water supply.

Table 5–6. WTC 1 and WTC 2 sprinkler system risers.

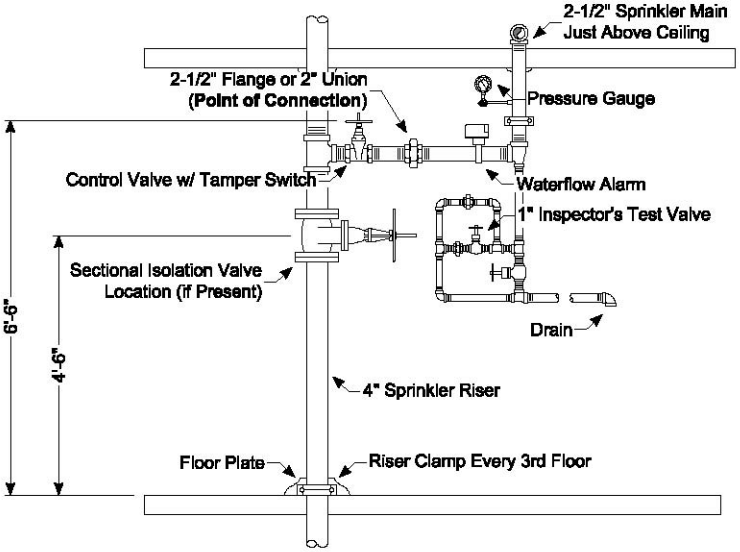
Zone	Riser	Lower Floor	Upper Floor
High	A	99	107
Mid-level	B	98	33
Low	C	32	1

Each sprinkler riser was supplied with water through a single connection to the standpipe system. Risers A and B in both towers were connected to the water storage tanks and standpipe system on the 109th floor. Riser A in each tower is referred to in this report as the high zone. Similarly riser B is referred to as the mid-level zone. Riser C was connected to the combined standpipe and sprinkler system tank on the 41st floor and supplied water to the low zone in each tower. The A risers were unique from the other gravity supply risers, since these risers were equipped with small booster pumps located on the 108th floor. Additionally, the A risers supplied standpipe hose stations on the 110th floor.

Sectional isolation valves were provided at floors 1 and 15 for riser C of WTC 1. A single sectional isolation valve was provided at floor 67 in riser B of WTC 1. Sectional isolation valves were also provided at floors 1 and 15 for riser C of WTC 2. However, a single sectional isolation valve was provided at floor 77 in riser B of WTC 2. Neither of the high zone (A) risers was provided with an intermediate sectional isolation valve (PANYNJ 1987a, 1972).

Floor Level Sprinkler System Components

A separate and independent sprinkler system was provided at each floor level. These systems were connected to the shared riser and water supply within each respective zone. Each system contained a floor control valve assembly separating it from the shared infrastructure. Figure 5–6 shows the configuration of a typical floor control valve assembly. In general, automatic fire sprinkler protection was provided throughout the WTC 1 and WTC 2 buildings, with the exception of the mechanical equipment room (MER) floor levels. Figure B–11 illustrates the areas of the building that were equipped with automatic sprinkler systems (PANYNJ 1972, 1987a, 2000).



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

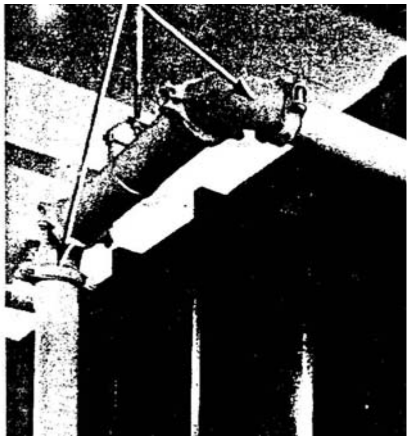
Figure 5–6. Typical floor control valve assembly.

Pipe and Fittings

The Port Authority fire protection design guidelines indicated that all sprinkler system piping was required to be standard weight schedule 40 black steel pipe with threaded cast Class 125 or malleable Class 150 iron fittings. The available drawings indicated that all floor sprinkler system piping was installed according to these specifications. The guideline specifications also explicitly excluded schedule 10 light-wall pipe, and schedule 30 pipe, groove and mechanical pipe joining methods. However, special approval could be given for the use of groove-type fittings. Figure 5–7 shows that groove-type fittings were installed. This photograph was taken from the O&M manual for the sprinkler systems (PANYNJ 1972, 1987a, 2000b).

The guideline specifications also identified the following requirements:

- Extra-heavy shoulder type nipples and made of the same material as the pipe. Close nipples, adjustable sprinkler nipples, and bushings were not permitted.
- Unions for piping connections 2 in. and smaller or flanged connections for piping 2 ½ in. or larger.
- Full-face gaskets for flanges made of rubber or neoprene 1/16 in. thick after compression with punched holes.
- Schedule 40 galvanized pipe with galvanized threaded fittings were permitted to be installed for pre-action systems.
- Schedule 40 galvanized pipe sleeves and chrome plated escutcheons for piping penetrating masonry walls. Openings around pipes were limited to ½ in. between pipe and sleeves.
- Insulation for all sprinkler piping and fittings within 15 ft of exterior walls.



Source: PANYNJ 1987a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–7. Examples of groove-type pipe fittings.

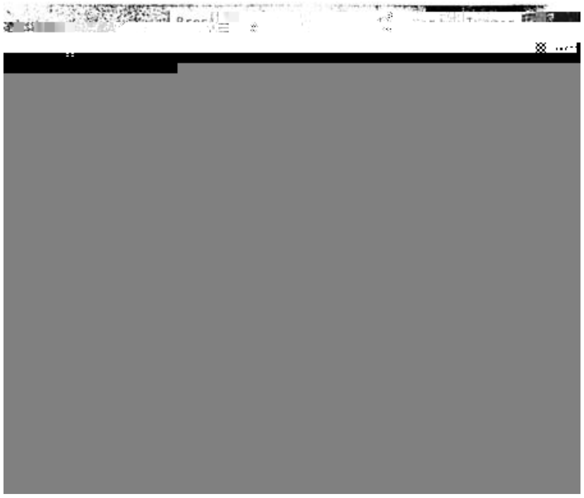
Information contained in the O&M manual for the sprinkler systems indicated that provisions were included in the design of the systems in WTC 1 and WTC 2.

Floor Control Valve Assemblies

The sprinkler risers and floor control valve assemblies were located in a janitor’s closet within the core area of each tower. Although the location of the risers varied within the buildings, all of the risers were located within the core area. Due to the large pressure differences established as a result of the elevation changes within each zone, two different types of control valve assemblies were required. One arrangement included an outside screw and yoke (OS&Y) valve rated for 175 psi and the other a combination control and pressure-reducing valve. The two assemblies were used since the piping for the sprinkler systems on each floor were installed with standard weight schedule 40 pipe and fittings rated for 175 psi. The guideline specifications also identified the following requirements for valves:

- 2 in. and smaller—threaded bronze body valves.
- 2 ½ in. and larger—flanged iron body valves.
- 6 in. and larger valves also required a by-pass connection.

The sprinkler system infrastructure experienced elevated pressure due to the extreme elevation differences. These pressure differences are discussed later in this report. The pressure-reducing valve type of floor control valve assembly was used to prevent water pressure from damaging sprinkler system components. These assemblies also included a pressure relief valve on the floor level sprinkler system side of the valve as an additional safety precaution to prevent damage to the sprinkler system piping. Figure 5–8 demonstrates a typical floor control valve assembly with a combination pressure-reducing control valve. This photograph was taken from the O&M manual (PANYNJ 1972, 1987a, 2000b).



Source: PANYNJ 1987a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–8. Combination pressure reducing control valve assembly.

A summary of the locations where each type of valve was used within each tower is provided in Table 5–7.

Table 5–7. Summary of WTC 1 and WTC 2 floor control valve assemblies.

Tower	Riser	Lower Floor	Upper Floor	OS&Y Valve	Pressure Reducing Valve with Pressure Relief Valve	Comments
WTC 1	A	99	107	●		
	B	87	98	●		
	B	32	86		●	MER floors 41, 42 and 76 did not contain sprinkler systems
	C	9	31	●		
	C	1	8		●	MER floors 7 and 8 were provided with 2½ in. capped outlets only
WTC 2	A	99	107	●		
	B	87	98	●		
	B	32	86		●	MER floors 41, 42 and 76 did not contain sprinkler systems
	C	9	31	●		
	C	1	8		●	MER floors 7 and 8 were provided with 2½ in. capped outlets only

The floor control valve assemblies also required the following:

- Floor control valves were required to have electrical tamper switches to monitor the position of the valves. The tamper switches were electrically connected to the fire alarm system and were used to detect and indicate when a valve was closed. Information in the O&M manual indicates that tamper switches were installed for the control valves in WTC 1 and WTC 2 (PANYNJ 1987a, 2000a).

- Drain and test valves were required at system low points. The drains were required to be connected to a drain receptacle or have a threaded hose and adapter at the valve outlet. Photographs of the sprinkler system riser and express drains in the O&M manual illustrate that drains were generally installed as required (PANYNJ 1987a, 2000a).

- Swing type check valves where required for all sprinkler systems and were installed as follows:

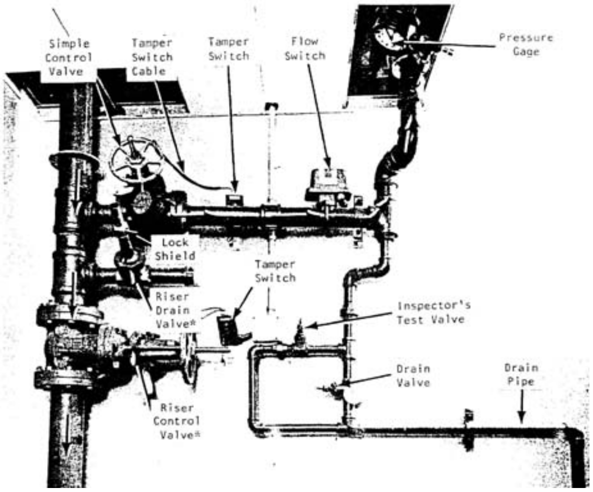
  – 2 in. and smaller—threaded bronze type

  – 2½ in. and larger—iron body type

- Vane or pressure type water flow switches were required to sense water flow. The flow switches were required to have two single-pole double-throw switches and adjustable pneumatic retard to prevent nuisance alarms associated with pressure surges. Information on the design drawings and in the O&M manual demonstrates that flow switches were installed (PANYNJ 1987a, 2000a).

- Pressure gauges, sight glasses, and valve tags were also installed.

Figure 5–9 demonstrates a typical floor control valve assembly with an OS&Y valve. This photograph was taken from the O&M manual (PANYNJ 1987a).



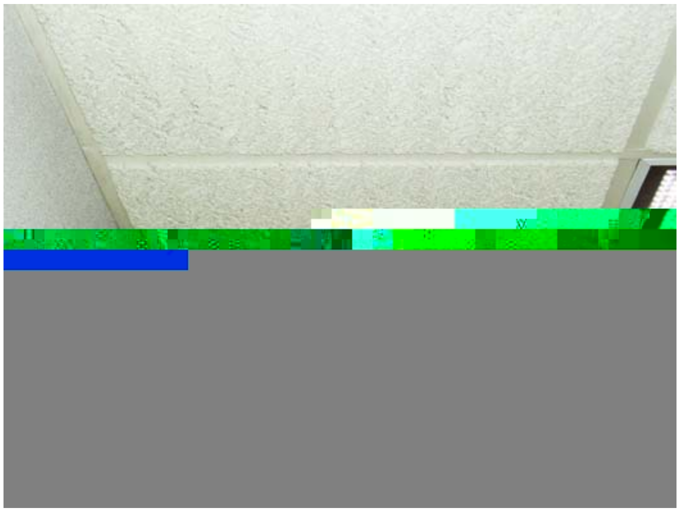
Source: PANYNJ 1987a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–9. Typical floor control valve assembly as installed in WTC 1 and WTC 2.

Pre-action systems required OS&Y type control valves and hydraulically operated differential diaphragm type deluge valves with manual and electric detectors. Pre-action systems also required self-contained automatic air maintenance devices. Information provided in the design documents and the O&M manual indicated that these features were included in the design of the sprinkler systems in WTC 1 and WTC 2 (PANYNJ 1987a).

Sprinklers

Concealed pendent sprinklers with chrome cover plates were installed in all finished areas. Figure 5–10 is a photograph of a typical concealed sprinkler cover plate. Upright or pendent type sprinklers were installed in areas without finished ceilings (PANYNJ 1987a). Figure 5–11 is a photograph of a standard spray pendent sprinkler. Sprinklers with an operating temperature rating of 165 °F were installed throughout most areas (PANYNJ 1987a). Higher temperature rated sprinklers were installed in areas with ceiling temperatures above 100 °F (PANYNJ 1987a). Protective guards or shields were installed in areas where sprinklers were potentially subject to mechanical damage (PANYNJ 1987a). Documentation indicated that ½ in. orifice sprinklers with a k-factor of 5.6 were installed throughout WTC 1 and WTC 2 (PANYNJ 1987a).



Source: NIST.

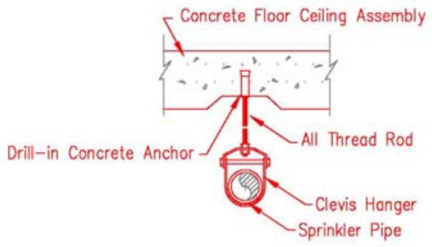
Figure 5–10. Typical concealed pendent sprinkler.

Source: NIST.

Figure 5–11. Typical standard spray pendent sprinkler.

Hangers and Supports

Clevis type hangers were used for the support of all sprinkler piping (PANYNJ 1972, 1987a). Additional anchors and support were required to accommodate all forces imposed by expansion joints in addition to the normal structural requirements (PANYNJ 2000a). Adequate clearances were specified to be maintained between sprinkler pipes and all other piping, equipment, and structures. Two typical hanger arrangements were permitted, one for attachment to steel beams or joists and the other for direct attachment to concrete floors and ceiling assemblies. Figure 5–12 illustrates the two arrangements. The hanger assembly for attachment to concrete assemblies included a concrete insert anchor, threaded rod, and a clevis hanger. The steel arrangement included a “c-clamp” or top-beam clamp attached to a steel beam or joist, a steel retaining strap, threaded rod, and a clevis hanger.



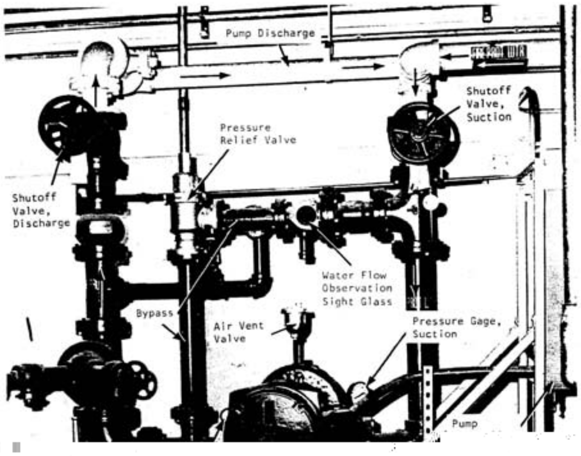
Drilled Concrete Anchor Hanger
Scale: N.T.S.

Steel C–Clamp Hanger With Retaining Strap
Scale: N.T.S.

Figure 5–12. Typical hanger arrangements.

High Zone Sprinkler Systems

The sprinkler systems supplied by riser A are referred to as the high zone and included the systems for floors 99 through 107. Figure B–12 provides a schematic representation of the high zone sprinkler system infrastructure. These systems were supplied with water from an automatic 500 gpm at 60 psi rated fire (booster) pump located in the mechanical room on the 108th floor of each tower. Figure 5–13 shows the fire pump from WTC 1, which was taken from the O&M manual (PANYNJ 1987a). The fire pumps were used to increase the water pressure for the sprinkler systems on the upper levels since the pressure due to the elevation difference between the water level in the tanks and the sprinkler pipes was less than the required pressure for the proper operation of the sprinkler systems.



Source: PANYNJ 1987a . Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–13. Automatic sprinkler system booster pump.

Pressure reducer type control valves were not required for the high zone sprinkler systems since the static pressures at the floor control valve elevations were less than the maximum working pressure of 175 psi for standard weight sprinklers and fittings. Therefore, OS&Y valves were installed for all floor level sprinkler systems in the high zone (PANYNJ 1972, 1987a). Table 5–8 provides a summary of the static pressures at each high zone sprinkler system floor control valve elevation along riser A within each tower.

Table 5–8. Summary of high zone static pressure.

Riser A Static Pressure at Floor Control Valves							
Floor	Pressure (psi)	WTC 1 Elevation (ft)	WTC 2 Elevation (ft)	Floor	Pressure (psi)	WTC 1 Elevation (ft)	WTC 2 Elevation (ft)
110	1.3	1,658	1,652	104	116.4	1,576	1,570
109	8.6	1,646	1,640	103	121.6	1,564	1,558
108	88.6	1,632	1,626	102	126.8	1,552	1,546
107	99.8	1,614	1,608	101	132.0	1,540	1,534
106	106.0	1,600	1,594	100	137.2	1,528	1,522
105	111.2	1,588	1,582	99	142.4	1,516	1,510

Mid-Level Zone Sprinkler Systems

The sprinkler systems for floors 32 to 98 were included in the mid-level zone. The primary water supply for these sprinkler systems was provided from tank 110A in WTC 1. Similarly, tank 110B provided water to the sprinkler systems in WTC 2. The primary and back-up water supplies for the mid-level zone sprinkler systems were shared with the high zone sprinkler systems. However, the mid-level zone sprinkler systems were supplied separately through riser B.

Unlike the high zone systems, a booster pump was not provided for the mid-level zone sprinkler systems. The pressure in the system increased at the rate of 0.433 psi per foot of elevation and is referred to as elevation or gravity head pressure. The water storage tanks were located on the 110th floor far above the mid-level zone sprinkler systems. The elevation difference was used to supply pressure to the mid-level zone sprinkler systems. The tank was located approximately 155 ft above the 98th floor sprinkler system, the highest of the mid-level zone systems. This elevation difference resulted in a normal operating pressure of approximately 67.5 psi at the 98th floor sprinkler system. Table 5–9 provides a summary of the static pressure at each floor control valve assembly for the systems supplied by riser B in the mid-level zone (PANYNJ 1972, 1987a, 2000b).

The mid-level zone served the largest number of floors, which resulted in the greatest variation in pressure from the top to the bottom of the sprinkler riser (PANYNJ 1972, 1987a). There was an elevation pressure difference of 351 psi between the sprinkler systems at the top (98th) and bottom (32nd) floors of the mid-level zone. A normal static pressure of 67.5 psi was observed at 98th floor sprinkler system (PANYNJ 1987a). However, a normal static pressure of 418.5 psi was observed at the 32nd floor sprinkler system. Since standard weight fittings rated at 175 psi were used for all individual floor level sprinkler systems, pressure-reducing valves were required to regulate the system pressures to within the working tolerances of the pipe and fittings (PANYNJ 1987a, 2000a). Table 5–7 identifies that combination control and pressure reducing valves were used for the sprinkler systems on floors 32 through 86 in both towers.

Low Zone Sprinkler Systems

The sprinkler systems floors 1 through 31 were identified as the low zone (PANYNJ 1987a). The primary water supply for the low zone sprinkler systems in WTC 1 was provided by reserve water storage tank 42A, which was located in the 41st/42nd floor MER. The riser for the low zone sprinkler system, riser C, was interconnected with the low zone system for WTC 2 through a 4 in. diameter main located on the B1 level (PANYNJ 1972, 1987a). The interconnecting pipe was provided with a manually operated isolation valve between the two building systems, which was referred to as the “tower isolating valve” (PANYNJ 1987a). This arrangement permitted the water storage tanks to be used as the primary water supply within the tower where the tank was located and the secondary water supply in the other tower. Refer to Fig. B–1. For example, tank 42B, located on the 42nd floor of WTC 2, was used as the secondary water supply for the low zone sprinkler systems in WTC 1. Similar to the mid-level zone sprinkler systems, water pressure was supplied by gravity. Table 5–10 provides a summary of the static pressure observed at each floor control valve assembly connected to riser C in the low zone.

Table 5–9. Summary of mid-level zone static pressure.

Riser B Static Pressure at Floor Control Valves							
Floor	Pressure (psi)	WTC 1 Elevation (ft)	WTC 2 Elevation (ft)	Floor	Pressure (psi)	WTC 1 Elevation (ft)	WTC 2 Elevation (ft)
98	67.5	1,504	1,498	64	248.3	1,084	1,082
97	72.7	1,492	1,486	63	253.4	1,072	1,070
96	77.9	1,480	1,474	62	258.5	1,060	1,058
95	83.1	1,468	1,462	61	263.6	1,048	1,046
94	88.3	1,456	1,450	60	269.0	1,036	1,034
93	93.5	1,444	1,438	59	274.1	1,024	1,022
92	98.7	1,432	1,426	58	279.2	1,012	1,010
91	103.9	1,420	1,414	57	284.3	1,000	998
90	109.1	1,408	1,402	56	289.4	988	986
89	114.3	1,396	1,390	55	294.6	976	974
88	119.5	1,384	1,378	54	300.0	964	962
87	124.7	1,372	1,366	53	305.1	952	950
86	129.9	1,360	1,354	52	310.3	940	938
85	135.1	1,348	1,342	51	315.5	928	926
84	140.3	1,336	1,330	50	320.7	916	914
83	145.5	1,324	1,318	49	326.0	904	902
82	150.7	1,312	1,306	48	331.1	892	890
81	155.9	1,300	1,294	47	336.3	880	878
80	161.1	1,288	1,282	46	341.5	868	866
79	166.3	1,276	1,270	45	346.7	856	854
78	172.3	1,262	1,256	44	352.8	842	840
77	177.5	1,250	1,244	43	358.8	828	828
76	183.5	1,236	1,230	42	364.0	814	814
75	189.5	1,222	1,216	41	371.0	800	800
74	195.5	1,208	1,202	40	377.0	786	786
73	200.7	1,196	1,190	39	382.1	774	774
72	205.8	1,184	1,178	38	387.3	762	762
71	210.9	1,172	1,166	37	392.5	750	750
70	216.0	1,160	1,154	36	397.7	738	738
69	221.1	1,148	1,142	35	403.0	726	726
68	226.2	1,136	1,130	34	408.1	714	714
67	233.0	1,120	1,118	33	413.3	702	702
66	238.1	1,108	1,106	32	418.5	690	690
65	243.2	1,096	1,094				

Table 5–10. Summary of low zone static pressure.

Riser C Static Pressure at Floor Control Valves							
Floor	**Pressure (psi)**	**WTC 1 Elevation (ft)**	**WTC 2 Elevation (ft)**	**Floor**	**Pressure (psi)**	**WTC 1 Elevation (ft)**	**WTC 2 Elevation (ft)**
31	59.0	678	678	15	142.9	486	486
30	65.0	666	666	14	148.1	474	474
29	70.1	654	654	13	153.3	462	462
28	75.3	642	642	12	158.5	450	450
27	80.5	630	630	11	163.7	438	438
26	85.7	618	618	10	168.9	426	426
25	90.9	606	606	9	174.1	414	414
24	96.1	594	594	8	178.4	404	404
23	101.3	582	582	7	184.5	390	390
22	106.5	570	570	6	189.5	379	379
21	117.7	558	558	5	194.5	367	367
20	116.9	546	546	4	199.4	356	356
19	122.1	534	534	3	204.3	344	344
18	127.8	522	522	2	209.4	332	332
17	132.5	510	510	1	214.5	310	310
16	137.7	498	498				

5.2.4 Electrical Power Supply

The primary electrical power supply for the WTC complex (including WTC 1 and WTC 2) was provided by the Consolidated Edison Company (Con-Ed) substation located in WTC 7 (McAllister 2002; Beyler 2002). Several substations and transformers were used to distribute power throughout the WTC complex. The primary electrical feeders were routed from the WTC 7 substation through the sub-grade level beneath the truck ramp to the main power distribution center on the B3 level. Reports indicate that the main power distribution center remained intact after the collapses of both WTC 1 and WTC 2. Separate feeders were independently routed from the main power distribution center to each tower (LZA Technology 2002; Beyler 2002).

The secondary power supply was provided by six 1,200 kW emergency generators (Beyler 2002; McAllister 2002). The critical equipment included, but was not limited to, emergency lighting, elevators and fire pumps. The generators were located on the B6 level along the West Street side of the complex and were reported to be intact after the collapse (Beyler 2002). Documentation of the secondary electrical system indicates that a single circuit supplied power to the manual fire pumps on the B1 level in both WTC 1 and WTC 2. It is likely that this circuit was lost after the collapse of WTC 2.

5.2.5 Special Hazard Suppression Systems

Several types of special suppression systems were installed in WTC 1 and WTC 2 on a limited basis to protect specific areas (PANYNJ 1987b). These systems included:

- Dry chemical and steam smothering systems
- Carbon dioxide (CO_2) systems
- Halon 1301 total flooding systems

These systems were supervised by the fire alarm systems in WTC 1 and WTC 2 and were designed to transmit signals to the FDNY upon activation (Keough and Grill 2005).

Dry Chemical Systems

Restaurant cooking appliances were equipped with dry chemical fire suppression systems (PANYNJ 1987b). These systems contained dry chemical fire suppression agents (potassium bicarbonate or ammonium phosphate). The dry chemical agents were stored in cylinders and were released by an actuator that would discharge the agent upon fusing of a thermal link located above the cooking appliance or within the exhaust duct. The dry chemical systems were also provided with manual release mechanisms to allow for the occupants to actuate the systems manually. The O&M manual described that these systems were installed in WTC 1 and WTC 2, but again did not identify specific locations.

Limited Steam Smothering Systems

The use of steam systems for fire suppression preceded the use of CO_2 and dry chemical fire suppression systems (PANYNJ 1987b). The exhaust ducts in the large kitchens at the WTC complex were equipped with steam smothering systems. The O&M manual indicated that steam smothering systems were installed in the kitchens at the following locations:

- PA Cafeteria
- The “Big Kitchen”
- The Sky Dive
- Windows on the World
- The New York State Cafeteria
- The Observation Deck

Carbon Dioxide Systems

Carbon dioxide (CO_2) is electrically nonconductive and is commonly used to extinguish fires involving electrical equipment. CO_2 suppression systems were installed in computer rooms in WTC 1 and WTC 2.

Smoke and heat detectors were used to detect fire and to actuate the releasing mechanism causing CO_2 to discharge into the room (PANYNJ 1987b).

A total flooding CO_2 system was used to protect the under floor space of a large computer room in WTC 2 (PANYNJ 1987b). Reference was found to other systems at the WTC complex, but there were no specific indications regarding the locations or details of these systems. CO_2 can cause asphyxiation to the displacement of air. These systems were provided with local alarm bells to indicate to the occupants that the system was activated and the room should be evacuated.

Halon 1301 Systems

The term halon refers to halogenated hydrocarbon gases which are used as fire extinguishing agents. (Halogenated compounds contain fluorine, chlorine, bromine and iodine.) Halon agents extinguish fires by interrupting the combustion process. These systems also require evacuation during activation.

Halon systems are used in both local and total flooding applications, similar to CO_2 systems. Halon 1301 total flooding systems were used for the protection of computer rooms in WTC 1 and WTC 2. Halon total flooding systems protect enclosed rooms or areas. Halon is stored in holding cylinders, which are actuated upon the response of a two cross-zoned smoke detectors. The O&M manual describes that two separate cross-zoned detection system zones were installed, and release occurred upon activation of a detector within each zone. The available drawings for WTC 1 show that two Halon 1301 systems were installed for protection of the computer room on the 70th floor. One system was installed for protection of the under floor space and the other for protection of the room (PANYNJ 1972, 1987a).

5.2.6 Fire Protection in the Initial Impact Areas

The fire protection systems in the initial impact areas were basically the same as all other areas throughout the towers. The damage estimates and operability of the fire suppression systems in WTC 1 and WTC 2 as a result of the September 11, 2001 incident are provided in Chapter 9.

WTC 1, Floors 89 through 110

The initial damage to the fire protection systems was sustained on floors 93–99 of WTC 1 within the initial impact area as a result of the collision by a commercial jet aircraft on September 11, 2001 (McAllister et al. 2005). This section of the report provides a description of the fire protection systems on those floors as well as multiple floors above and below the initial impact areas. A description of the fire protection systems on floors 89 through 110 is included in this section.

The high zone standpipe system in WTC 1 included all floors vertically between the 77th floor and the 110th floor (PANYNJ 1972). Three separate standpipes were installed, one in each stair enclosure (PANYNJ 1987a). The standpipes were interconnected at the bottom of the zone on the 76th floor and at the top of the zone on the 109th floor (PANYNJ 1972, 1987a). Check valves were installed at the top of two of the standpipes, FS-F2 and FS-F3, preventing water from flowing downward (PANYNJ 1972, 1987a). The third standpipe, FS-F1, was not provided with a check valve (PANYNJ 1972, 1987a). Each standpipe supplied 2 ½ in. hose valves with 2 ½ by 1 ½ in. reducers and either a hose cabinet or hose rack (PANYNJ 1972, 1987a).

Water was gravity supplied to standpipe FS-F1 from the 5,000 gal standpipe water storage tank on the 110th floor in the initial operating mode (PANYNJ 1987a). Water was supplied to the other standpipes from FS-F1. A series of manual fire pumps was installed to supply water to the standpipe system (PANYNJ 1987a). The high zone standpipe system was interconnected with the upper mid-level zone standpipe system immediately below the high zone (PANYNJ 1972, 1987a). A series of manual fire pumps were installed to supply water to the standpipe system. The standpipe system was also used to supply the secondary water supply to the sprinkler systems on floors 32 through 110. Two additional water storage tanks dedicated to the sprinkler systems were provided on the 110th floor (PANYNJ 1972, 1987a).

Two separate sprinkler risers supplied water to the sprinkler systems on floors 89 through 110 (PANYNJ 1972, 1987a). The high zone riser (riser A) was equipped with a single automatic 500 gpm electric drive fire pump. Riser A was located in a janitor's closet located in the building core at the north side of the building (PANYNJ 1972, 1987a). This riser supplied the high zone sprinkler systems on the 99th through 107th floors. Sprinkler systems were not installed in the mechanical rooms on the 108th through 110th floors (PANYNJ 1987a). Local application deluge systems were provided for protection of the fan filters in the air-handling units (PANYNJ 1987a).

The mid-level zone riser (riser B) gravity supplied water to the sprinkler systems on the 33rd through 98th floors. Isolation valves were provided at the top of the risers that would have permitted the individual shutdown of either sprinkler riser. An additional intermediate isolation valve was provided for riser B on the 77th floor. Riser B was located in the janitor's closet adjacent to stair 3.

The sprinkler systems on floors 89 through 110 each contained separate control valves and alarm switches. Each sprinkler system was installed in a complex loop configuration. The sprinkler systems were primarily designed for the protection of Light Hazard Occupancies. No information was found regarding the presence of special suppression systems on floors 89 through 110.

WTC 2, Floors 74 through 90

The fire protection systems in WTC 2 sustained damage on the 77th through 85th floors as a result of the initial impact by a commercial aircraft on September 11, 2001 (McAllister et al. 2005). This section of the report provides a description of the fire protection systems on the 74th through 90th floors of WTC 2.

The high zone standpipe system in WTC 2 was basically the same as the system that was installed in WTC 1. Three separate standpipes were installed, one in each stair enclosure (PANYNJ 1972, 1987a). The standpipes spanned floors 77 through 110 and were interconnected at the bottom of the zone on the 76th floor and at the top of the zone on the 109th floor (PANYNJ 1972, 1987a). Check valves were installed at the top of two of the standpipes. The third standpipe was not provided with a check valve (PANYNJ 1972, 1987a). Each standpipe supplied 2 ½ in. hose valves with 2 ½ by 1 ½ in. reducers and either a hose cabinet or hose rack (PANYNJ 1972, 1987a).

Water was gravity supplied to the standpipes from the 5,000 gal standpipe water storage tank on the 110th floor in the initial operating mode (PANYNJ 1987a). The high and upper mid-level zones of the standpipe system were interconnected within the MER on the 75th and 76th floors (PANYNJ 1972, 1987a). A 750 gpm manual fire pump was provided on the 75th floor (PANYNJ 1972, 1987a). This pump was connected in series with three manual fire pumps within WTC 2 below (PANYNJ 1972, 1987a). These fire pumps were all manually operated and intended to provide water for manual fire suppression efforts (PANYNJ 1972, 1987a). The standpipe system also provided a secondary water supply for the sprinkler systems (PANYNJ 1987a).

The mid-level zone riser (riser B) gravity supplied water to the sprinkler systems on the 33rd through 98th floors. Therefore, all of the sprinkler systems on floors 74 through 90 were gravity supplied with water from riser B. Isolation valves were provided at the top of the risers that would have permitted the individual shutdown of either sprinkler riser (PANYNJ 1972, 1987a). An additional intermediate isolation valve was provided for riser B on the 67th floor (PANYNJ 1972, 1987a). Riser B was located in the janitor’s closet adjacent to stair 3 (PANYNJ 1972).

The sprinkler systems on floors 74 through 90 each contained separate control valves and alarm switches. Each sprinkler system was installed in a complex loop configuration. The sprinkler systems were primarily designed for the protection of Light Hazard Occupancies (PANYNJ 1972, 1987a). Sprinkler systems were not provided for the MERs on the 75th and 76th floors (PANYNJ 1972, 1987a). Local application deluge systems were provided for protection of the fan filters in the air handling units (PANYNJ 1987a). No information was found that indicated the presence of special suppression systems on floors 74 through 90 of WTC 2.

5.3 FIRE SUPPRESSION SYSTEMS, WTC 7

5.3.1 Water Supplies

The following is a description of each water supply and the zone that each supplied in WTC 7. Check valves were located at the top of the low and mid-level zones for isolation. The check valves were oriented such that water from the automatic booster pump on the 46th floor could only supply the high zone, and the water storage tanks on the 46th floor could only supply the mid-level zone (Gensler and Associates 1995). See Fig. B–13 for the flow path and check valve orientation.

Water Storage Tanks

The combination system for the mid-level zone was primarily supplied with water from two 17,500 gal storage tanks (Syska & Hennessy 1984). The water storage tanks were located on the 46th floor and extended up to the 47th floor level. The tanks were used as a domestic water storage system (Syska & Hennessy 1984). However, each tank had a fire suppression system reserve capacity of 17,500 gal (Syska & Hennessy 1984).

The make-up water to fill each tank was supplied by three 435 gpm capacity booster pumps via an 8 in. domestic express supply riser from the second floor (Syska & Hennessy 1984). Each pump was provided with two electrode level control units in each tank (Syska & Hennessy 1984). A single pump operated when the water level dropped to a set point established by the electrode control unit (Syska & Hennessy 1984). The pumps operated individually but would operate simultaneously if the load exceeded the capacity of one pump (Syska & Hennessy 1984). The tanks were combination domestic and fire water storage tanks. Therefore, the pumps would turn on at a certain drop in water level, due to domestic usage or fire water usage.

The three domestic booster pumps on the second floor were supplied with water from two 7,000 gal domestic suction tanks on the third floor. Each suction tank had approximately 5,300 gal of useful capacity. These tanks were supplied directly from the 8 in. city service main. The supply to each tank was individually controlled using a solenoid valve located in the 4 in. fill pipe connections (Gensler and Associates 1995).

The domestic water storage tanks on the 46th floor were joined at the base by a connecting 8 in. pipe (Syska & Hennessy 1984). A control valve was in place below each tank on the discharge piping, such that the tanks could be isolated from the system. The 8 in. pipe supplied the automatic booster pump on the 46th floor and the risers in the mid-level zone (Syska & Hennessy 1984).

The elevation of the storage tanks was approximately 600 ft from the first floor (Syska & Hennessy 1984). The tanks provided a gravity fed supply to the base of risers R-5 and R-6 on the 20th floor (approximate elev. 255 ft) via standpipe riser R-4. Figure B–13 illustrates the arrangement. Note the location of the riser control valves.

The control valve at the base of riser R-4 would isolate the tank water supply from risers R-5 and R-6 if closed. Common practice would require valves to be provided to allow isolation of a standpipe without interrupting the supply to other standpipes for the same source of supply (NFPA 2000). Figure 5–14 illustrates the mid-level zone riser configuration.

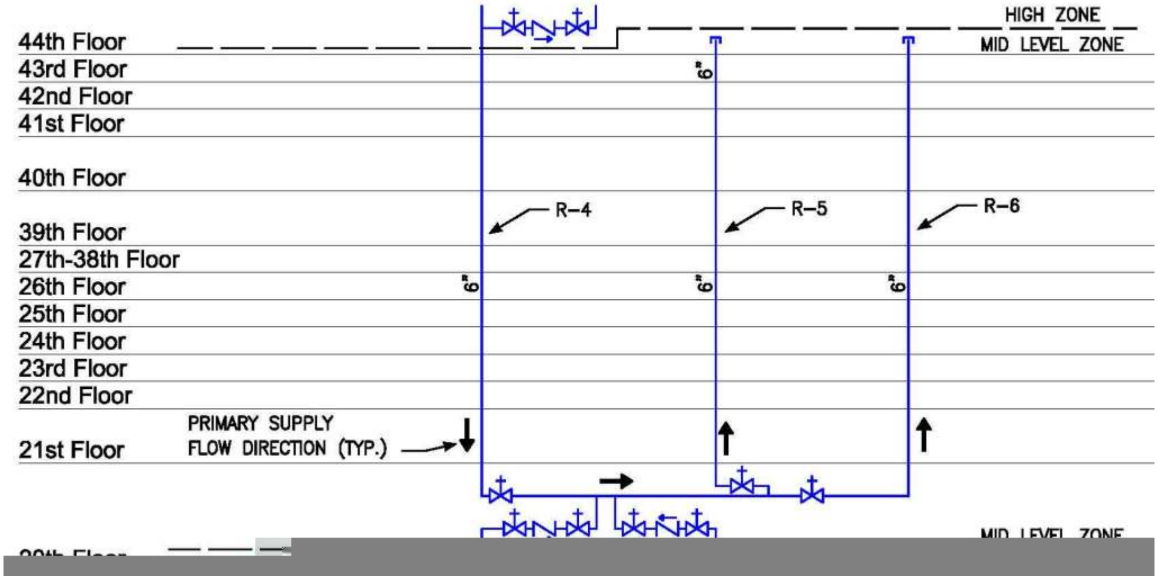


Figure 5–14. Mid-level zone riser supply configuration, WTC 7.

Fire Pumps

The automatic booster pump on the 46th floor supplied the combination system risers in the high zone. The pump was a single stage pump rated for 55 psi at 500 gpm (Syska & Hennessy 1984). The water supply for the booster pump came directly from the water storage tanks. Figure 5–15 illustrates the high zone supply riser configuration.

Figure 5–15. High zone riser supply configuration, WTC 7.

An automatic fire pump on the first floor supplied the combination system risers, hose connections, and sprinkler control valve assemblies in the low zone. The water supply for the fire pump came directly from two separate 8 in. connections to the 12 in. main on Washington Street. The connections to the 12 in. main were separated using an isolation valve (Gensler and Associates 1995).

The pump was a single stage horizontal split case pump rated for 120 psi at 500 gpm. The pump was equipped with a 50 hp, 460-volt, 3-phase electric driver. The pump was provided with an emergency power source via an automatic transfer switch (Syska & Hennessy 1984). Figure 5–16 illustrates the low zone supply configuration.

Figure 5–16. Low zone supply configuration, WTC 7.

Component	Location	Protection	Notes
One generator set with self contained 50 gal day tank System: SP	-9th floor -Along west wall of building	-Generator room provided with sprinkler protection (GC Engineering 1998b; Grill and Johnson 2005b). -Floor protected with wet pipe sprinkler system designed to Light Hazard occupancy criteria -Unknown design criteria	-Fuel oil piping extended from the shaft location to the generator room in the northwest corner of the building.

Source: Gensler Associates 1995; Swanke et al. 1998; Grill and Johnson 2005b; Emery et al. 1987; PANYNJ 1998b; McAllister 2002; GC Engineering 1998b.

5.4 DESIGN BASIS REVIEW

As part of this task, an evaluation of the design basis for WTC 1, 2, and 7 was performed. The intent of this evaluation was to determine if the installed fire protection systems in these three buildings were designed and installed in a manner consistent with performance expectations associated with applicable codes and standards as well as those related to recommended “best practices” at the time of the design and construction of the buildings. The evaluation was limited to the installation features associated with the fire suppression systems. A related hydraulic analysis was also performed as part of Task 2, the results of which are reported in Chapter 6.

This effort included evaluation of applicable design provisions and recommended best practices for the primary and secondary water supplies, the standpipes and pre-connected hoses, the automatic fire sprinkler systems, and the special suppression systems. Special suppression systems were located in WTC 7.

Applicable codes and standards associated with the design and installation of the fire protection systems in WTC 1 and WTC 2 included the following (Grill and Johnson 2005):

- Building Code of New York City, 1968
- Local Law No. 5, Fire Safety Requirement and Controls in Certain Office Buildings, January 18, 1973
- RS 17, Standard for Water Tanks for Private Fire Protection, NFPA 22 (1962 ed.), with modifications
- RS 17-1, Standpipe Construction
- RS 17-2, Standard for the Installation of Sprinkler Systems, NFPA 13 (1966 ed.), with modifications
- RS 17-3, Standard for the Installation of Fire Sprinkler, Standpipe, Smoke Detection, and other Alarm and Extinguishing Systems

The construction of WTC 7 was completed in the mid-1980s. The primary codes and standards applicable to the design and construction of the fire suppression systems were similar to those for WTC 1 and WTC 2 with some exceptions. They included the following (Grill and Johnson 2005; 2005a):

- Building Code of New York City, 1986, with Amendments through January 1, 1985
- Local Law No 5 (same as for WTC 1 and WTC 2)
- Local Law No. 16, Local Laws of the City of New York for the Year 1984 (effective date immediately except as noted), March, 1984
- RS 17-1 (same as for WTC 1 and WTC 2)
- RS 17-2, Standard for the Installation of Sprinkler Systems, NFPA 13 (1982 edition), with modifications
- RS 17-3 (same as for WTC 1 and 2)
- NFPA 22, Standard for Water Tanks for Private Fire Protection (1981 edition)

Detailed descriptions of the installed fire suppression systems are provided in Sec. 5.2 and 5.3. The descriptions are based on an extensive review of background information and associated design drawings, building/tenant records and manufacturers literature made available through the NIST WTC investigation document files and related information in the open literature.

Based on review of available design and operations/maintenance documentation, the fire protection systems in WTC 1, 2, and 7 appeared for the most part to be installed in a manner consistent with state-of-the-art best practices in existence at the time of their construction. A more detailed evaluation of specific performance aspects of the installed automatic sprinkler systems and the primary and secondary water supply systems that supplied them is presented in Chapter 6. The evaluation in Chapter 6 includes examination of factors such as the estimated xpected water spray density available to each sprinkler system, the sprinkler coverage areas used as part of the original design basis, and the occupancy hazard classification of the buildings, as well as other factors that could affect the performance of the systems.

Differences in related provisions of codes and standards that were applicable to the buildings resulted in some inconsistencies associated with the installed suppression systems. None of these inconsistencies were determined to result in the potential for degraded performance. For example, a provision in NFPA 13 required a 30 min stored volume primary water supply for the automatic fire sprinkler systems. However, Local Law No. 5 had a provision that permitted a 20 min stored volume provided that a source was available to automatically refill the stored water tank or reservoir to maintain the primary water supply for an additional 10 min. While the latter design was adopted, under the design conditions that existed the refill rate provided a continual water supply in excess of 30 min. In fact, based on calculations presented in Chapter 6, the duration exceeded the 30 min period in all but a few locations without accounting for the refill rate to the stored water tanks. Therefore, while a minor inconsistency existed, the design of the sprinkler systems appears to have met or exceeded the performance expectations that existed at the time of construction of these three buildings.

5.5 SUMMARY–TASK 1

There were several objectives associated with Task 1. Included were the following:

- Documentation of the fire suppression systems and related system infrastructures
- Identification of any special hazards suppression systems
- Description of particular suppression system features within the immediate initial impact areas in WTC 1 and WTC 2
- Assessment of the consistency of the system designs with applicable codes and standards provisions and state-of-the-art engineering “best practices” during the time of construction of the buildings

The following is a summary of Task 1 as related to these objectives.

5.5.1 Fire Suppression Systems, WTC 1 and WTC 2

The fire suppression systems in WTC 1 and WTC 2 included automatic sprinkler systems, standpipe systems, the related infrastructures, and water supplies. The WTC complex had two basic water supply system infrastructures, one for the sprinkler systems and the other for the standpipe systems.

Water Supplies

The source of water for WTC 1 and WTC 2 was the NYC water distribution system (PANYNJ 1972, 1987a, 1987b; Beyler 2002). Each system infrastructure had two loops, one on the B1 level and the other on the concourse level (PANYNJ 1972, 1987a, 1987b; Beyler 2002). All of the sprinkler and standpipe systems for the sub-grade levels and WTC 1 through WTC 6 were supplied by these loops. Two parallel (redundant) pumps were provided for each infrastructure (PANYNJ 1972, 1987a, 1987b; Beyler 2002). Twelve fire pumps and a single jockey pump were provided for the WTC complex (PANYNJ 1972, 1987a, 1987b; Beyler 2002).

Three 750 gpm manual electric drive fire pumps were installed in series for each tower standpipe system (PANYNJ 1972, 1987b). Additionally, one 500 gpm automatic electric drive fire pump was provided for the sprinkler systems for the 99th through 107th floors and pre-connected hose stations for the 110th floor and the rooftops (PANYNJ 1972, 1987b).

Three 5,000 gal water storage tanks were provided in WTC 1 and WTC 2 with a total holding capacity of 15,000 gal for the standpipe systems in each building (PANYNJ 1972, 1987b). These tanks were located on the 41st, 75th, and 110th floors. WTC 1 also contained a fourth tank located on the 20th floor (PANYNJ 1972, 1987b). Each building also had two additional 5,000 gal water storage tanks on the 110th floor for the sprinkler systems (PANYNJ 1972, 1987b).

The WTC complex was provided with 14 separate fire department connection (FDC) stations (PANYNJ 1972, 1987b). A total of 32 siamese type FDCs were provided for the sprinkler and standpipe systems (PANYNJ 1972, 1987b).

Standpipe Systems

The standpipe systems in WTC 1 and WTC 2 included four vertical water supply zones:

1. High (77th through the 110th floors)
2. Upper mid-level (42nd through 76th floors)
3. Lower mid-level (8th through the 41st floors)
4. Low (1st through 8th floors and the sub-grade levels)

The standpipes were installed during the original construction of the buildings. Three 6 in. standpipe risers (FS-F1, FS-F2, and FS-F3) were provided within each zone (PANYNJ 1972, 1987b). Standpipe riser FS-F1 was used to supply water to the other two risers for the initial fire suppression efforts. Water was gravity supplied by the storage tanks to the pre-connected hose lines for the standpipe systems until the manual fire pumps were started or water was pumped into the system by the FDNY through one of the FDCs.

Sprinkler Systems

The wet pipe automatic sprinkler systems in WTC 1 and WCT 2 were separate from the sub-grade sprinkler systems (PANYNJ 1987a, 1987b). The sprinkler systems for the towers were configured such that each floor was provided with a separate system (PANYNJ 1987a, 1987b). However, these systems shared common infrastructures and water supplies. The sprinkler system infrastructure included two dedicated water storage tanks, three sprinkler risers (A, B, and C), and connections to the standpipe systems (PANYNJ 1987a, 1987b).

The high zone sprinkler riser (A) was equipped with a single automatic 500 gpm electric drive fire pump and supplied water to the sprinkler systems on the 99th through 110th floors (PANYNJ 1972, 1987a). The mid-level zone sprinkler risers (B) were gravity supplied with water from the water storage tanks located on the 110th floors. The mid-level zone risers supplied the sprinkler systems on the 33rd through 98th floors. The low zone sprinkler risers were gravity supplied with water from the storage tanks located in the 41st/42nd floor mechanical room. Riser C supplied water to the sprinkler systems on the 1st through 32nd floors.

The sprinkler systems were installed in three phases. The sub-grade sprinkler systems were installed as part of the original construction (GC Engineering 1998). The second phase was completed in 1976 and included the retrofit installation of sprinkler risers and sprinkler systems for the core areas and select tenant spaces (GC Engineering 1998). The final phase included the installation of sprinkler systems throughout all tenant space areas and was completed from 1983 through early 2001 (GC Engineering 1998; PACO 2002). The sprinkler systems were designed and installed in accordance with the requirements of the BCNYC, NFPA 13 and the PANYNJ requirements.

Sprinkler systems were not installed in the mechanical rooms on the 108th through 110th floors (GC Engineering 1998, PANYNJ 1987a). Local application deluge systems were provided for protection of the fan filters in the air-handling units. Sprinklers were omitted from electrical rooms that met specific criteria outlined for omission (PANYNJ 1987a, 2000b).

Electrical Power Supply

The primary electrical power supply for the WTC complex (including WTC 1 and WTC 2) was provided by the Consolidated Edison Company (Con-Ed) substation located in WTC 7 (Beyler 2002; McAllister 2002). Separate feeders were independently routed from the main power distribution center to each tower (Beyler 2002).

The secondary power supply to fire pumps was provided by six emergency generators on the B6 level. Documentation of the secondary electrical system indicates that a single circuit supplied power to the manual fire pumps on the B1 level in both WTC 1 and WTC 2 (Beyler 2002).

Special Hazards Suppression Systems

Several types of special suppression systems were used in WTC 1 and WTC 2 (PANYNJ 1987b). These systems included (a) kitchen ventilation, dry chemical, and steam smothering systems, (b) carbon dioxide (CO_2) systems, and (c) Halon 1301 total flooding systems. These systems were supervised by the fire alarm systems in WTC 1 and WTC 2 and were designed to transmit signals to the FDNY upon activation.

The O&M manual indicated that ventilation and grease extraction systems were installed in restaurant kitchens above fryers, griddles, ranges, boilers and ovens, but did not provide specific locations where these systems were installed in WTC 1 and WTC 2 (PANYNJ 1987b).

The O&M manual indicated that steam smothering systems were installed in the kitchens at the following locations:

- PA Cafeteria
- The “Big Kitchen”
- The Sky Dive
- Windows on the World
- The New York State Cafeteria
- The Observation Deck

A total flooding CO_2 system was used to protect the under floor space of a large computer room in WTC 2. There is reference to other systems at the WTC complex, but specific information regarding the locations of these systems was not found. The available drawings for WTC 1 show that two Halon 1301 systems were installed for protection of the computer room on the 70th floor. One system was installed for protection of the under floor space and the other for protection of the room (PANYNJ 1972, 1987b).

WTC 1, Floors 89 through 110

The floors involved in the initial impact were essentially protected by wet pipe automatic sprinkler systems. The initial damage to the fire protection systems was most likely sustained on three floors (94 through 96) of WTC 1, within the initial impact area (McAllister et al. 2005). The area hit by the aircraft was within the high standpipe system zone. The high zone standpipe system in WTC 1 included all floors vertically between the 77th and the 110th floors. Three separate standpipes were installed, one in each stair enclosure (PANYNJ 1972, 1987b). Each standpipe supplied 2½ in. hose valves with 2½ in. by 1½ in. reducers and either a hose cabinet or hose rack. The water supply storage tanks were not located on the floors that incurred the initial impact damage (PANYNJ 1972, 1987b).

Two separate sprinkler risers supplied water to the sprinkler systems for floors 89 through 110 (PANYNJ 1972, 1987a). The high zone riser (riser A) was equipped with a single automatic 500 gpm electric drive fire pump (PANYNJ 1972, 1987a). This riser supplied the high zone sprinkler systems on the 99th through 107th floors. Sprinkler systems were not installed in the mechanical rooms on the 108th through 110th floors (PANYNJ 1972, 1987a). Local application deluge systems were provided for protection of the fan filters in the air-handling units. The mid-level zone riser (riser B) gravity supplied water to the sprinkler systems on the 33rd through 98th floors.

The sprinkler systems on floors 89 through 110 each contained separate control valves and alarm switches (PANYNJ 1987a). Each sprinkler system was installed in a loop configuration (PANYNJ 1972, 1987a). The sprinkler systems were primarily designed for the protection of Light Hazard Occupancies. No information was found that indicated the presence of special fire suppression systems on floors 89 through 110.

WTC 2, Floors 74 through 90

The fire protection systems in WTC 2 most likely sustained damage on the 78th through 81st floors as a result of the initial impact (McAllister 2005). The area hit by the aircraft was within the high standpipe system zone. The high zone standpipe system in WTC 2 was basically the same as the system that was installed in WTC 1. The high zone standpipe system in WTC 2 included all floors vertically between the 77th and the 110th floors (PANYNJ 1972, 1987b).

Water was gravity supplied to the standpipes from the 5,000 gal standpipe water storage tank on the 110th floor in the initial operating mode (PANYNJ 1987b). The high and upper mid-level zones of the standpipe system were interconnected within the MER on the 75th and 76th floors. A 750 gpm manual fire pump was provided on the 75th floor (PANYNJ 1972, 1987b). This pump was connected in series with three manual fire pumps in WTC 2. These fire pumps were all manually operated and intended to provide water for manual fire suppression efforts. The standpipe system also provided a secondary water supply for the sprinkler systems.

The mid-level zone riser (riser B) gravity supplied water to the sprinkler systems on the 33rd through 98th floors. Therefore, all of the sprinkler systems on floors 74 through 90 were gravity supplied with water from riser B. The sprinkler systems on floors 74 through 90 each contained separate control valves and alarm switches. Each sprinkler system was installed in a loop configuration. The sprinkler systems were primarily designed for the protection of Light Hazard Occupancies.

Sprinkler systems were not provided for the MERs on the 75th and 76th floors (PANYNJ 1987a). Local application deluge systems were provided for protection of the fan filters in the air handling units (PANYNJ 1987a, 1987b). No information was found that indicated the presence of other special fire suppression systems on floors 74 through 90.

5.5.2 Fire Suppression Systems, WTC 7

The fire suppression systems in WTC 7 also included automatic sprinkler systems, standpipe systems, the related infrastructures, and water supplies. The wet pipe sprinkler systems were designed and installed during construction in the mid 1980s.

Water Supplies

The water supplies for WTC 7 included a direct connection to the NYC water distribution system, water storage tanks, fire pumps, and fire department connections (Syska & Hennessy 1984; McAllister 2002; Beyler 2002). A single 500 gpm automatic electric drive fire pump and a 750 gpm manual electric drive fire pump located on the first floor supplied water to the lower 20 floors (Syska & Hennessy 1984; McAllister 2002; Beyler 2002). Two water storage tanks with a fire protection water reserve capacity of 7,500 gal each were located on the 47th floor (Syska & Hennessy 1984). These tanks supplied water to the upper floors (Syska & Hennessy 1984). Check valves located on the 20th floor prevented the downward flow of water from the storage tanks to the standpipes and sprinkler systems in the low zone (refer to Fig. B–13) (Syska & Hennessy 1984). A second 500 gpm automatic fire pump was located on the 46th floor (Syska & Hennessy 1984). This pump was used to supply the high zone sprinkler and standpipe systems. The two fire pumps on the first floor were used to provide the secondary water supply for the upper levels of the building through the combined sprinkler and standpipe system infrastructure piping.

Combined Standpipe and Sprinkler System Infrastructure

The infrastructure for the automatic sprinkler systems was combined with the standpipe systems. It included nine vertical risers. WTC 7 was divided into three basic water supply zones:

1. High
2. Mid-level
3. Low

The high zone included two 6 in. standpipe risers (risers 7 and 9) and one 6 in. combined (riser 8) riser. These risers were interconnected on the 44th floor and were supplied by the 500 gpm automatic fire pump located on the 46th floor. The mid-level zone included two 6 in. standpipe (risers 4 and 6) and one 6 in. combined (riser 5) riser. Water was gravity fed to these risers from the water storage tanks located on the 47th floor. Riser 4 was used to supply water from the tank to the other two risers. The low zone also included two 6 in. standpipe risers (risers 1 and 3) and one 6 in. combined (riser 2) riser. The low zone standpipe/risers were not supplied by the stored water supply.

Sprinkler Systems

The occupied areas in WTC 7 were protected by automatic sprinklers, with the exception of the electrical equipment areas (switchgear, networking, and switchboard rooms), generator rooms, and bathrooms. Sprinklers were not installed on most of the fifth floor nor on the seventh floor, which housed the OEM generators and fuel day tanks. A dry-pipe sprinkler system protected the first floor fuel storage tanks.

Electrical Power Supply

The primary electrical distribution system for WTC 7 was served by the Con-Ed power station located in WTC 7. The main building transformers for WTC 7 were located on the third floor. Power was distributed throughout the building via two main risers located on each end of the building core. The base building emergency power supply for WTC 7 was served from two 900 kW diesel generators located in the fifth floor generator room on the south side of the building facing the WTC complex. Three additional 500 kW diesel generators were retrofitted on the seventh floor 1998 for the OEM office on the 23rd floor.

Special Hazards–Protection of the Fuel Oil System

WTC 7 contained fuel oil powered generators located on the fifth, seventh, eighth, and ninth floors. Each generator set, with the exception of the generator on the eighth floor, was fueled via 275 gal day tanks located within the generator rooms (Swanke et al. 1998; GC Engineering 1998b; Grill and Johnson 2005b). The generator set on the eighth floor was manually filled. The day tanks were supplied with fuel oil by risers that extended from the first floor to the respective generator floor. The risers were located in two 2 h fire resistance rated shafts adjacent to the southeastern most elevators along Vesey Street (PANYNJ 2000a). The fuel oil was pumped to the day tanks from two 12,000 gal and one 6,000 gal fuel storage tanks. The fuel oil pump room was located on the first floor between the eastern most elevator shafts, behind the loading dock.

The fuel oil entering the day tank on the seventh floor was regulated by two high level switches. If the first switch failed to shut down the pump then the second switch would remain open and close the solenoid valve on the line entering the day tank as well as shut down the pump.

The loading berth and fuel oil pump rooms were protected by dry-pipe sprinkler systems. The room containing the tank was protected by an Inergen clean agent fire suppression system. The elevator storage area beneath the tank was protected by a wet pipe sprinkler system.

5.5.3 Consistency of Suppression System Designs with State-of-the-Art Engineering "Best Practices"

An evaluation of the consistency of the suppression system designs with applicable codes and standards provisions and state-of-the-art engineering "best practices" during the time of construction of the buildings was performed for WTC 1, 2, and 7. The intent of this evaluation was to determine if the installed fire protection systems in these three buildings were designed in a manner consistent with performance expectations associated with applicable codes and standards as well as those related to recommended best practices at the time of the design and construction of the buildings. The evaluation was limited to the installation features associated with the fire suppression systems. The results of this evaluation indicated that the fire protection systems in WTC 1, 2, and 7 were for the most part installed in a manner consistent with the state-of-the-art best practices in existence at the time of their construction. Several exceptions to this were identified, but none of the exceptions would have specifically affected the performance of the suppression systems under the impact effects that occurred on September 11, 2001.

Chapter 6
TASK 2: EVALUATION OF THE FIRE SPRINKLER WATER SUPPLIES

6.1 GENERAL

The objective of Task 2 was to document the design and capacity of the water supply system to the automatic fire sprinkler systems in World Trade Center (WTC) 1, 2 and 7, including supply system redundancies. Of particular interest were the capacity and duration of the water flow to the automatic fire sprinkler systems for normal operational conditions. Attention was also given to the role of system redundancies, including fire department capabilities, in supporting demand for water supply.

A detailed review of available information was performed in order to document the water supply infrastructure. The capacity of the water supply system was evaluated based on the available water flow "density" and duration to the automatic fire sprinkler systems under what would be considered normally expected conditions. These two parameters are the primary water supply factors associated with expected performance of control type automatic fire sprinklers. Finally, based on review of available drawings and information, key water supply redundancies were documented.

Selected information and results are summarized in this chapter. Extensive reference is made to detailed drawings located in Appendix B. The results documented in this chapter were input for analyses in Chapters 8 and 9.

6.2 DESCRIPTION OF THE NEW YORK CITY WATER SUPPLY

The primary source of water for the WTC complex was the New York City (NYC) water supply and distribution system. This system is operated by the New York City Department of Environmental Protection (NYC DEP). Two separate divisions (bureaus) of the DEP are responsible for the water supply and distribution system. The Bureau of Water Supply (BWS) and the Bureau of Water and Sewer Operations (BWSO) (LZA Technology 2002).

The BWS manages and operates three separate "upstate" reservoir systems, which supply approximately 1.1 to 1.2 billion gal of water a day to New York City. The reservoir systems are known as the Catskill, Delaware, and Croton watersheds. The reservoir systems are composed of 19 reservoirs (watersheds) and three controlled lakes with an approximate combined storage capacity of 580 billion gal. A series of interconnections are provided between the three reservoir water collection systems to permit water to be transferred between the systems. This increases the flexibility in the use and operation of these systems by controlling localized flooding and droughts (LZA Technology 2002; Beyler 2002).

The watersheds supply water to the NYC water distribution system through three separate transmission mains (aqueducts). Accordingly, these are referred to as the Catskill, Delaware, and Croton aqueducts. In the normal operating mode, approximately 95 percent of the supplied water is by gravity flow and 5 percent by pump systems. This provides a reliable water supply that is only minimally affected by power outages. However, additional pumping is required during drought conditions (Beyler 2002).

The BWSO is responsible for the operation and maintenance of the NYC water distribution system. The water transmission mains provide water to the NYC distribution system within a narrow pressure range controlled by multiple pressure reducing stations (valves). The pressure reducing valves maintain an approximate average steady state pressure of 50 psi (Beyler 2002).

The NYC DEP is responsible for regulation of the pressure and flow throughout the NYC water distribution system (Beyler 2002). Information reported at the 14th Street pressure regulators on September 11, 2001, from 6:40 a.m. and 11:50 a.m. was reported by Hoffer and is provided in Table 6–1. The data in Table 6–1 demonstrate stability of the water supply throughout the morning of September 11, 2001, while manual and automatic fire suppression systems were in operation at the WTC complex.

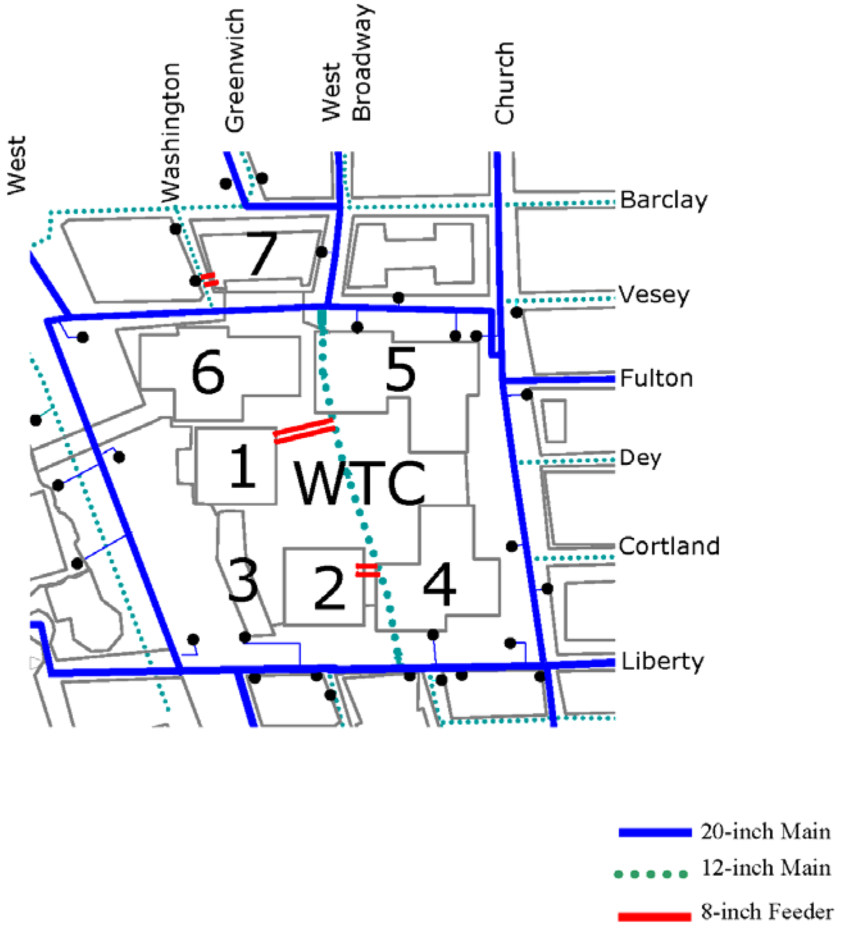
Table 6–1. Average water pressure observed at the 14th Street regulators.

Aqueduct – 14th Street	Regulator Identification	Average Steady State Pressure 6:40 a.m. to 11:50 a.m., September 11, 2001
Tunnel No.1, Shaft 18	SE Regulator: #1 Pressure	51 psi
Tunnel No.1, Shaft 18	SW Regulator: #2 Pressure	44 psi
Tunnel No.1, Shaft 18	NW Regulator: #3 Pressure	50 psi
Tunnel No.1, Shaft 19	Regulator	49 psi
Tunnel No.1, Shaft 20	SE Regulator	50 psi
Tunnel No.1, Shaft 20	NE Regulator	53 psi
Tunnel No.1, Shaft 20	NW Regulator	50 psi
Tunnel No.1, Shaft 21	Channel 3	60 psi

Source: Beyler 2002; Hoffer 2002.

The NYC water distribution system in lower Manhattan surrounding the WTC complex is composed of a complex gridded network of 20 in. and 12 in. ductile iron mains. Figure 6–1 provides a representation of the water distribution system surrounding the WTC complex. A 20 in. loop was located beneath the streets surrounding the WTC plaza where towers WTC 1 and WTC 2 were located. The mains were beneath Vesey Street to the north, Liberty to the south, Church Street to the east, and West Street to the west. These mains were inter-connected to a series of 20 in. and 12 in. mains, which permitted water to flow along a large number of flow paths, minimizing the effects of friction loss while flowing a large volume of water. The large volume of water within the distribution system mains, transmission mains, and at the source (watersheds in upstate New York) allowed for a large capacity of water to be available for firefighting capabilities (Beyler 2002).

A 20 in. main was located beneath West Broadway immediately to the east of WTC 7. This main supplied water to the 20 in. loop around the WTC plaza. A 12 in. main to the west of WTC 7, beneath Washington, supplied two parallel 8 in. lead-ins (feeders) for WTC 7 and connected to a 12 in. main at the north side of WTC 7 beneath Barclay and the 20 in. main beneath Vesey. The 12 in. main on Barclay increased to 20 in. diameter near the center of WTC 7 at Greenwich and interconnected to the 20 in. main on West Broadway. A 12 in. and a separate 20 in. parallel main connected to the 20 in. main on Barclay and continued to the north on Greenwich (Beyler 2002).



Source: Beyler 2002. Reproduced with permission of Silverstein Properties, Inc.

Figure 6–1. Municipal water distribution system surrounding WTC complex.

This arrangement of the water distribution system provides a near constant pressure for all flows that are normally anticipated for fire protection system demands i.e., the water supply provides a residual pressure that is nearly identical to the static pressure. Information provided by Beyler indicated that standard practice is to flow 500 to 750 gpm. Such flows typically would not cause a recognizable drop in the system pressure (Beyler 2002).

Based on review of documented water supply tests and related data, the following assumptions were used regarding the city water supply in performing the hydraulic calculations which served as the basis for evaluation of the water supply and the suppression systems:

- Static pressure: 50 psi
- Residual pressure: 11 psi
- Residual flow: 150,000 gpm

6.3 EVALUATION OF SPRINKLER SYSTEMS FLOW CAPACITY AND DURATION

Hydraulic calculations were performed to evaluate the expected sprinkler system performance based on the configuration of the water supplies. The objective of the analysis was to determine any variations in the performance of the sprinkler systems in each building and within each water supply zone. The systems were primarily gravity fed. A group of sprinkler systems from each building was selected for analysis. Sprinkler systems near the top and the bottom of each water supply zone were selected to bound the effects of elevation on the performance of these sprinkler systems. In some cases, intermediate systems were also selected for evaluation because the arrangements of the systems varied as a result of using outside screw and yoke (OS&Y) or pressure reducing type control valves. A commercial computer program, Hydraulic Analyzer of Sprinkler Systems (HASS), version 7.5, was used to perform the calculations (HRS 2004).

Several factors were examined as part of this analysis. Supply calculations were used as a means to compare the flow rate of water delivered from the primary and secondary supplies to the sprinkler systems. Calculations were performed for the highest and lowest floor level sprinkler systems to observe the effects of elevation on the discharge density of the sprinkler systems and water supply duration (i.e., how long the flow could be maintained). Calculations were also performed with variations in the number of sprinklers flowing water. The intent of this analysis was to provide sufficient information to characterize the capabilities of the water supplies.

As part of this task, redundancies in the water supply infrastructure to the sprinkler and standpipe systems were identified. The redundancies included both automatic and manually operated features of the systems.

6.3.1 Methodology

Hydraulic calculations are routinely used to characterize water flow through a pipe network, such as a sprinkler, standpipe, or water distribution system. Such calculations are typically conducted for design or analysis. As such, there are two types of hydraulic calculations that are used to evaluate sprinkler systems: demand calculations and supply calculations.

Demand calculations are used in the design of sprinkler systems to verify that minimum defined pressure and flow are provided to all sprinklers included in a defined design area. Sprinkler systems typically use the occupancy hazard fire control method as described in National Fire Protection Association (NFPA) 13, *Standard for the Installation of Sprinkler Systems* (NFPA 2002). Sprinkler systems designed or analyzed using the occupancy hazard fire control method are based on criteria specified for the particular occupancy hazard group contained within the building or building area. This methodology has existed in NFPA 13 for some time, including the periods when the sprinkler systems were designed for WTC 1, 2, and 7. Refer to Chapter 3 for a more detailed discussion of the occupancy hazard fire control design method.

For a demand calculation, the minimum performance requirements are defined in terms of an application or discharge density and a minimum design area as required by NFPA 13 or in this case the PANYNJ (which adopted NFPA 13 with modifications) (PANYNJ 2000b). The application or discharge density refers to a water flow rate over a unit area. For example, the design of a sprinkler system in an office area classified as a Light Hazard Occupancy according to the occupancy hazard fire control method is required to discharge 0.1 gpm/ft^2 over a design area of 1,500 ft^2. The spacing and coverage area per sprinkler dictates the number of sprinklers required to be included in the hydraulic calculations. The minimum number of sprinklers is determined by dividing the design area by the coverage area per sprinkler. A sprinkler system with branchlines spaced at 14 ft on center and sprinklers spaced at 14 ft on center along each branchline would require eight sprinklers. The coverage area per sprinkler would be 196 ft^2 (14 ft. by 14 ft). The number of sprinklers is determined by dividing the design area (1,500 ft^2) by the coverage area per sprinkler (196 ft^2).

Water density (gpm/ft^2) is used to specify the minimum flow rate to be discharged from an individual sprinkler in order to achieve adequate fire control for a particular hazard (NFPA 2002). In demand calculations, the minimum design density is specified for the group of sprinklers within the design area. Each sprinkler in the design area is required to flow sufficient water at sufficient pressure to provide the required discharge density. In the case of a Light Hazard Occupancy with sprinklers spaced at 196 ft^2 per sprinkler, a flow of 19.6 gpm would be required (NFPA 2002).

The defined flow also results in a minimum required pressure based on the orifice diameter and resulting k-factor for the sprinkler (NFPA 2002; COte 2003). However the actual amount of water (flow) discharged from each individual sprinkler is directly related to system pressure at the sprinkler orifice and varies from sprinkler to sprinkler.

The required pressure is determined by the equation (NFPA 2002; Cote 2003):

$$Q = k\sqrt{p} \tag{6–1}$$

where:

Q = flow, gpm

k = constant, gpm/psi$^{1/2}$

p = pressure, psi

The flow rate Q is equal to a constant, k, times the square root of the pressure (NFPA 2002; Cote 2003). The constant, or k-factor, is related to the orifice size (diameter) of the individual sprinkler installed. The Port Authority of New York and New Jersey (PANYNJ) guideline specifications indicated the use of Reliable Automatic Sprinkler Corporation of America, Inc. (RASCO) model G standard spray sprinklers (PANYNJ 2000b). The k-factor for this sprinkler is k=5.6 gpm/psi^{½} for a typical ½ in. diameter sprinkler. The flow rate from the sprinkler equals the k-factor times the square root of the minimum required pressure. The end sprinkler condition is defined as the greater of the flow associated with a minimum operating pressure of 7 psi, or the flow associated with the density times the sprinkler coverage area (NFPA 2002; Cote 2003).

The required flow and pressure at the most remote sprinkler are referred to as the “end sprinkler conditions” and ensure that the system is capable of providing the specified discharge density over the entire design area. The end sprinkler conditions are used as the starting point in demand calculations (NFPA 2002). By multiplying the discharge density by the design area, the minimum required flow rate can be determined. The flow rate in part defines the sprinkler system demand. The pressure or energy to overcome elevation and pressure loss through the sprinkler system, while flowing water defines the other component of the sprinkler system demand.

The flow of water through a length of pipe results in pressure loss due to friction (Cote 2003). An empirical relationship known as the Hazen-Williams formula was derived based on a series of laboratory tests to account for this pressure or friction loss (NFPA 2002; Cote 2003). The equation is expressed as follows (NFPA 2002; Cote 2003):

$$p_{fl} = 4.52 \frac{Q^{1.85}}{C^{1.85} d^{4.87}} \tag{6–2}$$

where:

p_{fl} = pressure loss due to friction, psi/ft

Q = flow, gpm

C = constant

d = inside diameter of pipe, inches

For a demand calculation, the pressure and water flow required to meet the end system conditions is related back to the sprinkler system supply (NFPA 2002; Cote 2003). At this point, a comparison of the sprinkler system demand and the water supply indicates whether the system is capable of providing the minimum required discharge density for the design area. This is shown graphically in Fig. B–18. If the sprinkler system demand is at or below the water supply on the graph, then the sprinkler system design and water supply are adequate to provide the minimum required discharge density for the design area. If the sprinkler system demand is above the water supply curve then the minimum discharge density is not provided, and a pump, water tank, or other provisions must be provided in order to meet the sprinkler system demand conditions.

For a “supply” calculation, the water supply and sprinkler system configuration are given. The water flow from the supply is relayed forward through the system, overcoming the pressure losses due to friction and elevation, until the water discharges from the designated sprinklers. Supply calculations are used to show the actual or maximum discharge density that the water supply is capable of delivering to the sprinkler system. Good practice in the design of sprinkler systems is to provide a margin of safety between the sprinkler system demand and the water supply (Cote 2003).

The margin of safety is usually a fixed percentage of the static pressure, such as 10 percent or 20 percent, or, the margin of safety can be defined as a fixed pressure, such as 10 psi or 20 psi. A margin of safety can be used to account for variations in a water supply, such as tanks with large changes in water level or seasonal or daily fluctuations in a water supply. These effects would not have been likely in the systems at the WTC buildings. However, a margin of safety is also included to account for modifications to systems and the addition of fittings and extra pipe that might be necessary to accommodate field installation conditions, which would have been common for tenant fit-outs.

The difference between the required discharge density and actual delivered discharge density is a direct indication of the margin of safety between the sprinkler system demand and the water supply curve. Supply calculations do not include “end sprinkler conditions.” Therefore, the user must interpret whether the minimum required discharge density is provided by the sprinkler system with the selected water supply. In supply calculations, the required design density, is used as a benchmark relative to the actual flow rate per unit area delivered by the system. If the delivered density is greater than the required design density then the system meets the requirements of the occupancy hazard fire control approach specified in NFPA 13. Since the objective of Task 2 was to evaluate the performance of the sprinkler systems water supply, these calculations were performed.

6.3.2 Approach

Hydraulic calculations using the supply calculation approach were used to analyze the capacity of the water supply to the sprinkler systems in WTC 1, 2, and 7. It was considered impractical to perform hydraulic calculations for every floor and every subsystem. Therefore, representative system configurations were selected to represent conditions within each water supply zone. Configurations were chosen to provide bounding results (in terms of available pressure, flow, and duration) for each vertical hydraulic zone in the buildings.

This approach limited the number of cases to a manageable level and at the same time provided representative results applicable to any location in the buildings. The results also provided the baseline information needed to evaluate the performance capabilities of the sprinkler systems. The calculations were based on the following bounding conditions for each vertical zone:

- Water supply
  - Primary–water storage tanks and/or automatic fire pumps
  - Secondary–manual fire pumps or water storage tanks
- Number of operating (opened) sprinklers
  - 4 sprinklers–smaller than the required design area
  - 8 to 15 sprinklers–design area for Light or Ordinary Hazard Occupancy
  - 18 to 25 sprinklers–larger than the required design area
- Floor level within the vertical zone
  - WTC 1 and WTC 2
    - 107th floor (highest floor system in high water supply zone)
    - 99th floor (lowest floor system in high water supply zone)
    - 98th floor (highest floor system in mid-level water supply zone)

    - 87th floor (lowest floor system in mid-level water supply zone without a PRV)
    - 86th floor (highest floor system in mid-level water supply zone with a PRV)
    - 32nd floor (lowest floor system in mid-level water supply zone with a PRV)
    - 31st floor (highest floor system in low water supply zone)
    - 9th floor (lowest floor system in low water supply zone without a PRV)
    - 7th floor (highest floor system in low water supply zone with a PRV)
    - 2nd floor (lowest floor system in low water supply zone with a PRV)
  - WTC 7
    - 47th floor (highest floor system in high water supply zone)
    - 40th floor (lowest floor system in high water supply zone)
    - 39th floor (highest floor system in mid-level water supply zone)
    - 21st floor (lowest floor system in mid-level water supply zone)
    - 20th floor (highest floor system in low water supply zone)
    - 1st floor (lowest floor system in low water supply zone)

Each combination of the conditions was used to develop supply calculations. The supply calculations provided estimates of the actual water flow rate and pressure that would be expected based on typical sprinkler system arrangements. The duration was determined by dividing the storage capacity by the calculated flow rate. The calculations did not account for the supplemental make-up supplies from the automatic re-fill lines supplied by the domestic water supply systems. The results of these calculations were intended to approximate the actual delivered discharge densities based on representative sprinkler system layouts provided from the available documentation of the systems. The results are considered to more accurately represent the actual performance as compared to using the minimum required flow rates determined by multiplying the density times the design area specified by NFPA 13 for the applicable hazard.

Calculations for the sprinkler systems in WTC 1 and WTC 2 were performed for several different coverage areas based on the available documentation for the systems. The calculations for Light Hazard areas in WTC 7 used a coverage area of 168 ft^2. The calculations for all systems used $k=5.6$ $gpm/psi^{½}$, ½ in. orifice sprinklers.

6.4 WTC 1 AND WTC 2

The sprinkler systems on floors 99 through 107 in WTC 1 and WTC 2 comprised the high zone and shared a common riser and water supply. These systems were supplied with water from the reserve storage tanks located on the 110th floor. Figure B–19 provides a representation of the water storage tanks and the feed main that supplied water to the top of riser A. Positive suction pressure was provided to a single shared booster pump located on the 108th floor, which supplied riser A and the high zone sprinkler systems. Figure B–20 illustrates the path of water flow from the water storage tanks at calculation node AST to the floor control assemblies (FCA) at the 107th and 99th floors (PANYNJ 1972).

Hydraulic calculations were performed for the sprinkler systems on the 107th and 99th floors of WTC 1. These systems represented the bounding conditions for the high zone water supply with sprinkler systems designed for the protection of Light Hazard Occupancies.

6.4.1 Floor System Layout, WTC 1, Floor 107

The sprinkler system layout for the restaurant located on the 107th floor was documented in a series of four drawings. Therefore, the drawings were used to lay out the hydraulic nodes used to represent that sprinkler system for the hydraulic analysis. The drawings are included as Figs. B–21 through B–24 and show the portions of the sprinkler system in the Northwest (NW), Northeast (NE), Southeast (SE), and Southwest (SW) quadrants of WTC 1, respectively.

The water supply to the sprinkler system was composed of a 4 in. diameter feed main connected to riser A at node A107 and to the FCA at node FM. Node FM to FCA included a 2½ in. diameter floor control assembly comprised of a control valve, vane-type water flow switch, and drain assembly as depicted in Fig. 5–6. A check valve was also included in the calculations although not shown in Fig. 5–6.

The floor level sprinkler system was a 2 in. diameter looped main with 2 in. interior cross connections, except where a 2½ in. diameter main connected calculation node FCA to calculation node M1. The mains are identified as nodes M1 through M9. A series of tree (dead-end) branchlines extended to the interior of the loop and outward toward the exterior walls of the building. Ten branchlines were included in the system layout. The configuration of the branchlines varied throughout the system and included 1 in. through 2 in. diameter pipes. Nodes B1 through B4 and B11 through B15 were used to represent the hydraulic nodes at the supply points to the branchlines from the looped 2 in. cross-mains.

The branchlines were identified using L and S nodes to represent tees and sprinklers, respectively, along each branchline. The average spacing per sprinkler was 10½ ft by 12 ft, resulting in an average coverage area of 126 ft^2 per sprinkler. Note that the spacing of sprinklers in other areas of the system varied somewhat from this arrangement.

6.4.2 Floor System Layout, WTC 2, Floor 107

The 107th floor sprinkler system in WTC 2 was significantly different than the WTC 1 system due to the location of an observatory on this floor in WTC 2. The fire sprinkler system was designed using the requirements for an Ordinary Hazard Group 1 Occupancy. Figures B–25 through B–28 depict the sprinkler system for the 107th floor in WTC 2 using quadrants similar to the layout of the system in WTC 1. The NW quadrant drawing indicated that the system was designed to provide a discharge density of 0.16 gpm/ft^2 over a design area of 1,500 ft^2 (PANYNJ 1972).

The water supply to the sprinkler system used a 3 in. feed main and floor control assembly that supplied a 2½ in. looped cross-main. Branchlines extended to the floor area inside of the looped cross-main and outward toward the exterior walls of the building. Sprinklers were spaced at approximately 14 ft by 8½ ft on center, resulting in an average coverage area of 119 ft^2 per sprinkler. However, the sprinklers closest to the exterior wall were located less than one-half the spacing between sprinklers along a branchline, requiring additional sprinklers to be included in the application (design) area. A total of 18 sprinklers were required in the approximate 1,500 ft^2 design area. Although dividing the application area by the number of sprinklers results in actual average coverage area of 83 ft^2, a coverage area of 119 ft^2 per sprinkler was used in this analysis. The sprinklers at the end of the branchlines flow water as if these sprinklers are protecting additional area beyond the exterior walls. This is referred to as a “phantom area” and is accountable for the additional five sprinklers that are required in the design area.

The nodes for this system were labeled in a similar manner as the system for WTC 1. The nodes for the mains were designated using M# nodes; the numbers for the supply point for the branchlines at the cross-mains were designated using B#; and the sprinklers and tees were designated using S and L, respectively.

6.4.3 Representative System Layout for all Other Floors

Accurate layouts of the systems for the 99th floor were not found in the documents associated with the literature review. Therefore, representative system layouts were designed using information from a number of different drawings (PANYNJ 1972). This approach resulted in prototype designs for the analysis that were not necessarily exact replications of the systems that were present in WTC 1 or WTC 2. However, the representative design layouts were adequate to accurately evaluate the capacity and duration available from the water supply.

The riser locations, layout for the feed mains and the cross-mains, in the core area were taken from PANYNJ drawings SP-4 through SP-8. The location and configuration of the floor control valve assemblies are shown on drawings SP-19 and SP-20. Figures B–29 through B–31 show the typical riser locations and core layouts for the high, mid-level, and low zone systems.

The layout for the 2½ in. looped cross-main was identified and located on drawings SP-13 and SP-14 for the 78th floor systems in WTC 1 and WTC 2 respectively. The typical arrangement of 2½ in. looped cross-main is shown in Fig. B–32.

The layout for a typical Ordinary Hazard system was taken from drawing SP-12, showing a partial system layout for the 44th floor system. This drawing shows a grid system configuration with 1-1/4 in. branchlines and a far grid main near the exterior wall. Each branchline also contained a single outrigger sprinkler on a 1 in. branchline pipe. Figure B–33 shows the typical grid sprinkler system layout. Spacing of 13-1/4 ft between branchlines and 9 ft between sprinklers along a branchline were used for the calculations. This resulted in an average coverage area of 119 ft^2 per sprinkler. A total of 15 sprinklers were included in the design area based on the actual configuration observed on the drawing. Again, the end sprinklers were located approximately 1 ft to 2 ft from the exterior wall, resulting in a phantom area.

The layout for a Light Hazard system was derived from the Ordinary Hazard system layout. The branchlines were changed to 1 in. diameter pipe, and the far grid cross-main was removed from the system. This created a loop system with tree type branchlines extended outward from the 2½ in. cross-main toward the exterior walls and inward toward the core. The sprinkler along each branchline that was closest to the cross-main was increased to 1-1/4 in. pipe for hydraulic calculations for the 98th, 86th, 7th and 31st floor system calculations. These systems were the upper floors in the respective zones or the highest floors with pressure reducing valves.

A case was examined with a sprinkler spacing of 12 ft between branchlines and 14 ft between sprinklers along a branchline. This resulted in an average coverage area of 168 ft^2 per sprinkler. Nine sprinklers were included in the 1,512 ft^2 design area. However, this arrangement did not provide results that represented the performance of typical sprinkler systems designed to protect a Light Hazard Occupancy. Therefore, a sprinkler spacing of 14 ft between branchlines and 14 ft between sprinklers along a branchline was examined for use in the calculations. This resulted in an average coverage area of 196 ft^2 per sprinkler. Eight sprinklers were included in the application area for a total of 1,568 ft^2 as the baseline case for each floor level sprinkler system. The results of the calculations using this arrangement were considered to represent a typical sprinkler system designed to protect a Light Hazard Occupancy. Therefore, the 14 ft by 14 ft sprinkler spacing was used in the hydraulic calculations for the Light Hazard scenarios.

6.4.4 High Zone

The hydraulic analysis of the high zone sprinkler systems included an assessment of the sprinkler systems on the 107th floor and the 99th floor of WTC 1 using the requirements outlined above for Light Hazard Occupancies. Additional hydraulic calculations were performed for the 107th floor system of WTC 2, which used the criteria for an Ordinary Hazard Group 1 Occupancy as outlined above. The sprinkler system layout for the 99th floor of WTC 1 was modified to represent a sprinkler system designed in accordance with an Ordinary Hazard Occupancy for comparative purposes.

The hydraulic analysis was also performed using the supply calculation conditions. A series of demand calculations were performed for the 107th floor system of WTC 1 to demonstrate the differences in the supply and demand calculations.

Calculations were performed with the number of sprinklers considered to represent the actual design application areas for the systems. Additional calculations were performed to examine the change in system performance with less than the required number of sprinklers and with more than the required number of sprinklers. These calculations were conducted for four different cases involving the sprinkler systems on the 107th and 99th floors using Light or Ordinary Hazard Group 1 conditions.

Additional hydraulic calculations were then performed to evaluate the operation of the sprinkler systems for the four cases using the required number of design sprinklers. The results of these calculations were used to compare the differences in the performance of the sprinkler systems using the primary and secondary water supplies.

The primary water supply for the high zone sprinkler systems included two 5,000 gal sprinkler reserve water storage tanks located on the 110th floor. Calculations were performed to determine the duration of a single 5,000 gal tank, the combined 10,000 gal for the two tanks, and for the condition including the third 5,000 gal standpipe system reserve storage tank. A booster pump located on the 108th floor was also used to increase the pressure for the high zone sprinkler systems since the gravity pressure provided by water storage tanks was not sufficient for the sprinkler systems. The fire pump was modeled as a 500 gpm pump operating at 60 psi using the default performance curve provided in the HASS computer hydraulics program.

The secondary water supply condition was selected to represent water being supplied to the sprinkler system by the standpipe system. There were a number of different arrangements that could have been used to supply water to the sprinkler systems using the standpipe systems infrastructure. Some of the possible cases included the following:

- The fire department using a single high pressure pumper and one of the two high pressure FDCs
- The fire department using a single FDC and any single manually operated fire pump in the standpipe system in series
- The B1 level or 7th floor level fire pump and another fire pump on an upper level used in series
- One or more upper level fire pumps using water stored in the standpipe system reserve water storage tanks

The secondary water supply condition was evaluated in a similar manner to the water storage tanks. The data entered for the water storage tanks were based on a fixed or constant water supply. The data were entered as residual pressure only. For the tanks on the 110th floor, a pressure of 1.3 psi was used. This information was taken from the static pressure diagram included in the O&M manual and drawings SP-22 and SP-23 (PANYNJ 1972, 1987a). The secondary water supply was identified as the pressure reducing valve station on the 109th floor where the standpipe system was interconnected to the high and mid-level zone sprinkler systems. The pressure reducing valve was configured to provide a maximum of 50 psi outlet pressure, which was identified in general note 2 on drawings SP-22 and SP-23 and the O&M manual. The water supply was modeled using a fixed pressure water supply with a residual pressure of 50 psi.

Light Hazard Calculations for High Zone with Primary Water Supply

A series of seven hydraulic calculation cases were performed using the Light Hazard requirements outlined above to evaluate the performance of the sprinkler systems connected to riser A and supplied with water by the high zone supply. Table 6–2 provides a summary of the number of operating sprinklers included in each of the cases evaluated.

Table 6–3 provides a summary of the results of these calculations.

The calculated delivered densities in Table 6–2 were obtained by dividing the total system flow by the actual application area. The maximum and minimum delivered flows were extracted from the hydraulic calculation results. Sprinklers at the remote ends of branchlines typically discharge less water than sprinklers closer to the sprinkler main. The reason for this difference is due to the pressure loss through the branchline pipes.

Table 6–2. Number of operating sprinklers, 107th and 99th floor, Light Hazard cases.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
107	4	S1, through S4
107	12	S1 through S12
107	13	S1 through S13
107	16	S1 through S16
99	4	S11 through S14
99	8	S11 through S14, and S16 through S19
99	16	S1 through S4, S6 through S9, S11 through S14, and S16 through S19

Table 6–3. High zone Light Hazard hydraulic calculations summary, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Area (ft^2)	Maximum Area per Sprinkler (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
107	4	504	126	112	0.22	0.10	36.6	23.2
107	12	1512	126	272	0.18	0.10	27.9	16.1
107	13	1638	126	286	0.17	0.10	29.5	15.1
107	16	2016	126	306	0.15	0.10	23.5	13.4
99	4	784	196	137	0.18	0.10	45.6	27.5
99	8	1568	196	252	0.16	0.10	42.1	25.2
99	16	3136	196	407	0.13	0.10	34.2	20.2

The cases involved in this series of hydraulic calculations included variations on the number of sprinklers operating and the vertical location of the sprinkler system within the high water supply zone. For WTC 1, four cases were examined for the 107th floor system and three for the 99th floor system. These calculations represented the performance range for the sprinkler systems in the high water supply zone that were designed for the protection of Light Hazard Occupancies. Although the system layouts and number of operating sprinklers in the baseline cases could not be directly compared, the results demonstrated the declining pressure principle. As the number of sprinklers operating in a particular system increased, the average delivered density decreased as a result of the decreasing pressure available at the location of each sprinkler due to the friction loss associated with the increase in water flow. The range of densities for the 107th floor system was 0.223 gpm/ft^2 with four sprinklers operating to 0.152 gpm/ft^2 with 16 sprinklers operating. The range of densities for the 99th floor system was from 0.175 gpm/ft^2 with four sprinklers operating to 0.130 gpm/ft^2 with 16 sprinklers operating.

Ordinary Hazard Calculations for High Zone with Primary Water Supply

Additional hydraulic calculations were used to evaluate the performance of sprinkler systems designed to protect Ordinary Hazard Occupancy areas. Calculations were performed for the sprinkler system on the

107th floor of WTC 2 and the 99th floor of WTC 1 using the spacing criteria consistent with Ordinary Hazard criteria. Table 6–4 identifies the assumed number of operating sprinklers in each of the cases.

Table 6–4. Number of operating sprinklers, 107th and 99th floor Ordinary Hazard calculations.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
107	4	S1 through S4
107	18	S1 through S18
107	22	S1 through S22
99	4	S1 through S4
99	15	S6 through S20
99	20	S1 through S20
99	25	S1 through S25

A summary of the results for the hydraulic calculations of the sprinkler systems connected to the high water supply zone and designed using the criteria for Ordinary Hazard Occupancies is provided in Table 6–5.

Table 6–5. High zone Ordinary Hazard hydraulic calculations summary, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Area (ft^2)	Maximum Area per Sprinkler (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
107	4	476	119	172	0.36	0.15	44.5	41.3
107	18	1,502	119	376	0.25	0.15	23.4	17.5
107	22	1,749	119	388	0.22	0.15	21.3	12.6
99	4	476	119	221	0.46	0.15	55.5	54.9
99	15	1,680	119	507	0.30	0.15	34.3	33.2
99	20	2,226	119	545	0.26	0.15	27.8	26.6
99	25	2,793	119	566	0.20	0.15	23.4	21.9

The calculated delivered densities in Table 6–5 were based on the same methods outlined above for Table 6–3. In all cases the calculated delivered density exceeded the required discharge density of 0.15 gpm/ft^2. It should be noted however that the minimum required flow was not delivered in all cases. For example, the case involving 22 sprinklers operating on the 107th floor of WTC 2 resulted in a condition where the average density exceeded the minimum required density. However, the flow per sprinkler ranged from 21.3 gpm to 12.6 gpm. For ½ in. orifice sprinklers, the minimum flow is 14.82 gpm and the required pressure is 7 psi for all sprinklers. Therefore, there would be some concern regarding the performance of a sprinkler that operated at this lower pressure and resulting flow. This calculated pressure and resulting flow were localized and in this case would not be expected to affect the overall system performance.

Calculation of Water Supply Duration

The water supply duration for the high zone sprinkler systems was evaluated using one, two, and three 5,000 gal storage tanks. The supply durations were calculated using the fixed volume of the tank, disregarding the make-up supply connections to the tanks. Therefore, the estimates of duration should be considered minimums. Table 6–6 provides a summary of the water supply durations for the Light and Ordinary Hazard scenarios presented above for sprinkler systems in the high water supply zone. As mentioned previously, the Ordinary Hazard calculations for the 107th floor apply to WTC 2 only.

Table 6–6. High zone primary water supply duration, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Hazard	Flow (gpm)	Duration (min)		
				5,000 gal	10,000 gal	15,000 gal
107	4	Light	112	44.56	89.13	133.69
107	12	Light	272	18.37	36.74	55.11
107	13	Light	286	17.49	34.99	52.48
107	16	Light	306	16.34	32.68	49.02
99	4	Light	137	36.52	73.05	109.57
99	8	Light	252	19.81	39.62	59.43
99	16	Light	407	12.30	24.60	36.90
107	4	Ordinary	172	29.04	58.07	87.11
107	18	Ordinary	376	13.29	26.57	39.86
107	22	Ordinary	388	12.89	25.78	38.67
99	4	Ordinary	221	22.67	45.33	68.00
99	15	Ordinary	507	9.86	19.71	29.57
99	20	Ordinary	545	9.18	18.37	27.55
99	25	Ordinary	566	8.84	17.67	26.51

The water supply durations indicated in Table 6–6 are based on all of the sprinklers operating in each case. The calculations do not account for the independent operation of individual sprinklers. The durations were calculated by dividing the fixed water storage volume in each tank (5,000 gal) by the calculated flow rate for the case. Therefore, the durations indicated for each case are considered to be the minimums.

Comparison of Primary and Secondary Water Supply Calculations

Hydraulic calculations were performed to evaluate the changes in the system performance while operating in a secondary water supply mode. The secondary water supply calculations used a fixed pressure of 50 psi at the pressure-reducing valve that was provided between the connection of the sprinkler systems to the standpipe system. Table 6–7 provides a comparison of the sprinkler system densities while operating in the primary and secondary water supply modes.

Table 6–7. Comparison of primary and secondary water supplies for high zone.

Floor	Water Supply Mode	Area (ft^2)	Hazard	Supply (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
107	Primary	1,512	Light	272	0.18	0.1	27.9	16.1
107	Secondary	1,512	Light	352	0.23	0.1	35.2	21.0
99	Primary	1,568	Light	252	0.16	0.1	42.1	25.2
99	Secondary	1,568	Light	300	0.19	0.1	49.9	30.1
107	Primary	1,502	Ordinary	376	0.25	0.15	23.4	17.5
107	Secondary	1,502	Ordinary	481	0.32	0.15	29.8	22.5
99	Primary	1,680	Ordinary	507	0.30	0.15	34.3	33.2
99	Secondary	1,680	Ordinary	591	0.38	0.15	39.9	38.7

The added pressure to the sprinkler systems due to the addition of the secondary water supplies resulted in both higher individual sprinkler flows and average discharge densities. Secondary water supply durations were not calculated due to the complexities of quantifying a fixed volume of secondary water storage with multiple possible arrangements.

Comparison of Supply and Demand Calculations

Demand calculations were performed for the WTC 1 107th floor sprinkler system to compare to the supply calculations that were performed using 4, 12, 13, and 16 operating sprinklers. The comparison shows the difference between the minimum required density and the calculated delivered density. Table 6–8 provides a summary of the supply and demand calculation results.

The baseline cases for comparison were the demand and supply calculations with 12 sprinklers. These cases represent the intended design of 0.1gpm/ft^2 with an application area of 1,512 ft^2. This comparison also incorporates a margin of safety that is typically included in the design of sprinkler systems. The design calculations identified that the actual density based on the system demand was 0.168 gpm/ft^2, and the primary water supply was actually capable of delivering a discharge density of 0.18 gpm/ft^2.

The case involving 16 sprinklers resulted in less than 7 psi at several sprinklers; therefore, the results of the demand calculation were not valid for this condition. This is observed by looking at the flow at the sprinkler with the lowest flow rate. Dividing 13.4 gpm by a coverage area of 126 ft^2 results in a calculated delivered density of 0.106 gpm/ft^2. However, a flow of 13.4 gpm equates to a minimum end pressure of approximately 5.73 psi. This pressure is less than the minimum requirement of 7 psi for end sprinkler pressure in NFPA 13.

Table 6–8. Light Hazard hydraulic calculations summary, 107th floor, WTC 1 and WTC 2.

Calculation Type	Number of Operating Sprinklers	Area (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
Supply	4	504	112	0.22	0.10	36.6	23.2
Demand	4	504	73.4	0.15	0.10	24.2	15
Supply	12	1,512	272	0.18	0.10	27.9	16.1
Demand	12	1,512	254.7	0.17	0.10	26.1	15
Supply	13	1,638	286	0.17	0.10	29.5	15.1
Demand	13	1,638	284.4	0.17	0.10	29.4	15
Supply	16	2,016	306	0.15	0.10	23.5	13.4

6.4.5 Mid-Level Zone

The sprinkler systems on floors 32 through 98 in WTC 1 and WTC 2 composed the mid-level zone and shared a common riser and water supply (PANYNJ 1972, 1987a). These systems were supplied with water from the reserve storage tanks located on the 110th floor. Figure B–19 provides a representation of the water storage tanks and the feed main that supplied water to the top of riser A. Riser B supplied the mid-level sprinkler systems using gravity pressure. Figure B–34 demonstrates the path of water flow from the water storage tanks at node AST to the floor control assemblies at the 98th, 87th, 86th, and 32nd floors.

The representative layout identified in the high zone section was used for the hydraulic calculations for the systems in the mid-level zone. The sprinkler systems on floors 86 through 32 contained pressure-reducing type control valves. An additional hydraulic node PRV was added to the hydraulic calculations using the primary water supply. This node is identified as FPRV in the 32nd floor hydraulic calculations using the secondary water supply, and was treated as a fixed pressure loss device. The pressure was adjusted, and the reiterations of the hydraulic calculations were performed until the inlet and outlet pressures were in agreement with the specified pressure loss curves for the 2 ½ in. valves.

The hydraulic analysis of the mid-level zone sprinkler systems included supply calculations using the requirements for both Light and Ordinary Hazard Group 1. Calculations were performed to determine the water supply durations for the primary water supply.

Additional hydraulic calculations were performed for the Light Hazard and Ordinary Hazard layouts using the secondary water supply configuration. Four secondary supply calculations were performed, one calculation for each scenario involving the number of sprinklers included in the required design area at the 32nd floor and 98th floor sprinkler systems. The secondary water supply was simulated in the same manner that was used in the high zone analysis. A fixed pressure of 50 psi was identified at the hydraulic node PRV, as identified in Fig. B–19, at the connection of the standpipe system and sprinkler system infrastructure piping in the 109th floor MER.

Light Hazard Calculations for Mid-Level Zone with Primary Water Supply

Twelve cases were evaluated for the mid-level zone sprinkler systems. Table 6–9 provides a summary of the scenarios.

Table 6–9. Number of operating sprinklers, 98th, 87th, and 32nd floor, Light Hazard calculations, WTC 1.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
98	4	S11 through S14
98	8	S11 through S14, and S16 through S19
98	16	S1 through S4, S6 through S9, S11 through S14, and S16 through S19
87	4	S1 through S4
87	9	S11 through S14, and S16 through S19
87	18	S5 through S7, S10 through S24
87	4	S11 through S14
87	8	S11 through S14, and S16 through S19
87	16	S1 through S4, S6 through S9, S11 through S14, and S16 through S19
32	4	S11 through S14
32	8	S11 through S14, and S16 through S19
32	16	S1 through S4, S6 through S9, S11 through S14, and S16 through S19

A series of three hydraulic calculations was performed for four different representative Light Hazard systems. The system on the 87th floor was used to determine an appropriate sprinkler spacing and coverage area to use in the calculations for all of the sprinkler systems. Two different system arrangements were selected. The first used sprinklers spaced at 14 ft by 12 ft and the other 14 ft by 14 ft. These scenarios resulted in coverage areas of 168 ft^2 and 196 ft^2, respectively. The results of these calculations are summarized in Table 6–10.

The performance of the sprinkler system on this floor using the coverage area of 196 ft^2 was considered to accurately represent a Light Hazard sprinkler system design. Therefore, all of the other calculations used this typical arrangement.

The results indicate that the system capabilities exceeded the minimum requirements for the design. This is attributed to the arrangement of the cross-mains. The interior cross-mains routed through the corridor of the core area significantly increased the flow capacity throughout the floor. A second 3 in. riser was used to supply water to the 32nd through 82nd floor level systems. A secondary floor control valve assembly and feed main was provided for the systems on these floor levels. However, only one riser was accounted for in the calculation of the sprinkler systems on these floors. Under normal operating conditions, additional water would be available from the other riser supplying the floor, increasing the average delivered density to the design sprinklers. However, in practice, risers are sometimes isolated due to maintenance while still providing protection to all sprinklers through the other riser. Therefore, this was a conservative approach to determining the supply capabilities of the water supply system.

Table 6–10. Mid-level zone Light Hazard hydraulic calculations summary, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Area (ft^2)	Maximum Area per Sprinkler (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
98	4	784	196	117	0.15	0.10	39.1	23.3
98	8	1,568	196	210	0.13	0.10	35.2	20.9
98	16	3,136	196	322	0.10	0.10	27.2	15.8
87	4	672	168	185	0.27	0.10	44.2	28.1
87	9	1,512	168	293	0.19	0.10	49.1	25.1
87	18	3,024	168	441	0.15	0.10	34.6	18.8
87	4	784	196	138	0.18	0.10	45.8	27.6
87	8	1,568	196	251	0.16	0.10	42	25.1
87	16	3,136	196	398	0.13	0.10	33.5	19.7
32	4	784	196	151	0.19	0.10	50.3	30.4
32	8	1,568	196	272	0.17	0.10	45.3	27.2
32	16	3,136	196	436	0.14	0.10	36.7	21.7

The calculations involving the 32nd floor system used a fixed pressure loss device to simulate the pressure-reducing valve. A pressure-reducing valve was required to maintain the system pressure below the 175 psi threshold for the floor level sprinkler system components. The pressure-reducing valve also reduced the calculated delivered density to these systems. The use of the pressure-reducing valves resulted in uniform performance within the range established for the systems on the 98th and 87th floors, which did not include pressure-reducing valves, and therefore, demonstrated the true effect of gravity (head) pressure.

Ordinary Hazard Calculations for Mid-Level Zone with Primary Water Supply

Fourteen Ordinary Hazard calculations were performed for the mid-level zone sprinkler systems. Hydraulic calculations were performed for the highest and lowest floor level systems with and without pressure-reducing valves. Calculations were performed to evaluate three scenarios:

1. The performance of the sprinkler systems using an equivalent number of sprinklers to the design area
2. The performance of the systems using four operational sprinklers (less than the design area)
3. The performance of the systems with large number of operational sprinklers (more than the number of sprinklers in the design area)

The hydraulic calculations revealed an inherent limitation in the design of sprinkler riser B, which supplied the sprinkler systems in the mid-level zone. An imposed flow limitation existed as a result of friction loss within the 4 in. diameter supply pipe connecting the water storage tanks to the top of riser B.

The friction loss due to the long travel distance exceeded the net positive head pressure provided by the elevated water storage tank, creating a negative atmospheric pressure (vacuum) at flows exceeding 440 gpm.

The arrangement of the mid-level zone sprinkler systems and the extremely high head pressure resulted in significant excess flow being provided to these sprinkler systems. In several cases, the large number of sprinklers assumed to be operating resulted in excess flow that exceeded the 440 gpm limitation of the supply pipe on the 109th floor. In these cases, the pressure observed at the top of riser B was lower than atmospheric pressure, and the HASS hydraulic program terminated the calculations. A maximum of 25 sprinklers was included for all systems. The cases shown in Table 6–11 and Table 6–12 with maximum values of less than 25 sprinklers indicate the actual number of sprinklers that could be supported by the water supply systems before termination, based on output from the hydraulic analysis.

The combined effects of gravity and the grid system layout resulted in significant flow rates and densities being supplied to the mid level zone sprinkler systems as shown in Table 6–12. The fixed losses for the pressure-reducing valves in the calculations for the 32nd and 86th floor system calculations required reiterative calculations to account for the pressure loss effects of these valves. The systems on the 32nd and 86th floors demonstrated similar performance for the cases with four sprinklers operating. As with the calculations using the Light Hazard requirements, the performance of the sprinkler systems with the pressure-reducing valves were within the range established by the highest and lowest floor sprinkler systems without pressure-reducing valves.

Table 6–11. Number of operating sprinklers, 98th, 87th, 86th and 32nd floor Ordinary Hazard calculations, WTC 1.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
98	4	S6 through S9
98	15	S6 through S20
98	20	S1 through S20
98	25	S1 through S25
87	4	S1 through S4
87	15	S6 through S20
87	20	S1 through S20
86	4	S1 through S4
86	15	S6 through S20
86	20	S1 through S20
86	25	S1 through S25
32	4	S1 through S4
32	15	S6 through S20
32	16	S5 through S20

Table 6–12. Mid-level zone Ordinary Hazard hydraulic calculations summary, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Area (ft^2)	Maximum Area per Sprinkler (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
98	4	476	119	163	0.34	0.15	41.1	40.6
98	15	1,680	119	371	0.22	0.15	25.1	24.3
98	20	2,226	119	402	0.18	0.15	20.5	19.6
98	25	2,793	119	420	0.15	0.15	17.4	16.2
87	4	476	119	219	0.46	0.15	55.2	54.5
87	15	1,680	119	509	0.30	0.15	34.4	33.3
87	20	2,226	119	548	0.25	0.15	28	26.7
86	4	476	119	176	0.37	0.15	44.3	43.8
86	15	1,680	119	363	0.22	0.15	24.5	23.7
86	20	2,226	119	397	0.18	0.15	20.3	19.3
86	25	2,793	119	424	0.15	0.15	17.6	16.3
32	4	476	119	174	0.37	0.15	43.8	43.2
32	15	1,680	119	440	0.26	0.15	29.7	28.8
32	16	1,904	119	441	0.23	0.15	28	27

Calculation of Water Supply Duration

The water supply duration for the sprinkler systems connected to riser B in the mid-level water supply zone were evaluated using one, two, and three 5,000 gal tanks. This was the same method used to evaluate the primary water supply for the high water supply zone. Two sprinkler reserve storage tanks and the single standpipe reserve storage tank on the 110th floor were included in this analysis. These tanks were shared with the high zone sprinkler systems. A summary of the water supply durations is provided in Table 6–13.

Table 6–13. Mid-level zone primary water supply duration, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Hazard	Flow (gpm)	Duration (min)		
				5,000 gal	10,000 gal	15,000 gal
98	4	Light	117	42.81	85.62	128.42
98	8	Light	210	23.83	47.66	71.50
98	16	Light	322	15.54	31.08	46.63
87	4	Light	185	27.10	54.20	81.30
87	9	Light	293	17.06	34.13	51.19
87	18	Light	441	11.33	22.66	33.99
87	4	Light	138	36.36	72.73	109.09
87	8	Light	251	19.89	39.78	59.67
87	16	Light	398	12.56	25.12	37.68
32	4	Light	151	33.03	66.05	99.08
32	8	Light	272	18.40	36.81	55.21
32	16	Light	436	11.47	22.94	34.41
98	4	Ordinary	163	30.62	61.24	91.86
98	15	Ordinary	371	13.48	26.96	40.44
98	20	Ordinary	402	12.45	24.90	37.35
98	25	Ordinary	420	11.92	23.84	35.76
87	4	Ordinary	219	22.82	45.64	68.46
87	15	Ordinary	509	9.83	19.67	29.50
87	20	Ordinary	548	9.12	18.23	27.35
86	4	Ordinary	176	28.39	56.79	85.18
86	15	Ordinary	363	13.79	27.58	41.37
86	20	Ordinary	397	12.58	25.17	37.75
86	25	Ordinary	424	11.80	23.59	35.39
32	4	Ordinary	174	28.77	57.54	86.31
32	15	Ordinary	440	11.37	22.75	34.12
32	16	Ordinary	441	11.35	22.69	34.04

As with all of the cases, the water supply duration for each case did not account for progressive operation of the sprinklers, but rather assumed that all of the operating sprinklers opened at the same time. The calculations were based on the flow rates determined from the hydraulic supply calculations. The durations were calculated by dividing the fixed volume of water in the storage tank by the flow rate for each case. Therefore, as previously explained, the duration would be expected to be significantly greater than indicated in Table 6–13 from the beginning stages of fire growth when the first sprinkler(s) operate.

Comparison of Primary and Secondary Water Supply Calculations

Calculations were performed to simulate the operation of the sprinkler system in a secondary supply mode. These calculations used a fixed pressure of 50 psi at the pressure-reducing valve at the interconnection of the sprinkler and standpipe system infrastructures. Table 6–14 provides a summary of the results for the sprinkler system operating performance while operating in the primary and secondary supply modes.

Table 6–14. Comparison of primary and secondary water supplies for mid-level zone.

Floor	Water Supply Mode	Area (ft^2)	Hazard	Supply (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
98	Primary	1,568	Light	210	0.13	0.1	35.2	20.9
98	Secondary	1,568	Light	281	0.18	0.1	46.8	28.2
32	Primary	1,568	Light	272	0.17	0.1	45.3	27.2
32	Secondary	1,568	Light	277	0.18	0.1	46.1	27.8
98	Primary	1,680	Ordinary	371	0.22	0.15	25.1	24.3
98	Secondary	1,680	Ordinary	510	0.33	0.15	34.4	33.4
32	Primary	1,680	Ordinary	440	0.26	0.15	29.7	28.8
32	Secondary	1,680	Ordinary	643	0.41	0.15	43.4	42.2

In all cases the secondary water supply resulted in increased water flow and discharge density. The cases involving the Light Hazard calculations demonstrated uniformity in the performance of the systems in the secondary supply mode. The Ordinary Hazard calculations indicated a significant increase in the water flow rates and discharge densities while operating in the secondary supply mode. Additionally, the results showed a significant increase due to the effects of elevation.

The different configurations used for the Light Hazard and Ordinary Hazard system layouts had a significant impact on the hydraulic performance of the systems. The Light Hazard systems were configured with dead-end branchlines extending from a 2 ½ in. looped cross-main. The Ordinary Hazard system layout also included this looped cross-main and a secondary (far) grid cross-main near the exterior of the building. This far cross-main reduced the effects of friction loss and provided evenly distributed water throughout the application area. This accounted for the increased flows observed in the hydraulic calculations for the sprinkler systems based on the Ordinary Hazard layout.

6.4.6 Low Zone

The sprinkler systems on floors 1 through 31 in each tower comprised the low zone. A single 5,000 gal water storage tank was provided on the 41st floor in WTC 1 to supply the low zone systems. A similar tank was provided in WTC 2. Figure B–35 illustrates the water storage tank and feed main arrangement on the 41st floor. The low zone (C) risers for both towers were interconnected on the B1 level and were provided with an isolation valve that permitted the risers to function as part of the same system or separately. Figure B–36 shows the arrangement of the low zone risers. This arrangement permitted the tank in either building to serve as the primary water supply for the low water supply zone in the building

A summary of the hydraulic calculation results for the Light Hazard sprinkler systems supplied by riser C is provided in Table 6–16.

Table 6–16. Low zone Light Hazard hydraulic calculations summary, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Area (ft^2)	Maximum Area per Sprinkler (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
31	4	784	196	110	0.14	0.10	36.8	21.9
31	8	1,568	196	200	0.13	0.10	33.5	19.8
31	16	3,136	196	319	0.10	0.10	27.6	15.6
2	4	784	196	150	0.19	0.10	50	30.2
2	8	1,568	196	270	0.17	0.10	45	27.1
2	16	3,136	196	477	0.15	0.10	40	23.8

The results of the calculations demonstrate that the system capabilities meet or exceed the minimum requirements for Light Hazard Occupancies. The results also demonstrate that the lower level systems were capable of discharging more than the upper level systems as a result of the increased pressure. The pressure-reducing valves installed on the lower level systems restricted the flow somewhat.

Ordinary Hazard Calculations for Low Zone with Primary Water Supply

Fourteen Ordinary Hazard cases were analyzed for the low zone sprinkler systems. The calculations included floors 31 and 9, which represented the highest and lowest floor level systems without pressure-reducing valves. Additional calculations were included for floors 2 and 7, which represented the highest and lowest floor level systems with pressure-reducing valves. Multiple calculations were performed to evaluate the range of scenarios involving more than, less than, and equal to the number of sprinklers in the design area. Table 6–17 provides a summary of the active sprinklers in each scenario.

The calculations for the systems on the ninth floor with more than nine operating sprinklers resulted in pressure lower than atmospheric pressure at the top of riser C. Again, this is the result of the friction loss exceeding the net positive head pressure provided by the elevated tank. The friction loss through the supply pipe to the top of riser C imposed an inherent water flow limitation of approximately 640 gpm to the low zone sprinkler systems. The results of the calculations for all of the Ordinary Hazard calculations for the low zone sprinkler systems are provided in Table 6–18.

Table 6–17. Number of operating sprinklers, 31st, 9th, 7th and 2nd floor Ordinary Hazard calculations, WTC 1.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
31	4	S1 through S4
31	15	S6 through S20
31	20	S1 through S20
31	25	S1 through S25
9	4	S1 through S4
9	15	S6 through S20
7	4	S1 through S4
7	15	S6 through S20
7	20	S1 through S20
7	25	S1 through S25
2	4	S1 through S4
2	15	S6 through S20
2	20	S1 through S20
2	25	S1 through S25

Table 6–18. Low zone Ordinary Hazard hydraulic calculations summary, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Area (ft^2)	Maximum Area per Sprinkler (ft^2)	Flow (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
31	4	476	119	157	0.33	0.15	39.6	39.1
31	15	1,680	119	401	0.24	0.15	27.1	26.3
31	20	2,226	119	447	0.20	0.15	22.8	21.8
31	25	2,793	119	476	0.17	0.15	19.7	18.3
9	4	476	119	265	0.56	0.15	66.7	65.9
9	15	1,680	119	636	0.38	0.15	42.9	41.7
7	4	476	119	209	0.44	0.15	52.7	52
7	15	1,680	119	486	0.29	0.15	32.8	31.9
7	20	2,226	119	553	0.25	0.15	28.3	27
7	25	2,793	119	576	0.21	0.15	23.9	22.2
2	4	476	119	240	0.50	0.15	60.4	59.7
2	15	1,680	119	486	0.29	0.15	32.8	31.8
2	20	2,226	119	549	0.25	0.15	28	26.7
2	25	2,793	119	575	0.21	0.15	23.6	22.2

The low zone sprinkler systems demonstrated similar performance to the systems in the mid-level zone. The calculated discharge density and flow rate for the system on the 31st floor were nearly identical to those for the systems on the 98th floor. As would be expected, the results also demonstrated a decrease in discharge density as the number of operating sprinklers increased. The average discharge density for all cases exceeded the minimum required density. The hydraulic calculations for the sprinkler systems on the seventh and second floors included a fixed pressure loss device representing the pressure-reducing valves. The value of the fixed pressure loss was adjusted to match the pressure loss curves for the straight pattern pressure-reducing valve at the calculated flow rate. This required multiple iterations for each case. This approach reasonably simulated the pressure limits and associated maximum water flow to the floor level sprinkler systems through the pressure-reduction valves.

Calculation of Water Supply Duration

The water supply duration for the low zone sprinkler systems was evaluated using one 5,000 gal storage tank. Table 6–19 provides a summary of the calculated water supply duration for each of the low zone scenarios.

Table 6–19. Low zone primary water supply duration, WTC 1 and WTC 2.

Floor	Number of Operating Sprinklers	Hazard	Flow (gpm)	Duration (min) Based on 5,000 gal
31	4	Light	110	45.50
31	8	Light	200	25.05
31	16	Light	319	15.70
2	4	Light	150	33.27
2	8	Light	270	18.51
2	16	Light	477	10.48
31	4	Ordinary	157	31.79
31	15	Ordinary	401	12.46
31	20	Ordinary	447	11.19
31	25	Ordinary	476	10.52
9	4	Ordinary	265	18.88
9	15	Ordinary	636	7.87
7	4	Ordinary	209	23.89
7	15	Ordinary	486	10.28
7	20	Ordinary	553	9.04
7	25	Ordinary	576	8.69
2	4	Ordinary	240	20.84
2	15	Ordinary	486	10.29
2	20	Ordinary	549	9.12
2	25	Ordinary	575	8.70

The fixed water storage volume of a single 5,000 gal storage tank was divided by the calculated flow rate to determine the duration. The actual operation sequence of individual sprinklers was not accounted for in the calculation. Additionally, the calculation does not account for supplemental water supplied to the tank by the domestic water system through the 2 in. automatic re-fill connection. Therefore, the calculated durations represent a lower limit for the assumed number of operating sprinklers under normal conditions. A case involving both the primary and secondary water storage tanks is examined in the next section.

Comparison of Primary and Secondary Water Supply Calculations

Hydraulic calculations were performed using the secondary water supply for the low zone sprinkler systems. Table 6–20 provides a comparison of the results to the similar cases with the primary water supply mode.

Table 6–20. Comparison of primary and secondary water supplies for low zone.

Floor	Water Supply Mode	Area (ft^2)	Hazard	Supply (gpm)	Calc. Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Highest Delivered Flow (gpm)	Lowest Delivered Flow (gpm)
31	Primary	1,568	Light	200	0.14	0.10	36.8	21.9
31	Secondary	1,568	Light	172	0.11	0.10	29.1	17.1
2	Primary	1,568	Light	270	0.17	0.10	45	27.1
2	Secondary	1,568	Light	272	0.17	0.10	45.3	27.3
31	Primary	1,680	Ordinary	401	0.24	0.15	27.1	26.3
31	Secondary	1,680	Ordinary	266	0.17	0.15	34.4	33.4
2	Primary	1,680	Ordinary	486	0.29	0.15	32.8	31.8
2	Secondary	1,680	Ordinary	436	0.28	0.15	43.4	42.2

Unlike the high and mid-level zones, the friction loss associated with the long travel path from the water storage tank in one building through the risers and sub-grade level piping resulted in less water being delivered to the sprinkler systems in the secondary supply mode. The average density provided in the secondary water supply mode exceeded the minimum. However, the minimum required end sprinkler pressure was not maintained for all sprinklers in the Light Hazard case for the 31st floor.

Table 6–21 provides a comparison of the calculated water supply durations for the low zone sprinkler systems operating in both the primary and secondary modes.

The combined water supply duration adds the two single tank durations. The calculations do not account for refilling of the tanks, the individual operation of sprinklers, or fire department operations.

Table 6–21. Low zone primary water supply duration, WTC 1 and WTC 2.

Floor	Water Supply Mode	Number of Operating Sprinklers	Hazard	Flow (gpm)	Duration (min) Based on 5,000 gal	Combined Duration of Primary and Secondary Supplies (min)
31	Primary	8	Light	200	25.05	54.11
31	Secondary	8	Light	172	29.06	
2	Primary	8	Light	270	18.51	36.89
2	Secondary	8	Light	272	18.38	
31	Primary	15	Ordinary	401	12.46	31.25
31	Secondary	15	Ordinary	266	18.79	
2	Primary	15	Ordinary	486	10.29	21.76
2	Secondary	15	Ordinary	436	11.47	

Manual Operations and Related Procedures

The building maintenance and engineering staff at the WTC complex included supervisors and approximately 15 maintenance personnel. Two O&M manuals indicated some of the required emergency procedures for the engineering and maintenance staff (PANYNJ 1987a). The information in O&M Manual 23 *Fire Protection Systems* provided an overview of the intended operations for the fire pumps, sprinkler systems, and standpipe systems in WTC 1 and WTC 2. Additional information in O&M Manual 18 S*prinkler Systems* provided clarification regarding the operation of the sprinkler system and pumps and requirements of the standpipe systems.

The primary action required of the engineering and maintenance staff involved operation of the manual fire pumps. Chapter 11 of O&M Manual 23 provided a description of the fire pumps in WTC 1 and WTC 2. Fire pumps were provided on the B1, 7th floor, 41st floor and 75th floor levels of each tower. The O&M manual indicated that the maintenance staff was required to place pump 294A or 294B in operation for a fire anywhere in the complex. Either of these pumps was capable of providing water to any of the other upper level pumping stations. The O&M manual also describes the following:

- Pump 7A (WTC 1) or 7B (WTC 2) was required to be manually started if a fire was reported on any floor between the 7th floor and the roof.
- Pump 41A (WTC 1) or 41B (WTC 2) was required to be manually started if a fire was reported on any floor between the 41st floor and the roof.
- Pump 75A (WTC 1) or 75B (WTC 2) was required to be manually started if a fire was reported on any floor between the 75th floor and the roof.

All of the pumps were rated at 750 gpm. Table 6–22 provides a summary of the net pressure head provided by each of the pumps, indicating the height that the pumps could lift water in the systems.

Table 6–22. Summary of manual fire pump pressure limitations at rated flow (750 gpm), WTC 1 and WTC 2.

Tower	Pump	Floor	Floor and (Net) Elevation in Feet	Net Head Provided by Pump (ft)	Net Head Pressure Provided by Pump (psi)
WTC 1	294A	B1 Level	294 (0)	831	360
	7A	7th floor	390 (96)	800	346
	41A	41st floor	800 (506)	831	360
	75A	75th floor	1,222 (928)	526	228
WTC 2	294B	B1 Level	294 (0)	831	360
	7B	7th floor	390 (96)	800	346
	41B	41st floor	800 (506)	831	360
	75B	75th floor	1,216 (922)	526	228

The operating procedures for the buildings included manually starting either pump 294A or 294B for a fire on any floor in WTC 1 or WTC 2. The operating procedures also identified that the pumps on the B1 level and the 7th floor level would be manually started for fires reported between the 7th and the 40th floors in the respective building, and, pumps 294A and 7A would be started in WTC 1 and pumps 294B and 7B would be started in WTC 2 (PANYNJ 1987a).

The operating procedures describe that the pumps on the B1, 7th floor and 41st floor levels were to be manually started for fires reported between the 41st and 74th floors. Pumps 294A, 7A, and 41A were to be manually started in WTC 1, and pumps 294B, 7B and 41B were to be manually started in WTC 2.

The operating procedures also identify that fires reported on the 75th floor or above would have all four fire pumps manually started in the respective tower. The maintenance staff was available to open and close sectional isolation valves or control valves.

6.5 WTC 7

6.5.1 High Zone

Representative Sprinkler Layout

Supply calculations were performed for the highest (most demanding) and lowest (least demanding) floors of each zone. Floors 40 and 47 were calculated for the high zone. In performing the supply calculations for WTC 7, the proper selection of the sprinkler design area was necessary so that the performance of the sprinkler systems on different floors could be compared to one another. In determining the design area for analysis, two factors were considered, location and hydraulic remoteness.

The location for the design area on the 47th floor was designated at the end of the northeast supply main as illustrated in Fig. B–37. This area was chosen because it was the hydraulically most remote area on the floor based on the 4 in. main location indicated in the figure (Gensler and Associates 1995).

The location for the design area on the 40th floor was designated on the south side of the 2 ½ in. sprinkler loop as illustrated on the typical floor layout in Fig. B–38. This area was primarily chosen due to its hydraulic remoteness from the connection to the system riser and its location along Vesey Street, or the "exposed" side of the building facing south towards the WTC complex.

A representative coverage area of 168 ft^2 per sprinkler was used to determine the number of sprinklers flowing in the calculations for the 47th floor system and 40th floor systems, as illustrated in Figs. B–37 and B–38. The sprinkler spacing on the 40th floor was 14 ft by 12 ft, based on drawing reviews (Gensler and Associates 1995; Disk 2, # 52). Figures B–39 and B–40 illustrate a typical sprinkler layout as defined by the Syska and Hennessy construction drawings. Although Fig. B–40 illustrates a spacing of 15 ft by 12 ft along Vesey Street where the remote area is defined, typical ceiling tiles are arranged in 2 ft by 2 ft or 2 ft by 4 ft units. Therefore, sprinklers installed in a center of tile arrangement with a maximum spacing of 12 ft on center by 14 ft on center are representative for the 40th floor. It should be noted that the maximum spacing for a Light Hazard Occupancy is 15 ft by 15 ft, or 225 ft^2.

Having reviewed the available system and subsystem drawings, a 12 ft by 14 ft spacing was considered representative and suitable for hydraulic calculations on the 40th and 47th floor.

Analysis and Results

The primary supply for the high zone was an automatic fire (booster) pump on the 46th floor that took suction from the two 7,500 gal water storage tanks. The booster pump was rated to supply 500 gpm with a discharge head pressure of 120 psi. The booster pump was a model 41F12B single stage horizontal split case fire pump manufactured by Peerless Pump Company, Inc. (PANYNJ 1987a, Syska & Hennessy 1984). The characteristic fire pump curve, obtained from the manufacturer, was used in the hydraulic calculations.

Refer to Figs. B–41, B–37, and B–38 for the hydraulic node placement that identifies all pipe intersections and diameter changes. The flow path from the discharge side of the pump to the supply side of the floor control valve assemblies on the 40th and 47th floors are illustrated in Fig. B–41. The primary supply flow path for the high zone systems extends from node PD3 through TR4C, MR8A and MR8B to each floor level sprinkler system supplied by riser 8. Nodes TR8 and BR8 represent the nodes on the supply side of the floor control valves on the 47th floor and 40th floor, respectively.

A 750 gpm at 310 psi manual fire pump located on the first floor was used to provide the secondary supply for all of the sprinkler and standpipe system zones. The manual fire pump was supplied with water through a redundant direct connection to the NYC water distribution system. The pump was a Peerless model 5TUTF16 single stage, horizontal split case pump. The characteristic pump curve, obtained from the manufacturer, was used in the calculations.

The flow path from the manual fire pump to the high zone is illustrated in Fig. B–41. The flow path extended from the discharge side of the manual fire pump at node PD2, up risers 1 and 2 to nodes TR1 and TR2, respectively. The flow path then extended up riser 4 to node TR4C.

Three supply calculations were performed on each floor for each water supply. The calculations were conducted with four, nine and eighteen operating sprinklers. Refer to Fig. B–37 for the sprinkler locations on the 47th floor and Fig. B–38 for the sprinkler locations on the 40th floor. Table 6–23 lists the number of operating sprinklers for each scenario on the respective floor.

Table 6–23. Number of operating sprinklers for hydraulic supply calculations, 47th and 40th floors, WTC 7.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
47	4	S1, S2, S5, S6
47	9	S1, S2, S3, S4, S5, S6, S7, S8, S12
47	18	S1 through S18
40	4	S8, S9, S11, S12
40	9	S4, S5, S6, S7, S8, S9, S10, S11, S12
40	18	S1 through S18

The calculation results are summarized in Table 6–24. The supply column lists the calculated delivered flow rate for the given number of operating sprinklers for the respective supply. The delivered density is the average ratio of the calculated delivered flow rate, or supply, over the applicable sprinkler coverage area associated with the number of sprinklers assumed to be operating. It should be noted that the representative sprinkler spacing on the 40th and 47th floors was 168 ft^2 for each sprinkler. Therefore, the sprinkler coverage area was 168 ft^2 times the number of operating sprinklers. The “required density” is the minimum flow rate per unit area specified for a Light Hazard Occupancy in accordance with RS-17 and NFPA 13 as referenced in the BCNYC (BCNYC 1968).

The supply duration is the time of water availability for the specific flow and corresponding density. The volume available in the tanks limited the primary supply for the high zone sprinkler systems. The supply duration was equal to the number of gallons available in the tanks divided by the supplied flow rate. The durations listed in Table 6–24 for the normal operating conditions do not account for the make-up water available to the tanks, the use of stored domestic water in the tanks, or the incremental increase in actuated sprinklers. The durations were calculated using the calculated flow for all of the sprinklers flowing water at the same time. Therefore, as previously described, the durations listed in Table 6–24 are considered to be minimums.

The supply duration for the secondary water supply is not listed because the water supplied from the city main is not limited. The calculations were conducted under normal operating conditions for the systems.

The coverage area that involved nine sprinklers was 1,512 ft^2. This corresponded to a required density of 0.10 gpm/ft^2 per NFPA 13 for a Light Hazard Occupancy. The calculations involving the nine sprinkler scenario on the 47th floor resulted in an average delivered density of 0.18 gpm/ft^2 and 0.25 gpm/ft^2 for the primary and secondary water supplies, respectively. This demonstrates that the primary supply for the high zone was not only adequate, but delivered almost twice the necessary demand required by NFPA 13. The 47th floor was the most demanding floor in the high zone.

The coverage area that involved 18 sprinklers was approximately 3,024 ft^2, twice the required system design area per NFPA 13. The calculation results indicate that the primary and secondary water supplies for the 40th and 47th floors were also above the minimum required for a Light Hazard Occupancy per NFPA 13.

Table 6–26. Mid-level zone hydraulic calculations summary, WTC 7.

Floor	Calc. I.D.	Qty/Area (ft^2)	Source	Supply (gpm)	Calc. Delivered Density (gpm/ft^2)	High Delivered Density (gpm/ft^2)	Low Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Supply Duration (min)
39	10a	9/1,512	Primary	245	0.16	0.18	0.15	0.10	61
39	10c	9/1,512	Secondary	492	0.33	0.35	0.30	0.10	NA
21	11a	9/1,512	Primary	290	0.19	0.21	0.18	0.10	52
21	11c	9/1,512	Secondary	303	0.20	0.22	0.19	0.10	NA
39	13a	4/672	Primary	113	0.17	0.17	0.16	0.10	133
39	13c	4/672	Secondary	230	0.34	0.35	0.33	0.10	NA
21	14a	4/672	Primary	183	0.27	0.28	0.27	0.10	82
21	14c	4/672	Secondary	190	0.28	0.29	0.28	0.10	NA
39	16a	18/3,024	Primary	411	0.14	0.15	0.13	0.10	36
39	16c	18/3,024	Secondary	813	0.27	0.29	0.25	0.10	NA
21	17a	18/3,024	Primary	337	0.11	0.12	0.10	0.10	45
21	17c	18/3,024	Secondary	356	0.12	0.13	0.11	0.10	NA

Note the difference between the average delivered density on the 39th floor and 21st floor in the 18 sprinkler scenario. The average delivered density with the secondary supply was 0.12 gpm/ft^2 on the 21st floor and 0.27 gpm/ft^2 on the 39th floor. This large difference was due to the pressure reducing valve on the 21st floor. The delivered flow rate on the 21st floor was 356 gpm, while the flow rate on the 39th floor was 813 gpm. This example demonstrates the effect the pressure reducing valves have on the system.

6.5.3 Low Zone

Representative Sprinkler Layout

The location for the design area on the 20th floor was designated on the south side of the 4 in. sprinkler loop as illustrated on the typical floor layout on Fig. B–38 (Gensler and Associates 1995). This area was chosen because it represents a hydraulically remote portion of the floor, and it is on the side of the building directly exposed to the balance of the WTC complex. The floor plan, as defined in the high zone narrative and Fig. B–38 was representative for the floors on the low level zone, with exception of the unsprinklered areas addressed in previous chapters. The representative coverage area of 168 ft^2 was used in the calculations.

The first floor loading dock area was provided with a dry pipe sprinkler system. The layout for this system was consistent with Ordinary Hazard spacing. Refer to Fig. B–42 (Swanke Hayden Connell 1998). The spacing was approximately 10 ½ ft by 12 ft with a coverage area of approximately 126 ft^2 per sprinkler. The maximum coverage area for an Ordinary Hazard Occupancy is 130 ft^2 per sprinkler, in accordance with NFPA 13.

Analysis

The primary water supply for the 1st through 20th floors was the automatic fire pump in the 1st floor fire pump room (Syska & Hennessy 1984). The pump was a horizontal split case, model 3ABF9 fire pump manufactured by Peerless Pump Company, Inc. (Syska & Hennessy 1984) The fire pump had a rating of 500 gpm at 120 psi (Syska & Hennessy 1984). The characteristic pump curve obtained from the manufacturer was utilized in the calculations. The secondary supply was provided from the manual fire pump, also located in the fire pump room on the first floor.

Three supply calculations were performed on each floor for the primary water supply and secondary water supply. The calculations were conducted with 4, 9, and 18 sprinklers operating as described in the methodology for the 20th floor system, and 4, 12, and 18 sprinklers operating for the 1st floor calculations. A case assuming 12 open sprinklers was evaluated because 12 sprinklers at 126 ft^2 equals a total flow area of 1,512 ft^2. The total required design area for an Ordinary Hazard Group area is 1,500 ft^2 at a density of 0.15 gpm/ft^2 per NFPA 13. Refer to Figs. B–41, B–38, and B–43. Table 6–27 lists the number of open sprinklers assumed for each case on the respective floor.

Table 6–27. Number of operating sprinklers for hydraulic supply calculations, 1st and 20th floors, WTC 7.

Floor	Number of Operating Sprinklers	Sprinkler Node Identification
20	4	S8, S9, S11, S12
20	9	S4, S5, S6, S7, S8, S9, S10, S11, S12
20	18	S1 through S18
1	4	S14, S15, S17, S18
1	9	S7 through S18
1	18	S1 through S18

The results are provided in Table 6–28.

Table 6–28. Low zone hydraulic calculations summary, WTC 7.

Floor	Calc. I.D.	Qty/Area (ft^2)	Source	Supply (gpm)	Calc. Delivered Density (gpm/ft^2)	High Delivered Density (gpm/ft^2)	Low Delivered Density (gpm/ft^2)	Required Density (gpm/ft^2)	Supply Duration (min)
20	19a	9/112	Primary	285	0.19	0.21	0.18	0.10	NA
20	19c	9/1,512	Secondary	436	0.29	0.31	0.27	0.10	NA
1	20a	12/1,512	Primary	311	0.21	0.24	0.18	0.15	NA
1	20c	12/1,512	Secondary	312	0.21	0.24	0.18	0.15	NA
20	22a	4/672	Primary	151	0.22	0.23	0.22	0.10	NA
20	22c	4/672	Secondary	214	0.32	0.33	0.31	0.10	NA
1	23a	4/504	Primary	191	0.38	0.39	0.36	0.15	NA
1	23c	4/504	Secondary	192	0.38	0.40	0.37	0.15	NA
20	25a	18/3,024	Primary	391	0.13	0.14	0.12	0.10	NA
20	25c	18/3,024	Secondary	644	0.21	0.23	0.20	0.10	NA
1	26a	18/2,268	Primary	341	0.15	0.19	0.12	0.15	NA
1	26c	18/2,268	Secondary	344	0.15	0.19	0.12	0.15	NA

6.5.4 Manual Operations and Related Procedures

The WTC 7 building maintenance and engineering staff was familiar with the locations of emergency equipment and the required actions to support the systems in an emergency situation. Such actions during a fire event included starting the manual fire pump on the first floor. Other emergency actions included closing isolation valves to support systems in the case of a ruptured pipe. The operations and maintenance manual included a riser diagram that indicated the arrangement of valves on the systems (PANYNJ 1987). The use of system isolation valves was referenced as follows: “Emergency conditions unrelated to a system response to a fire, which may require actions based on this manual include: Isolation of a riser or sprinkler zone because of a rupture, also a mechanical failure which will activate the flow switch resulting in an alarm. Both conditions require isolation of the ruptured pipe or sprinkler head.”

The City of New York has a common firefighting challenge with other large cities. The challenge involves firefighting operations among the ever-growing number of high-rise office buildings. The Fire Department of New York (FDNY) addressed this challenge by developing a standard set of procedures for dealing with high-rise office building fires. In 1986, the FDNY developed *Fire Fighting Procedures* and *Fire Operations for High-Rise Office Buildings* to meet the challenge (FDNY 1990). Among the procedures and operations outlined in the manual are the methods used by the FDNY to supplement automatic sprinkler systems and standpipe systems within high-rise office buildings.

The NYC Building Code requires all new high-rise buildings to have a primary water supply and a secondary water supply to supplement the fire protection water demands (BCNYC 1968). In buildings over 300 ft, a manual fire pump, or combination of manual fire pumps must be installed as a secondary water supply. However, fire department connections (FDC) are also required as an auxiliary water supply. Therefore, in buildings over 300 ft, the FDNY procedures include connecting to the FDC to provide a tertiary supply to the automatic sprinkler systems and standpipe systems in high-rise office buildings (Grill and Johnson 2005, 2005a). A system of color-coded caps identify whether the FDC supplies a standpipe system, automatic fire sprinkler system, combined sprinkler and standpipe system, or a high pressure supply for upper floor level systems. Specific procedures and recommended pressures are outlined in the *Fire Fighting Procedures* and *Fire Operations for High-Rise Office Buildings* manual developed by the FDNY (FDNY 1990, 1990a).

The FDNY has two types of pumper engines, conventional and high-pressure. The conventional pumpers contain two-stage pumps with either 1,000 or 2,000 gpm capacity. The high-pressure pumpers contain a third stage capability that can supply 500 gpm at 700 psi. Whether used singly or supplementarily, these pumpers have the capability of supplying floors in high-rise buildings up to 110 stories. The *Fire Fighting Procedures* and *Fire Operations for High-Rise Office Buildings* manual suggests supplying the standpipe systems with at least two pumpers at two different siamese connections to ensure that an adequate water supply is added to the system.

The *Fire Fighting Procedures* and *Fire Operations for High-Rise Office Buildings* manual outlines the recommended pump pressures to be used based on floor level and nozzle type attached to the hose lines. The pressures are based on calculations that take into account nozzle pressure, friction loss of three lengths of 2 ½ in. hose, head loss, system friction losses, and the friction loss of two lengths of 3 ½ in. hose supplying the siamese FDC. Table 5–2 provides a summary of the recommended FDNY pump pressure for high-rise buildings (FDNY 1990).

6.6 WATER SUPPLY AND PRIMARY SPRINKLER SYSTEM REDUNDANCIES

The following section provides a discussion of the redundant features provided in WTC 1, 2, and 7.

6.6.1 WTC 1 and WTC 2

The redundant features of the automatic fire sprinkler and standpipe systems are indicated on Figs. B–44 through B–49.

Water Supply

The WTC complex was provided with two separate feed (supply) connections to the NYC water distribution system. Three isolation valves were positioned to permit the independent shut down of either of these connections without impairing the sprinkler and standpipe systems at the WTC complex. Figure B–44 shows isolation valves on the 12 in. supply main for the WTC complex and the two connections to the NYC water distribution system (Beyler 2002).

Fire Pumps

Separate distribution infrastructures were provided for the sprinkler and standpipe systems for the low zone systems and sub-grade levels (Beyler 2002).

Two parallel, manually controlled fire pumps were provided on the B1 level for the standpipe systems infrastructure. Either of the pumps could be manually started for a fire anywhere in the complex. The failure of either pump could be overcome by starting the other B1 level pump. Refer to Figs. B–44 and B–45.

Two additional parallel, manually controlled pumps were provided on the B1 level for the sub-grade sprinkler systems infrastructure. Either of these pumps could be manually started to supply water to the sub-grade sprinkler systems anywhere in the complex. Configuration of the system as shown in Figs. B–44 and B–45 permits the failure of either pump to be overcome by starting the other B1 level pump.

Each building was provided with four manually operated fire pumps connected in series, including the B1 level pumps. Refer to Fig. B–45. The B1 level pump and any of the other pumps could supply water at sufficient flow (750 gpm to 1,125 gpm) and sufficient pressure to supply water to the high or mid-level sprinkler systems. Failure of any two tower pumps would not impact the function of the sprinkler systems. Two fire pumps would be able to supply adequate water volume to a single standpipe for manual fire suppression efforts. Any single manual fire pump and a single FDNY pumper could supply adequate water to the sprinkler systems in both the high and mid-level zones without additional pumping operations.

Tanks

Three separate 5,000 gal tanks were provided for the upper and mid-level zone sprinkler and standpipe systems (PANYNJ 1972, 1987b; GC Engineering 1998). Refer to Figs. B–45, B–46, and B–47. Each tank was provided with a separate automatic fill (make-up) connection from the domestic water supply, and was provided with a separate discharge isolation valve at the connection to the standpipe system infrastructure on the 109th floor level (PANYNJ 1972, 1987b). The configuration of the water storage tanks for the high and mid-level zone sprinkler systems allowed for independent operation of either sprinkler reserve water storage tank. The impairment of a single tank would allow the sprinkler systems to remain fully operational (PANYNJ 1987b).

A single 5,000 gal tank was provided in each tower on the 41st floor (PANYNJ 1972, 1987b). These two tanks were interconnected through the 4 in. tower cross-connection on the B1 level of the complex (PANYNJ 1972, 1987b). This configuration is shown in Figs. B–45 and B–48. Each tank was provided with a separate automatic fill connection provided by the domestic water supply (PANYNJ 1972, 1987b). Additionally, each tank was provided with a separate discharge isolation valve at the connection to the sprinkler risers. The automatic operation of the sprinkler systems would be maintained in both towers if either tank were disabled.

Standpipes

The standpipe systems in WTC 1 and WTC 2 were configured with four vertical water supply zones with three risers per zone (PANYNJ 1972, 1987b). Damage to any single standpipe riser within a single zone could be localized using the isolation valves. Refer to Fig. B–45. In the normal operating mode, water would be supplied to the standpipes using the manual fire pumps and FDCs. The closure of two isolating valves on a standpipe riser would allow water to be supplied to the preconnected hose stations from the storage tanks (PANYNJ 1972, 1987b). The section of the riser below the lower valve would be supplied with water from the manual fire pumps and FDCs.

Fire Department Connections

The FDNY was provided with a number of different ways to provide water to the high and mid-level water supply zones as shown in Fig. B–49. Two (total) high-pressure FDCs were provided for WTC 1 and WTC 2. Refer to Fig. B-2 (PANYNJ 1987b). The FDNY could use either of these FDCs to provide water to the high and mid-level zone standpipe systems without the use of the manual fire pumps in the building (PANYNJ 1987b; FDNY 1990).

Fourteen separate FDCs were provided around the perimeter of the WTC complex (PANYNJ 1972, 1987b). The FDC at any location in combination with any single fire pump could provide water to the high and mid-level zone sprinkler and standpipe systems (PANYNJ 1987b; Beyler 2002). The low zone standpipe systems were also supplied by these FDCs as shown in Figs. B–45 and B–49. Isolation valves were provided between the FDC stations (PANYNJ 1972, 1987b). The isolation valves allowed the FDNY to isolate an individual building or section of the WTC complex in the event that damage was sustained to the sub-grade loops. The FDNY could then supply water to the systems through a pumper supplied by the fire hydrants (FDNY 1990; PANYNJ 1987b).

Two separate FDCs were provided for the low zone sprinkler systems (PANYNJ 1972, 1987b). Figures B–45, B–48, and B–49 show that isolation valves were provided to permit the operation of either FDC if a single FDC was impaired.

6.6.2 WTC 7

Water Supply

The systems infrastructure had three water supplies, one automatic and two manually operated (Syska & Hennessy 1984). The combined standpipe and sprinkler systems infrastructure included three water supply zones. The primary water supply for each zone was automatic (Syska & Hennessy 1984). A booster pump with tank was provided for the high zone, gravity water storage tank was provided for the mid level zone, and an automatic fire pump was provided for the lower zone (Syska & Hennessy 1984). The secondary water supplies for all zones were provided by the manual fire pump on the first floor and the three fire department connections on the perimeter of the building. If the primary supplies were to fail, the building maintenance and engineering personnel and the FDNY could provide water to the systems via the manual fire pump and fire department connections (PANYNJ 1987; FDNY 1990).

Fire Pumps

The automatic fire pump on the 1st floor was a redundant water supply for the 21st through 24th floors. These floors were primarily supplied by the gravity tanks on the 47th floor and secondarily supplied by the manual fire pump and fire department connections on the 1st floor. Refer to Fig. B–50.

Water Service

The building was provided with two 8 in. fire water services (Syska & Hennessy 1984). The services were connected to the 12 in. water main on Washington Street on opposite sides of an isolation valve. One service could be isolated from the system for repairs while maintaining a supply from the other water service main. The original design criteria required that all standpipe and sprinkler system calculations be conducted with the assumption that one of the two fire services from the city was to be disconnected (Gensler and Associates 1995).

6.7 SUMMARY OF TASK 2

The objective of Task 2 was to document the design and capacity of the water supply system to the automatic fire sprinkler systems and pre-connected hose systems in WTC 1, 2, and 7. A detailed review of available information was performed in order to document the water supply system infrastructure and associated redundancies. The capacity of the water supply system was evaluated based on available water flow density. The duration of water supply was evaluated based on what would be considered normally expected conditions. These two parameters were the primary factors associated with the expected performance of the sprinkler systems in WTC 1, 2, and 7.

The primary source of water for the WTC complex was the New York City water distribution system. A complex grid of 20 in. and 12 in. mains surrounded the WTC complex, forming a robust water supply with an average steady state pressure of 50 psi. Each building was supplied with water from the NYC water distribution system.

The WTC complex was provided with two separate supply connections at Vesey and Liberty Streets with isolation valves to permit independent operation. WTC 7 was provided with two connections from the 12 in. main on the Washington Street side of the building within 12 ft of each other.

The water supply components included water storage tanks, fire pumps, and fire department connections. The primary water supplies for the automatic fire sprinkler and standpipe systems, in most cases, consisted of gravity tanks and booster pumps.

Three separate 5,000 gal water storage tanks were provided for the high and mid-level zone sprinkler and standpipe systems at the tops of WTC 1 and WTC 2. A single 5,000 gal storage tank was provided on the 41st floor of each tower, and they were interconnected through a 4 in. main. Each tank was provided with a separate re-fill connection. The maintenance and engineering staff supplied water to the fire suppression systems using manually operated fire pumps. The FDNY could supply water to the fire suppression systems using the fire department connections.

The systems in WTC 7 included one automatic and two manually operated water supplies. The combined systems were provided with a single automatic fire pump for the low zone. The high and mid-level zones were supplied from two water storage tanks located on the 47th floor. The high zone also included a booster fire pump. A single 750 gpm fire pump supplied the secondary water. The FDNY could also supply water to the systems using the fire department connections.

The sprinkler and standpipe system infrastructures were reconstructed using the available documentation of the systems. Typical floor sprinkler systems were also reconstructed based on available documentation. Hydraulic calculations were performed to evaluate the normally expected performance of the sprinkler systems based on the configuration of the primary and secondary water supplies. Several sprinkler systems were selected to evaluate each water supply zone.

A commercial computer program, HASS, was used to perform the calculations. Bounding conditions were established to limit the number of calculations and to allow for comparison of the results. Calculations were performed based upon the performance criteria for both Light and Ordinary Hazard areas. The results of the analysis demonstrate robust performance of the sprinkler systems throughout the buildings.

The supply calculations provided estimates of the actual water flow rate and allowed for calculation of the water supply duration. The volume of water stored in tanks was divided by the calculated flow rate to determine the duration. Variations in the number of operating sprinklers or supplemental make-up supplies were not accounted for in this evaluation.

The results of the calculations using the Light Hazard criteria for the sprinkler systems in WTC 1 and WTC 2 indicate that a density of 0.14 to 0.27 gpm/ft^2 could be provided to four sprinklers for 33.3 to 89 min; a density of 0.13 to 0.17 gpm/ft^2 could be provided to eight sprinklers for 18.5 to 47.7 min; and a density of 0.10 to 0.16 gpm/ft^2 could be provided to 16 sprinklers for 10.5 to 32.7 min.

The results of the calculations using the criteria for Ordinary Hazard Group 1 for the sprinkler systems in WTC 1 and WTC 2 indicate that a density of 0.33 to 0.56 gpm/ft^2 could be provided to four sprinklers for 18.9 to 61.2 min; a density of 0.22 to 0.38 gpm/ft^2 could be provided to 15 sprinklers for 7.9 to 27.6 min;

a density of 0.18 to 0.26 gpm/ft^2 could be provided to 20 sprinklers for 9.0 to 25.2 min; and a density of 0.15 to 0.21 gpm/ft^2 could be provided for up to 25 sprinklers for 8.7 to 23.9 min on most floors.

The results of the calculations using the Light Hazard criteria for the sprinkler systems in WTC 7 indicate that a density of 0.17 to 0.38 gpm/ft^2 could be provided to four sprinklers for 82 to 133 min; a density of 0.16 to 0.22 gpm/ft^2 could be provided to nine sprinklers for 45 to 61 min; and a density of 0.11 to 0.16 gpm/ft^2 could be provided to 18 sprinklers for 31 to 45 min. The durations do not apply to the low zone sprinkler systems because water was supplied from an automatic fire pump drawing suction from the NYC distribution. Therefore, the supply would be provided as long as the water distribution and electrical systems were intact and operational.

Chapter 7

TASK 3: DIFFERENCES IN INSTALLED SUPPRESSION SYSTEMS IN WTC 1, 2, AND 7

7.1 GENERAL

Differences existed in basic construction between World Trade Center (WTC) 7 and the two towers (WTC 1 and WTC 2). In addition, WTC 7 contained fuel tanks for emergency power that required special fire protection features. The objectives of Task 3 were to identify significant differences in the design of the fire suppression systems in WTC 1, 2, and 7 and to estimate the impact of these differences on the level of fire control provided.

7.2 PRIMARY SYSTEM(S) FEATURES

The primary elements of the fire suppression systems that were compared for each of the three buildings included the following:

- Primary Water Supply for Sprinkler Systems
- Primary Water Supply for Standpipe Systems
- Primary Water Supply Redundancy
- Secondary Water Supply for Sprinkler Systems
- Secondary Water Supply for Standpipe Systems
- Sprinkler Systems
- Standpipe Systems
- Special Systems Protection Areas

The major features of the suppression systems in WTC 1, 2, and 7 are summarized in Table 7–1. Most of the information in Table 7–1 was derived from the analyses and documentation in Chapters 5 and 6.

7.2.1 Water Supplies

Primary Water Supplies for Sprinkler Systems

The primary water source for all three buildings originated from the New York City (NYC) water distribution system (Beyler 2002). The city water distribution system had the capacity to provide a nearly infinite supply to the buildings, provided that the integrity of the distribution system was maintained. Two separate and remote 16 in. connections supplied a single 12 in. fire service main located in the utility rack for the WTC complex. The two supplies were located at Vesey and Liberty Streets at the north and south sides of the complex. Isolation valves allowed for the independent shut down of either connection without impairing the fire suppression systems in WTC 1 and WTC 2. Two 8 in. mains were also provided for WTC 7. The two mains were supplied from the same 12 in. water distribution system main on Washington Street at the southwest corner of the building. The two mains were located approximately 12 ft apart and supplied both the automatic and manual fires pumps for WTC 7.

Table 7–1. Summary of active fire suppression system features, WTC 1, 2, and 7

System Component	WTC 1 and WTC 2	WTC 7
Primary water source	NYC water distribution system for entire complex. Nearly infinite capacity.	NYC water distribution system for entire complex. Nearly infinite capacity.
Primary water supply for sprinkler systems	Two 5,000 gal storage tanks with 2 in. automatic refill supplied the high and mid-level zone systems. The high and mid-level zones were supplied from independent risers each tower. The high zone riser was supplied by a 500 gpm booster pump located on the 108th floor. The mid-level riser was gravity supplied. A single 5,000 gal storage tank with a 2 in. automatic refill was provided for the low zone systems in each tower. The two low zone sprinkler systems infrastructures were connected through a 4 in. main located on the B1 level.	Two 18,000 gal storage tanks with 7,500 gal fire protection reserve and make-up supply connections were provided for the high and mid-level zone combined standpipe and sprinkler systems. The primary water supply for the high zone standpipes and sprinkler systems was a 500 gpm at 55 psi booster pump that took suction from the two 7,500 gal storage tanks. The mid-level sprinkler systems were gravity supplied water from the two 7,500 gal gravity storage tanks. The primary supply for the low zone systems was a single 500 gpm at 120 psi automatic fire pump that took suction from the NYC water distribution system.
Primary water supply for standpipe systems	The primary water supply for the standpipe systems included several 5,000 gal storage tanks located on the 110th, 76th, and 42nd floors. The tank located on the 110th floor supplied the high zone standpipe system risers, the tank on the 76th floor supplied the upper mid-level zone standpipe system risers, and the tank on the 42nd floor supplied the lower mid-level zone standpipe system risers. A single 5,000 gal storage tank was provided on the 20th floor of WTC 1 for the low zone standpipe systems in both towers and other portions of the WTC complex.	Since the building contained a combination sprinkler/standpipe system, the primary supply described for the sprinkler systems also applies to the standpipe systems.
Primary water supply redundancy	The sprinkler system supply tanks for the upper zones each functioned independently. The automatic make-up water connections could have refilled the tanks at a rate equal to or greater than the water depletion rate through the single 4 in. connection.	Two water storage tanks supplied the high and mid-level zones. Water was supplied to both tanks by an 8 in. express riser, which was provided with three 450 gpm automatic domestic pumps on the 2nd floor.

System Component	WTC 1 and WTC 2	WTC 7
Secondary water supply for sprinkler systems	The secondary water supplies were provided for the sprinkler systems from the standpipe system. A cross connection at the top of the standpipe zones at the 109th floor and 41st floor supplied a secondary source to the sprinkler risers. The standpipe storage tanks and the 750 gpm manual fire pumps functioned as secondary water supplies for the sprinkler systems. High pressure and standard pressure fire department connections also served as a secondary supply.	The secondary water supply to all three zones was from a 750 gpm manual fire pump on the 1st floor. The three fire department connections on the perimeter of the building acted as a secondary supply capable of supplying the entire sprinkler and standpipe system.
Secondary water supply for standpipe systems	The secondary water supply for the standpipe systems was from the 750 gpm manual fire pumps located on the B1 level, 7th, 41st, and 75th floors.	Since this was a combined sprinkler/standpipe system, the secondary supplies were provided from the 750 gpm manual fire pump on the 1st floor and the fire department connections, described above.
Sprinkler system description	Sprinklers were provided throughout the buildings except in MERs and electrical rooms. A wet pipe sprinkler system infrastructure was provided throughout each tower. The infrastructures were composed of three vertical water supply zones each supplied by a separate riser. The high zone sprinkler riser supplied water to floors 99 through 110 using a 500 gpm booster fire pump located on the 108th floor. The mid-level zone sprinkler riser supplied water to the sprinkler systems on floors 32 through 98, and the low zone sprinkler riser supplied water to the sprinkler systems on the 31st floor and below. Each floor was provided with a separate wet pipe sprinkler system.	The sprinkler systems provided throughout the building were automatic wet pipe systems with exception to the 1st floor dock area. This area was a dry system. Sprinklers were not installed in bathrooms, electrical rooms, telephone/data rooms, most of the 5th floor, or the OEM generator room on the 7th floor. The system infrastructure was a combination wet pipe sprinkler/standpipe system.
Standpipe system description	The standpipe system was similar to the nationally recognized Class III automatic wet pipe system. The system was equipped with: 2½ in. hose valves, 2½ in. by 1½ in. adapters, 125 ft of 1½ in. hose, and a nozzle at every floor level of every stair. Additional hose cabinets were provided such that the entire building was within 25 ft of the end of a hose nozzle.	The standpipe system was similar to the nationally recognized Class III automatic wet pipe system that was part of the combination sprinkler/standpipe system. The system was equipped with: 2½ in. hose valves, 2½ in. by 1½ in. adapters, 125 ft of 1½ in. hose, and a nozzle at every floor level of every stair. Additional hose cabinets were provided such that the entire building was within 25 ft of the end of a hose nozzle.
Number of vertical zones	There were three zones for the sprinkler infrastructure and four zones for the standpipe infrastructure.	There were three zones for the combinations sprinkler/standpipe infrastructure.

System Component	WTC 1 and WTC 2	WTC 7
Number of sprinkler risers per vertical zone	One sprinkler riser was provided per vertical zone. All sprinkler risers were supplied from tanks above.	There was one sprinkler riser per vertical zone. All sprinkler zones were supplied from tanks above, except the low zone was supplied from an automatic fire pump located on the 1st floor.
Number of standpipe risers per vertical zone	There were three standpipes per vertical zone.	There were three standpipes per vertical zone.
Type of sprinklers (response and characteristics)	In general, ordinary temperature (165 °F) sprinklers were used. High temperature sprinklers were used where required based on environmental conditions. Standard spray sprinklers were used in all sprinkler systems. Both quick response and standard response were used.	In general, ordinary temperature (165 °F) sprinklers were used. High temperature sprinklers were used where required based on environmental conditions. Standard spray sprinklers were used in all sprinkler systems. Both quick response and standard response were used.
Type of hose stations	Hose stations and hose cabinets were located in the stair enclosures. Additional hose cabinets were used in corridors and tenant spaces to provide adequate coverage on some floors.	Hose reels located in the stair enclosures and hose cabinets located throughout the floors in order to provide adequate coverage.
Hose length	125 ft	125 ft
Special hazard suppression systems	Dry chemical fire suppression systems were provided for the protection of cooking appliances and hoods. Steam smothering systems were provided for the protection of the exhaust duct systems. Carbon dioxide, Halon 1301, and clean agent systems were used to protect large and valuable computer rooms. Local application deluge sprinkler systems were used for the protection of fan units.	A dry-pipe sprinkler system was provided for the protection of the two 12,000 gal fuel oil storage tanks located beneath the loading berths on the south side of the building adjacent to Vesey Street. An Inergen clean agent suppression system was provided for the protection of a 6,000 gal fuel oil storage tank room located on a mezzanine 8 ft above the elevator storage area on the 1st floor. The fuel pumps were located on the 1st floor near the loading dock and were protected by a dry-pipe sprinkler system.

Water storage tanks were provided as the primary supply for all of the sprinkler systems in WTC 1 and WTC 2. The water storage tanks were supplied by the water distribution system via domestic water supply pumps (Beyler 2002; PANYNJ 1987, 1987a).

The sprinkler systems on the 21st through 47th floors of WTC 7 were also supplied from water storage tanks. However, the 1st through 20th floors were supplied from an automatic fire pump located on the 1st floor that took suction directly from the city water distribution system.

As indicated in Chapters 5 and 6, the water supply capacity and durations were similar for these three buildings.

Primary Water Supply for Standpipe Systems

Each standpipe system zone in WTC 1 and WTC 2 was supplied by 5,000 gal water storage tanks on the 110th, 76th, and 42nd floors of WTC 1 and WTC 2 and the 20th floor of WTC 1 (PANYNJ 1972, 1987b). The standpipe system for WTC 7 was supplied by the same sources as the sprinkler systems (i.e., a combined sprinkler/standpipe system) (Syska & Hennessy 1984). Automatic booster pumps located on the 108th floor of both WTC 1 and WTC 2 and the 46th floor of WTC 7 supplied the highest zone of each building (PANYNJ 1972, 1987b; Syska & Hennessy 1984).

The only differences in primary water supplies were the number of vertical zones and the number of risers supplying each zone. The high and mid-level zones in WTC 1 and WTC 2 shared two 5,000 gal sprinkler reserve water storage tanks. The low zone sprinkler zones were supplied from a single 5,000 gal storage tank shared with the standpipe system located on the 42nd floor. The two system infrastructures were interconnected to allow the tanks to supply the sprinkler systems in the other building.

The combined sprinkler and standpipe systems in WTC 7 were supplied by two 18,000 gal water storage tanks located on the 47th floor (Syska & Hennessy 1984). Each tank was used for combined domestic and fire protection use and contained a 7,500 gal fire protection reserve water storage capacity (Syska & Hennessy 1984). These tanks supplied water to the high and mid-level zone systems on the 21st through 47th floors (Syska & Hennessy 1984).

As discussed above, the automatic fire pump located on the 1st floor served as the primary water supply for the low zone sprinkler and standpipe systems located on the 1st through 20th floors of WTC 7. This pump took suction from the NYC water distribution system. Since both the primary and secondary water supplies for the low zone sprinkler and standpipe systems in WTC 7 were provided by the NYC water distribution system, loss of the water main on Washington Street could have prevented water from being supplied to these systems.

It is unknown if the dependence of the low zone standpipe system arrangement in WTC 7 on the Washington Street supply main had a significant impact on the performance of the sprinkler and standpipe systems in WTC 7 on September 11, 2001. The standpipe system in WTC 7 was reportedly used to supply water to fight fires at other buildings. This, along with any damage to the Washington Street supply main due to the collapse of WTC 1 and WTC 2, would have significantly reduced the effectiveness of the sprinkler and standpipe systems to the lower floors in WTC 7.

Differences in the water supplies were relatively insignificant, and were limited primarily to the capacity and location of the supply tanks, which basically affected the maximum available duration of the primary water supply(s). However, the capacities and supply durations were consistent with the associated requirements in the BCNYC and would normally have provided adequate primary water supply until fire department operations were initiated to supplement the water supply.

Primary Water Supply Redundancies

The three 5,000 gal water storage tanks located on the 110th floors of WTC 1 and WTC 2 were designed to operate independently, providing redundant water supplies for the sprinkler systems from the 32nd through 98th floors (PANYNJ 1972, 1987b). The 5,000 gal storage tank located on the 42nd floor of WTC 1 and the 5,000 gal storage tank on the 42nd floor of WTC 2 were interconnected at the B1 level

(PANYNJ 1972, 1987b). Each of these tanks also functioned independently and could redundantly supply the sprinkler systems on the 2nd through 32nd floors of the other building.

The two water storage tanks in WTC 7, each with a fire reserve capacity of 7,500 gal, also functioned independently (Syska & Hennessy 1984; PANYNJ 1987). These tanks provided redundant water supplies to the sprinklers on the 21st through 47th floors. A single 500 gpm automatic fire pump supplied the 1st through 20th floors of WTC 7 (Syska & Hennessy 1984; PANYNJ 1987). The automatic fire pump was supplied from two independent 8 in. water service connections from the 12 in. water supply main on Washington Street. The stored water tanks in WTC 7 did not supply the lower zone (i.e., floors 1 through 20).

Secondary Water Supply for Sprinkler Systems

The 750 gpm manual fire pumps that were located at the base of each vertical standpipe zone of WTC 1 and WTC 2 provided a secondary water supply to the sprinkler systems (PANYNJ 1972, 1987a). A connection was made at the top of the highest standpipe zone between the standpipe system and the sprinkler system (PANYNJ 1972, 1987a). The connection was made through a check valve allowing flow from the standpipe system to the sprinkler system (PANYNJ 1972, 1987a). Therefore, the manual fire pumps from the standpipe system provided a secondary water supply to the sprinkler systems on the 33rd floor through the 110th floor from the connection on the 110th floor. Fire department connections located around the perimeter of WTC 1 and WTC 2 also provided a secondary supply to the sprinkler systems (PANYNJ 1972, 1987a). Two high pressure and 14 low pressure fire department connection stations were provided for the upper zone sprinkler systems through the standpipes (PANYNJ 1972, 1987a). Two fire department connections were provided for the low zone sprinkler systems (PANYNJ 1972, 1987a).

The 750 gpm manual fire pump that was located in the first floor fire pump room in WTC 7 was installed in parallel with the automatic fire pump (Syska & Hennessy 1984; PANYNJ 1987). Since the standpipe system and sprinkler system infrastructure was a combination sprinkler/standpipe system, i.e., a standpipe served as a sprinkler riser, the 750 gpm manual fire pump served as a secondary supply to all of the sprinkler systems in the building (Syska & Hennessy 1984; PANYNJ 1987). The three fire department connections for the building served as a tertiary supply that served all of the systems in the building (Syska & Hennessy 1984; PANYNJ 1987).

Secondary Water Supply for Standpipe Systems

The secondary water supply for WTC 1 and WTC 2 consisted of 750 gpm manual fire pumps located on the B-1, 7th, 41st, 75th and 108th floor of each building (PANYNJ 1972, 1987a). These fire pumps supplied the entire building. The secondary water supply for WTC 7 was a single 750 gpm manual fire pump.

Additionally, WTC 1 and WTC 2 were equipped with standard and high pressure fire department connections that served as the secondary supplies to the standpipe systems (PANYNJ 1972, 1987a). Typically, a high pressure pumper truck could have supplied the entire standpipe system in WTC 1 and WTC 2 by connecting to the high pressure connections (FDNY 1990). The three fire department connections surrounding WTC 7 also provided the secondary supply to the standpipe systems (PANYNJ 1987).

Three standpipe risers were used in WTC 1 and WTC 2 to supply each zone above the locations of the manual fire pumps. Therefore, if two of the three standpipes were isolated on each vertical standpipe zone for WTC 1 or WTC 2, water could still be supplied to zones above. However, in WTC 7 only two of the three standpipes were used to supply water to the 20th floor, and, only one standpipe supplied floors 21 through 47.

The primary difference in the secondary supplies to the standpipe systems was the redundancy in the supply risers. While WTC 1 and WTC 2 supplied upper zones with three risers (interconnected at the top), WTC 7 supplied the mid-level zone with only two risers and the high zone with one riser, without interconnections. Additionally, the single standpipe used to provide the secondary water supply to the upper zone standpipe systems served as the primary supply riser for the mid-level sprinkler systems.

7.2.2 Sprinkler Systems

All three buildings were protected essentially throughout by wet pipe automatic fire sprinkler systems (PANYNJ 1972, 1987a). Some areas of the buildings were excluded from coverage by the wet pipe systems. Each building contained three vertical water supply zones (PANYNJ 1972, 1987a). The primary differences in the sprinkler systems in WTC 1, 2, and 7 were that the systems in WTC 7 were supplied from a combined sprinkler and standpipe system infrastructure. Although the standpipe systems in WTC 1 and WTC 2 were used to supply secondary and tertiary water supplies to the high and mid-level zone sprinkler systems, the sprinkler system infrastructures in WTC 1 and WTC 2 functioned separately from the standpipe systems in the primary water supply mode (PANYNJ 1987b).

The mechanical and electrical rooms in WTC 1 and WTC 2 were the only areas in these buildings above the B1 levels that were not protected by automatic sprinklers (PANYNJ 1987a; GC Engineering 1998). The generator rooms for WTC 1 and WTC 2 were located on the B1 levels (PANYNJ 1972).

The electrical, data/telephone, day tank, and generator rooms that were part of the core areas in WTC 7 were not protected by wet pipe sprinkler systems (Syska & Hennessy 1984; PANYNJ 1987). One exception was the seventh floor generator room, which was protected by a wet pipe automatic sprinkler system. Portions of the first floor loading dock area in WTC 7 were protected by a dry pipe automatic fire sprinkler system in order to prevent freezing of the system (Swanke et al. 1998).

The absence of sprinkler protection in bathrooms of Light Hazard Occupancy buildings is not an unusual practice and is permitted under both the Building Code of the City of New York (BCNYC) and National Fire Protection Association (NFPA) 13. Based on the limited information available, it is doubtful that the absence of automatic fire sprinkler protection in the bathrooms of WTC 7 played a significant role in the collapse of WTC 7 on September 11, 2001. In addition, the hydraulic analyses documented in Chapters 5 and 6 indicate that the fire sprinkler system would be expected to control a fire that occurred in an unsprinklered bathroom unless an unusual fire load was present.

7.2.3 Standpipe Systems

The standpipe systems in all three buildings were similar to Class III standpipes. The standpipe systems in WTC 1 and WTC 2 were separate from the automatic sprinkler systems within the protection zones. In WTC 7, the systems were combined. Either method is commonly used to protect these types of buildings.

The standpipe systems in WTC 1 and WTC 2 were virtually the same. The primary differences in the standpipe systems in WTC 1 and 2 included additional hose stations in the corridors and tenant spaces on individual floors and an additional storage tank located on the 20th floor of WTC 1.

The standpipe systems in WTC 1 and WTC 2 were interconnected at the top of each zone with check valves that prevented downward flow in two of the three risers. This arrangement permitted upward flow through all three risers while operating in the secondary supply modes using the manual fire pumps or fire department connections. The standpipe systems in WTC 7 did not have a similar interconnection at the top of the standpipe zones. This could have adversely affected firefighting activities, as well as automatic sprinkler performance on the upper floors of WTC 7, if the main tank supplies had been interrupted.

7.3 SPECIAL SYSTEMS PROTECTION

Several special hazards fire suppression systems were installed in WTC 1, 2, and 7. Special hazards systems in WTC 1 and WTC 2 were provided for the protection of kitchen hoods and ducts, HVAC fan units, and computer rooms. Special hazards systems in WTC 7 were provided for protection of the fuel oil systems (Syska & Hennessy 1984; Emery et al. 1987; Gensler and Associates 1995; Swanke et al. 1998).

Dry chemical fire suppression systems were provided for protection of cooking appliances and hoods in the restaurants in WTC 1 and WTC 2 (PANYNJ 1987b). Steam smothering systems were provided for the protection of the exhaust duct systems. Carbon dioxide, Halon 1301, and clean agent systems were used to protect computer rooms in WTC 1 and WTC 2 (PANYNJ 1987b). Local application deluge sprinkler systems were used for the protection of fan units in WTC 1 and WTC 2 (PANYNJ 1987a). It is unlikely that the presence of these localized systems in WTC 1 and WTC 2 had any significant impact on the outcome of the events on September 11.

WTC 7 contained fuel oil powered generators and day tanks located on the fifth, seventh, eighth, and ninth floors. The fire suppression protection varied for each component of the fuel oil supply to the generators. A dry-pipe sprinkler system was provided for the protection of the two 12,000 gal fuel oil storage tanks located beneath the loading berths on the south side of the building adjacent to Vesey Street. An Inergen suppression system was provided for the protection of the 6,000 gal fuel oil storage tank room located on a mezzanine 8 ft above the elevator storage area on the first floor. The area below this room was protected by a wet pipe sprinkler system. The fuel pumps were located on the first floor near the loading dock and were protected by a dry-pipe sprinkler system.

The piping between the pumps and the storage tanks was located in an underground concrete trench. No fire suppression was provided in these areas. The vertical risers for the fuel oil systems were located in two vertical masonry shafts that did not have fire suppression. The generator and day tank enclosures on the fifth, eighth, and ninth floors were not protected by automatic sprinklers. These omissions of sprinkler coverage were permitted under the BCNYC. They also resulted in the potential for large quantities of combustible liquids (fuel oil) to become involved in the fires which occurred on September 11, 2001, in WTC 7. This would have significantly contributed to rapid fire spread in these areas.

7.4 DISCUSSION

The comparisons drawn among the fire suppression features in WTC 1, 2, and 7 demonstrate that the differences were primarily a function of the sizes of the systems. For example, WTC 7 required only one manual fire pump to provide a secondary supply to the standpipe system through the 47th floor, while WTC 1 and WTC 2 required two of the five manual fire pumps per building to provide a secondary supply to the entire building. Although the sizes and configurations of system components differed, there were no appreciable differences in expected fire control based on the major fire suppression features identified.

There was one relatively major difference between the standpipe systems that were in each of the three buildings and the type of systems that are currently required by NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*. BCNYC did not specify an automatic water supply requirement for standpipe systems. NFPA 14, *Standard for the Installation of Standpipe and Hose Systems* (2003 Edition), Section 5.4.1.2 requires that “Class I standpipe systems in buildings classified as high-rise buildings be automatic, or semi-automatic.” Section 5.4.3 states that all Class II and Class III standpipe systems be automatic-wet or semiautomatic-wet systems…,” regardless of whether it is in a building classified as a high-rise or not. Therefore, in all three buildings, if the fire department or building personnel did not activate the manual fire pumps, or if a pumper truck was unavailable to connect to a fire department connection, the only water available for manual fire fighting activities on the fire floor would have been from residual flow available from the water storage tanks. The automatic water supply required by NFPA 14 is 250 gpm at the two most remote hose connections on the most remote standpipe and 250 gpm at the most remote hose connections at the next most remote standpipes, not to exceed 1,000 gpm for a fully sprinklered building. The minimum required residual pressure is 100 psi.

The water storage tanks provided a reasonable level of fire control from the hose connections at floors well below the water storage tanks. However, the level of fire control provided from a standpipe system installed in accordance with NFPA 14 would have greatly increased the capacity of the automatic water supply available, assuming continued access to the city water supply. While not a requirement in the BCNYC, it has been a requirement in NFPA 14, and would represent “best practice” at the time of installation as well as today.

7.5 SUMMARY OF TASK 3

The primary water source for all three buildings originated from the New York City water distribution system. The towers were supplied from the sub-grade loops on the north and south sides of the complex at two remote locations. The two mains provided redundant supplies and had isolation valves to allow for independent operation of either main without impairing the fire suppression systems in the WTC complex. Two mains, located within 12 ft of each other, supplied WTC 7 from the same NYC water distribution system main.

The primary difference between the sprinkler and standpipe systems in WTC 7 and those in the towers was that the sprinkler and standpipe systems in WTC 1 and WTC 2 were separate, and the sprinkler and standpipe systems in WTC 7 were combined. Both arrangements were permitted.

Multiple water supply zones were provided in each building. The standpipe systems in WTC 1 and WTC 2 included four vertical zones. The sprinkler systems infrastructures in WTC 1 and WTC 2 included three vertical zones. The combined sprinkler and standpipe systems in WTC 7 included three vertical zones.

Water storage tanks were used as the primary water supplies for all sprinkler and standpipe system zones in WTC 1, 2, and 7, except for the low zones of WTC 7, which were supplied by the NYC water distribution system through a 500 gpm automatic fire pump.

A single 750 gpm manual fire pump was used as the secondary water supply for the combined sprinkler and standpipe systems in WTC 7. A series of four vertical 750 gpm manual fire pumps were used in each tower.

Sprinklers were provided essentially throughout all areas of WTC 1, 2, and 7. Sprinklers were omitted in the mechanical equipment rooms (MERs) in WTC 1 and WTC 2. In addition, the electrical, data/telephone, and generator rooms that were part of the core areas in WTC 7 were not protected by the wet pipe sprinkler systems. This included areas on floors 5, 7, 8, and 9.

The sprinkler systems in all three of the buildings were designed with looped mains and were capable of delivering robust discharge densities exceeding the code required minimum densities. Pressure reducing valves were used in all three buildings.

The standpipe systems in all three buildings were similar to Class III standpipes. The standpipe systems in WTC 1 and WTC 2 were separate from the automatic sprinkler systems within the protection zones. In WTC 7, the systems were combined. In practice, either method is used.

The types of special hazard fire suppression systems in each building were different, but no information was found that indicated that these systems played a significant role in fire control or the loss of fire control on September 11, 2001.

While limited information was available regarding the actual performance of the installed fire suppression systems on September 11, 2001, several design features were identified that could be improved upon in future installations. For example, in WTC 1 and WTC 2, the supply pipe from the primary water storage tanks on the 110th floor to the sprinkler systems included a long horizontal length (>100 ft) of pipe on the floor directly under the tanks that leads to the vertical riser. Due to the associated friction loss in this run of pipe, the flow was restricted to the upper floors.

In WTC 7, the automatic sprinkler systems on floors 1 through 20 were supplied directly from the city distribution system through an automatic fire pump located on the 1st floor. Either a loss of power to the fire pump or significant damage to the underground city main in the vicinity of the building could interrupt the water supply to these sprinkler systems. A simple means of backing up the primary water supply for floors 1 through 20 would have been to provide secondary access to the stored water on the upper floors of the building.

Chapter 8
TASK 4: EXPECTED PERFORMANCE OF THE SUPPRESSION SYSTEMS UNDER SPECIFIC BUILDING FIRE SCENARIOS

8.1 GENERAL

The objective of Task 4 was to determine the expected performance of the automatic fire sprinkler systems and the standpipe/pre-connected hoses in World Trade Center (WTC) 1, 2 and 7 under a number of representative fire conditions. The analysis used for this task included hydraulic calculations of the sprinkler and standpipe systems in each building with several variations to observe performance of the suppression systems for four scenarios specified in the scope of work. A lack of performance criteria and history for standpipe systems limited the evaluation of the pre-connected hoses. Therefore, the primary emphasis was on evaluation of the performance expectations of the installed automatic sprinkler systems. Some analysis and discussion of the capacity of the standpipe/pre-connected hose systems are included in Sec. 8.3.

8.2 HYDRAULIC ANALYSIS FOR AUTOMATIC SPRINKLER SYSTEMS

This analysis relied extensively on the baseline hydraulic calculations documented in Chapter 6. The calculations in Chapter 6 demonstrated the “normal” performance of the sprinkler systems with discharge application areas corresponding to the design areas specified in National Fire Protection Association (NFPA) 13, *Installation of Sprinkler Systems*. In the analysis presented here, the discharge application area was varied to assess conditions involving small fires (less than the design area), large fires (larger than the design area), and multiple fires on multiple floors. The following fire scenarios were evaluated as part of this analysis:

- A single fire much smaller than the design area
- A single fire much larger than the design area
- Multiple fires on different floors that result in a number of small fires
- Multiple fires assumed to be equivalent to the design area on the same or multiple floors

The performance of the sprinkler systems was measured in terms of the calculated delivered density for the application area and the remote end-sprinkler pressure, based on the number of operating sprinklers. Hydraulic calculations were performed to determine the average delivered density of the sprinkler systems over the entire application area, based on the available water supply. The minimum density and pressure established in NFPA 13 were used as the performance limits for this analysis. It was assumed that if the calculated average delivered density and pressure were at or above the minimum levels specified in NFPA 13, then fire control or suppression would be expected.

This analysis was intended to identify conditions where the minimum pressures and design densities would be reduced to levels below the minimum recommended levels in NFPA 13. As the system pressures and densities drop below these levels, some degradation in system performance could begin to occur.

8.2.1 WTC 1 and WTC 2

Based on the sprinkler system descriptions developed in Chapter 5, it was concluded that the installed sprinkler systems in WTC 1 and WTC 2 were essentially the same. Therefore, the hydraulic analyses presented in this section were based on the assumption that the results from WTC 1 would apply to both WTC 1 and WTC 2.

Baseline Capacity

An analysis was conducted to determine the effects of an increasing number of sprinklers operating on a single floor. This analysis was intended to assess the two scenarios involving fires smaller than the design area and fires larger than the design area on a single floor. The analysis used the Light Hazard Occupancy sprinkler system arrangements described in Chapter 6 as representative of those that existed in both WTC 1 and WTC 2. The highest and lowest floor level sprinkler systems in each of the high, mid-level, and low water supply zones were included. The calculated average delivered densities for these systems were used to estimate the limits for the anticipated performance range of the sprinkler systems within the associated zone. This approach was appropriate for systems without pressure reducing valves. Floor level sprinkler systems with pressure reducing valves were also evaluated to compare the performance of these systems with those systems without the pressure reducing valves.

The sprinkler systems on seven floor levels were selected to evaluate the performance range throughout WTC 1 and WTC 2. The sprinklers systems on floors 107 and 99 were selected to represent the high zone. Neither of these systems incorporated pressure-reducing valves. The sprinkler systems on floors 98, 87, and 32 were used to evaluate the sprinkler systems in the mid-level zone. The sprinklers on floors 98 and 87 provided the limitations of the sprinkler systems without pressure-reducing valves, and the sprinkler system on floor 32 provided an estimate of the performance of the systems with pressure-reducing valves. The sprinkler systems on floors 2 and 31 were evaluated for the low zone. The sprinkler systems on floors 2 through 8 were equipped with pressure-reducing valves. The other floors in the low zone did not have pressure-reducing valves.

The evaluation of each individual sprinkler system included the calculation of the sprinkler system hydraulic performance for a range of specified coverage areas involving the operation of up to 24 sprinklers. Figure 8–1 provides a depiction of the performance ranges within each of the vertical water supply zones.

Figure 8–1. Summary of sprinkler systems performance for all zones—calculated average delivered density vs. number of open sprinklers, WTC 1 and WTC 2.

The analysis of the high zone included hydraulic calculations for the sprinklers systems on the 107th and 99th floors in WTC 1. These systems would be expected to bound the hydraulic performance of all of the sprinkler systems in the high zone. As previously discussed in Chapters 5 and 6, all of the sprinkler systems in the high water supply zone included floor control valve assemblies with outside screw and yoke (OS&Y) type control valves. None of these systems contained the pressure reducing type of control valves. Although the 107th floor sprinkler system layout differed from the typical layout used for the other sprinkler systems, the hydraulic capacity of this system represented an upper limit relative to all other floor level systems in the zone. Figure 8–2 illustrates the effect on delivered density of assuming sequentially opened sprinklers on floors 99 and 107.

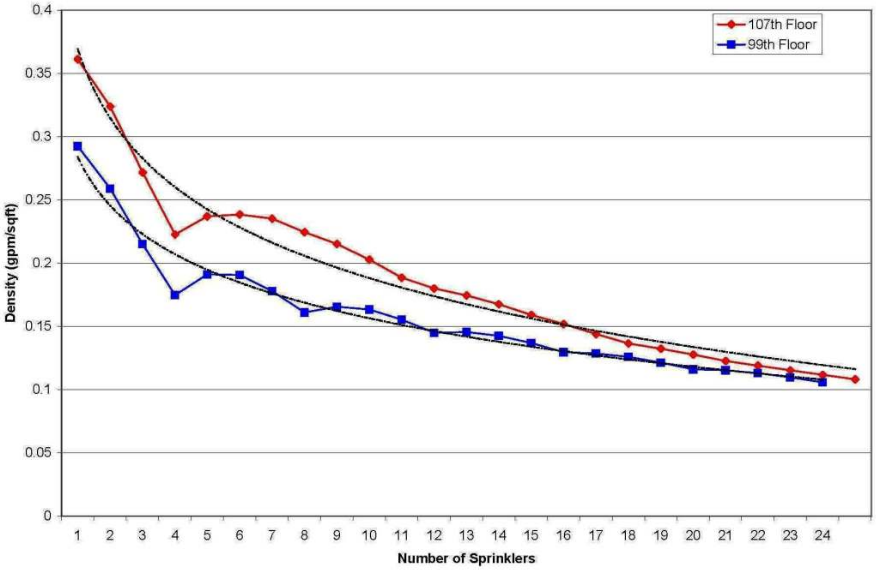


Figure 8–2. High zone sprinkler systems performance—calculated average delivered density vs. number of open sprinklers, WTC 1 and WTC 2.

The performance of the sprinkler systems on the 99th and 107th floors of WTC 1 was evaluated by conducting a series of hydraulic calculations to determine the maximum number of sprinklers that could be supplied by the available water supply before the delivered density dropped below 0.1 gpm/ft^2. The initial calculation included a single sprinkler. Each subsequent hydraulic calculation included the addition of a single sprinkler, up to 24 operating sprinklers. From these calculations it was determined that a maximum of 24 sprinklers, three times the number for the design area, could operate and still maintain at least an average delivered water density of 0.1 gpm/ft^2.

Representative cases of the mid-level zone sprinkler systems in WTC 1 and WTC 2 included sprinklers systems on the 98th, 87th, and 32nd floors. The systems on the 98th and 87th floors of WTC 1 represented limiting cases for the mid-level zone sprinkler systems without pressure-reducing valves. The systems on the 32nd through 86th floor levels included pressure-reducing valves. The hydraulic calculations for the 32nd floor sprinkler system represented the performance of the sprinkler systems with pressure-reducing valves. Figure 8–3 provides a graphical depiction of the effect of the number of operating sprinklers on the calculated delivered water density for the mid-level zone.

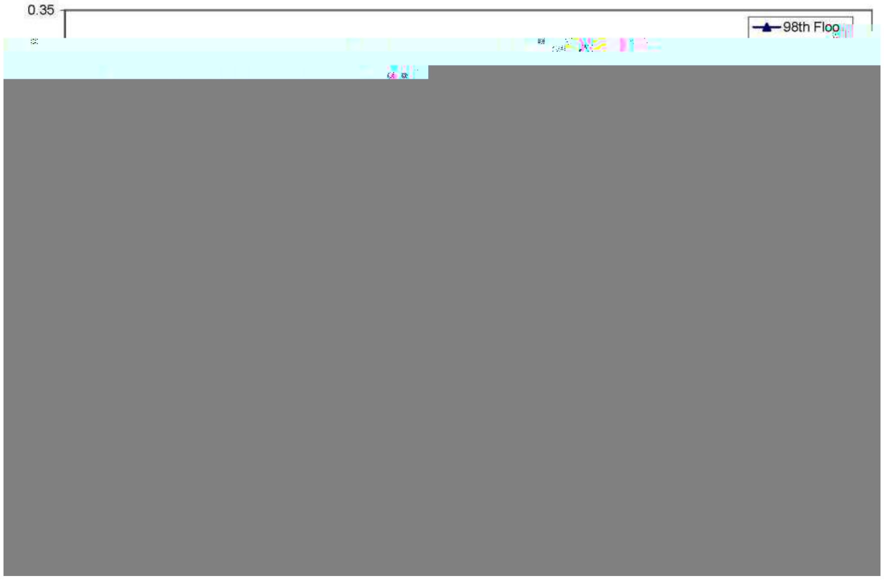


Figure 8–3. Mid-level zone sprinkler systems performance—calculated average delivered density vs. number of open sprinklers, WTC 1 and WTC 2.

The performance of the sprinkler systems on the 98th and 87th floors of WTC 1 bounded the mid-level sprinkler systems. As observed in Fig. 8–3, the hydraulic capacity of the sprinkler systems on the 32nd and 87th floors were nearly identical. However, the maximum flow rate to the sprinkler systems was limited by the flow of water to the supply main on the 109th floor level. The water flow to riser B was limited to approximately 440 gpm. As a result, the sprinkler system on the 87th floor was limited to 19 sprinklers, and the system on the 32nd floor was limited to 17 sprinklers. The hydraulic calculations for the sprinkler system on the 98th floor demonstrated that the infrastructure and water supply were capable of providing the minimum 7 psi operating pressure to 17 sprinklers at or above a density of 0.1 gpm/ft^2, which was over twice the size of the design area.

Hydraulic calculations of the sprinkler systems on the 31st and 2nd floors in WTC 1 were used to evaluate the hydraulic capacity of the low zone floor level sprinkler systems for WTC 1 and WTC 2. These systems were expected to bound the performance of the low zone sprinkler systems. The hydraulic calculations for the second floor sprinkler system represented the performance of a sprinkler system with a pressure-reducing valve. The systems on the second through eighth floor levels included pressure-reducing valves. Figure 8–4 provides a graphical depiction of the effect on delivered density associated with operating increasing numbers of sprinklers on these two floors in the low zone.

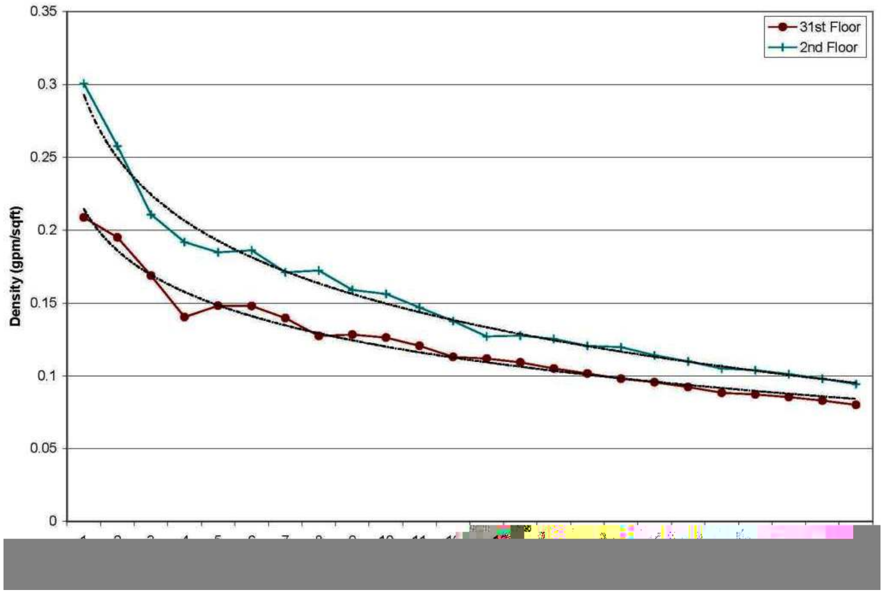


Figure 8–4. Low zone sprinkler systems performance—calculated average delivered density vs. number of open sprinklers, WTC 1 and WTC 2.

The performance of the sprinkler systems on the 31st and 2nd floors of WTC 1 bounded the low zone sprinkler systems in both WTC 1 and WTC 2. The sprinkler systems on the 32nd floor were able to provide the minimum 7 psi operating pressure and 0.1 gpm/ft^2 density for up to as many as 16 sprinklers, which is twice the size of the design area. The system on the second floor was able to provide the minimum 7 psi operating pressure and 0.1 gpm/ft^2 density for up to 21 sprinklers.

Operation of Sprinklers on Multiple Floor Levels

Calculations were performed to evaluate the likely performance of the sprinkler systems with an increasing number of sprinklers operating on multiple floors. This analysis was intended to assess two scenarios, one involving fires smaller than the design area, and the other involving fires approximately equal to the size of the design area on multiple floor levels in WTC 1 and WTC 2. The analysis used the Light Hazard system layouts described in Chapter 6.

The results indicated that the water supply could support four operating sprinklers on four consecutive floor level systems in the mid-level zone. The pressure loss through the supply main on the 109th floor level limited the flow of water and the maximum number of sprinklers that could be supported by the water supply. The maximum flow rate that could be supplied to the mid-level systems was determined to be approximately 440 gpm. This was observed in all cases involving the mid-level zone calculations.

Additional calculations were performed to evaluate scenarios involving sprinkler systems at the interface of the high and mid-level zones. Calculations were conducted for the systems on the 98th floor and 99th floor. These calculations demonstrated the performance of the systems with four open sprinklers on a single floor, i.e., either four sprinklers on the 98th floor or four sprinklers on the 99th floor. Next, hydraulic calculations were performed with four sprinklers operating simultaneously on both floors. Additional calculations were performed adding sprinklers on the 100th, 97th, and 101st floor levels. Table 8–3 summarizes the results of these calculations.

Table 8–3. High zone and mid-level zone average delivered density per floor vs. number of floors flowing (four sprinklers/floor), WTC 1 and WTC 2.

Floor	98	99	98 & 99	98–100	97–100	97–101
101	-	-	-	-	-	0.1656
100	-	-	-	0.1832	0.1811	0.1707
99	-	0.1967	0.1957	0.1880	0.1860	0.1760
98	0.1513	-	0.1497	0.1472	0.1390	0.1360
97	-	-	-	-	0.1457	0.1426

The results indicated that the water supply could support four sprinklers on five consecutive floor levels at the interface of the high and mid-level zones.

Multiple Fires Equivalent to the Design Area

Calculations were performed to evaluate the scenarios involving larger fires, equivalent in size to the design area of the sprinkler systems. Two separate locations were investigated, one involving sprinkler systems in the high zone and the other involving sprinkler systems in the mid-level zone.

Scenarios were evaluated involving multiple fires on the 102nd through 106th floor levels, i.e., representing the high zone. Each case included eight sprinklers per system starting with the 106th floor level system and adding eight sprinklers on the subsequent floor level below until the water supply could not support any additional sprinklers and maintain the limiting delivered density of 0.1 gpm/ft^2. Table 8–4 summarizes the results from the cases evaluated.

Table 8–4. High zone average delivered density per floor vs. number of floors flowing (eight sprinklers/floor), WTC 1 and WTC 2.

Floor	106	105 & 106	104–106	103–106	102–106
106	0.1386	0.1268	0.1101	0.0913	0.0753
105	-	0.1314	0.1149	0.0964	0.0803
104	-	-	0.1200	0.1018	0.0858
103	-	-	-	0.1074	0.0920
102	-	-	-	-	0.0983

The results indicated that the water supply could support eight sprinklers on three consecutive floor levels and provide a minimum average density greater than 0.1 gpm/ft^2. The results also indicated that the water supply and supply piping could support a maximum of five sprinkler systems, although the delivered densities and end-sprinkler pressures could drop slightly below 0.1 gpm/ft^2 and 7 psi, respectively.

Calculations were performed to evaluate scenarios involving multiple fires on the 98th and 97th floor. Table 8–5 provides a summary of the results of these calculations.

Table 8–5. Mid-level zone average delivered density per floor vs. number of floors flowing (eight sprinklers/floor), WTC 1 and WTC 2.

Floor	98	97 & 98
98	0.1288	0.1200
97	-	0.2346

The results involving the sprinkler systems in this mid-level zone indicate that the riser and water supply would be expected to control or extinguish two fires equal to the size of the design area. The supply riser size limited the water flow to 440 gpm, which was a limiting factor for the system capabilities. As a result of this limitation, further analysis of the high and mid-level zones was not performed.

Single Fire Larger than the Design Area

Estimates of the maximum fire size (greater than the design area of the sprinkler system) were made based on the results in Tables 8–4 and 8–5. The results indicated that a fire approximately three times the size of the design area (~4,500 ft^2) located in the upper water supply zone would be controlled by the sprinkler system, based on the performance criteria used in this analysis. The maximum fire size was approximately two times the design area for the mid-level locations.

The estimates of the maximum fire size coincided with the maximum sprinkler coverage area that could deliver the minimum spray density of 0.1 gpm/ft^2 at pressures greater than or equal to 7 psi throughout the coverage area. These fire sizes (3,000 to 4,500 ft^2) represent a relatively small part of the total occupied floor area of approximately 31,000 ft^2. However, automatic sprinkler systems are designed to control or suppress fires that are initially considerably smaller than the 1,500 ft^2 design area, which are the types of fires normally encountered in high-rise office buildings.

delivered density for the Ordinary Hazard system on the first floor was also much greater than was required. For instance, for a fire area of 750 ft^2, or six sprinklers, the calculated average delivered density was greater than 0.3 gpm/ft^2. This is twice the required density of 0.15 gpm/ft^2 for Ordinary Hazard Group 1 Occupancies in NFPA 13.

Single Fire Larger than the Design Area

In the case of the Light Hazard Occupancy floors, greater than nine opened sprinklers corresponded to a fire area greater than the design area. The results in Fig. 8–5 illustrate the results up to 18 sprinklers. This corresponds to an area of approximately 3,000 ft^2, or twice the Light Hazard design area.

The delivered densities remained greater than 0.15 gpm/ft^2 for up to 12 sprinklers. The delivered densities remained above the minimum required density of 0.1 gpm/ft^2 for up to 18 open sprinklers. The trend, with the exception of the 1st and 21st floors, indicated that the actual delivered density would remain above the minimum required Light Hazard density as additional sprinklers greater than 18 were added. The trend for the Ordinary Hazard system on the first floor indicated that the average delivered density would remain above 0.15 gpm/ft^2 for up to 18 open sprinklers. (Note that a sprinkler activation area of 3,000 ft^2 corresponds to approximately 7 percent to 8 percent of the total typical floor area of 42,000 ft^2 in WTC 7).

Table 8–6 lists the lowest residual pressure for each system when 18 sprinklers (i.e., twice the design area) were opened. The lowest pressure occurred at the most remote sprinkler in the design area. The results provided in Table 8–6 are consistent with the results graphed in Fig. 8–5. The first floor Ordinary Hazard system approached the minimum required density of 0.15 gpm/ft^2 and minimum pressure of 7 psi when 18 sprinklers were assumed to be open and flowing water. The 40th floor system provided an average delivered density of approximately 0.16 gpm/ft^2 with a minimum residual sprinkler pressure of 19.3 psi, well above the minimum required for a Light Hazard Occupancy.

Table 8–6. Lowest residual pressure at open sprinklers for each system.

Floor	Pressure (psi)
47	12.2
40	19.3
39	14.1
21	9.4
20	12.8
1	7.5

Figures 8–6, 8–7, and 8–8 illustrate the calculated average delivered density compared to the number of open sprinklers for the high, mid-level, and low zones, respectively. Each set of results was fit with a trend line. Each trend line was extrapolated to the minimum required density for the respective hazard classification.

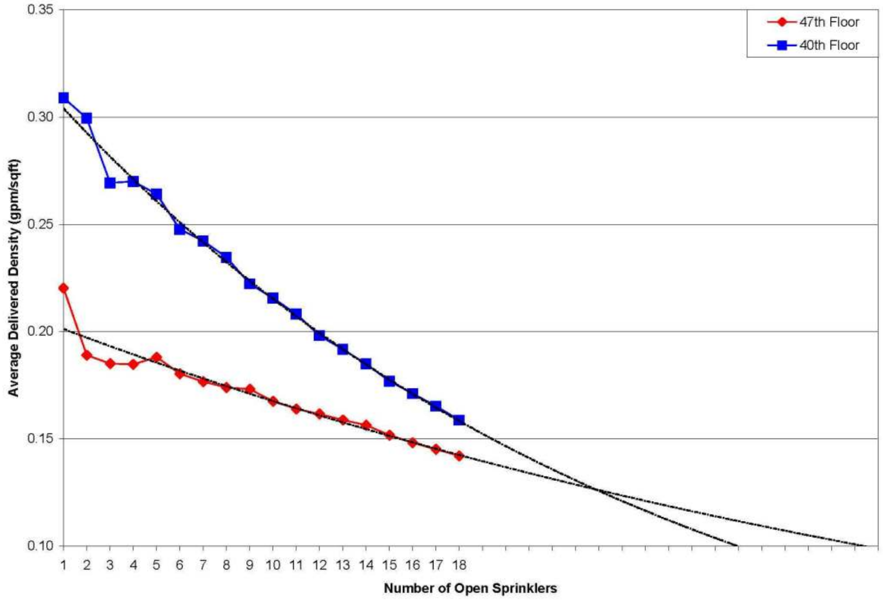


Figure 8–6. High zone, average delivered density vs. number of open sprinklers.

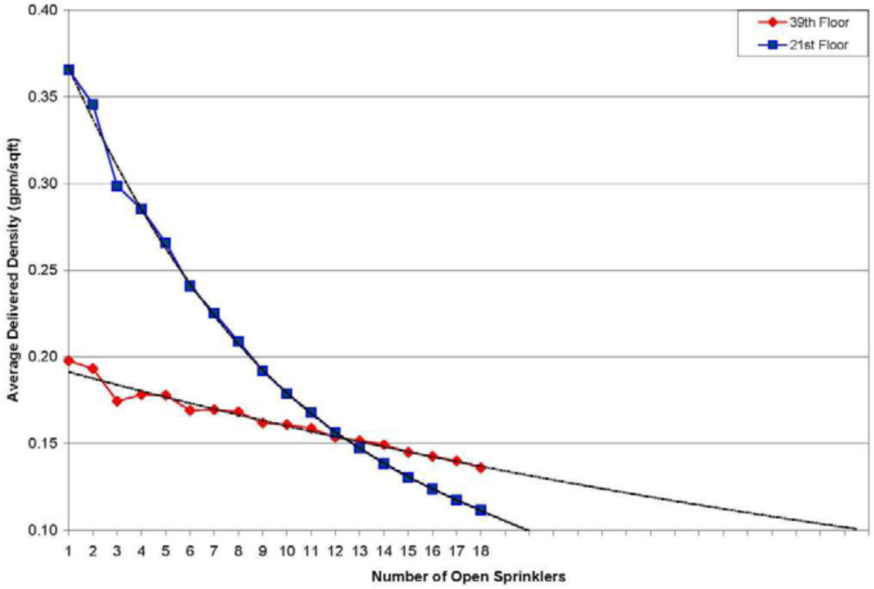


Figure 8–7. Mid-level zone, average delivered density vs. number of open sprinklers.

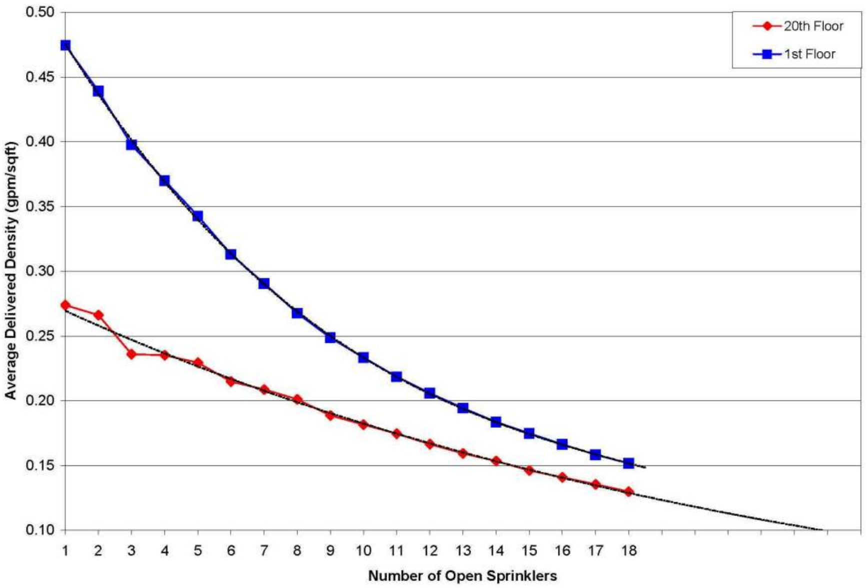


Figure 8–8. Low zone, average delivered density vs. number of open sprinklers.

Multiple Small Fires

The third scenario involved calculations to determine the capacity and expected performance of the sprinkler systems when small fires occur on multiple floors. For these cases it was assumed that the fires would open no more than four sprinklers. This was a conservative assumption since most fires in high-rise office buildings are controlled or suppressed by less than four sprinklers. The floors to be analyzed started with the 39th floor. The 39th floor was chosen because it represents the hydraulically most demanding floor supplied from the primary water supply. Four sprinklers were assumed to have operated on each subsequent floor, incrementally. Table 8–7 provides a summary of the results of the calculations by comparing the average delivered density to the floor number for each multiple fire floor scenario.

Table 8–7. Average delivered density per floor vs. number of floors flowing (four sprinklers/floor).

Floor	39	38 & 39	37–39	36–39	35–39	34–39	33–39	32–39	31–39
39	0.1677	0.1637	0.1577	0.1494	0.1396	0.1286	0.1158	0.1021	0.0863
38	-	0.1759	0.1699	0.1625	0.1536	0.1435	0.1321	0.1199	0.1071
37	-	-	0.1780	0.1711	0.1631	0.1542	0.1438	0.1333	0.1223
36	-	-	-	0.1813	0.1735	0.1649	0.1548	0.1455	0.1354
35	-	-	-	-	0.1845	0.1765	0.1679	0.1589	0.1491
34	-	-	-	-	-	0.1875	0.1795	0.1711	0.1619
33	-	-	-	-	-	-	0.1902	0.1818	0.1735
32	-	-	-	-	-	-	-	0.1926	0.1845
31	-	-	-	-	-	-	-	-	0.1955

It should be noted that the calculated average delivered density was still greater than the minimum required density for the case involving water flow on eight floors. The minimum residual sprinkler pressure was 8.8 psi for the eight-floor case. The minimum sprinkler pressure occurred on the 39th floor.

When a 31st floor was added (for total of 9 floors), the average delivered density on the 39th floor dropped below 0.10 gpm/ft^2 to approximately 0.087 gpm/ft^2. Also, the minimum sprinkler pressure on the 39th floor was 6.3 psi, 0.7 psi below the minimum required pressure per the requirements of NFPA 13. Therefore, the hydraulic analysis indicated, based on the minimum density and pressure selected for this analysis, that up to eight fires (limited to an area covered by four sprinklers) could simultaneously occur in different locations or on different floors and the installed sprinkler systems would be expected to control or extinguish them.

Multiple Fires Equivalent to the Design Area

The fourth scenario involved calculations to determine the performance of the sprinkler system when multiple fires approximately equivalent to the design area occurred at different locations, including on different floors. The design area was determined to be approximately 1,500 ft^2. Like the previous scenario, the floors to be analyzed started with the 39th floor. Table 8–8 provides a summary of the calculation results.

Table 8–8. Average delivered density per floor vs. number of floors flowing (nine sprinklers/floor).

Floor	39	38 & 39	37–39	36–39	35–39
39	0.1620	0.1468	0.1286	0.1084	0.0866
38	-	0.1600	0.1434	0.1255	0.1069
37	-	-	0.1434	0.1284	0.1135
36	-	-	-	0.1399	0.1262
35	-	-	-	-	0.1392

Based on these results, the sprinkler system could deliver more than the minimum required density over a design area of 1,500 ft^2 for up to four simultaneous fires on the same or different floors. The calculated average delivered density dropped below 0.10 gpm/ft^2 when a fifth fire was included in the calculations. The minimum residual sprinkler pressure for the five floor calculation occurred on the 39th floor. The minimum residual sprinkler pressure on the 39th floor, assuming fires on all five floors, was 5.7 psi.

The results in Table 8–8 indicate that sprinklers within the required design area could be activated on four different floors or at four separate locations on one floor, and the system would still have had the capacity to deliver more than the minimum required density. The fire hazard occupancy control approach to sprinkler system design, applicable to systems designed in accordance with NFPA 13, only requires the water supply to provide the minimum density to sprinklers that cover a single design area. The water supply system in WTC 7 was capable of supplying the minimum required density to all sprinklers within the design area for four separate fires, each roughly the size of the design area. This would normally be considered a very robust capability for an installed fire sprinkler system.

8.3 STANDPIPE/PRE-CONNECTED HOSE PERFORMANCE

8.3.1 General

Hydraulic calculations were performed to determine if the standpipe systems were designed to provide flow rates and pressures consistent with the provisions of the BCNYC (BCNYC 1968) and NFPA 14, Standard for the Installation of Standpipes and Hose Systems (NFPA 14 2000). The BCNYC does not provide specific performance requirements as outlined in NFPA 14, so a direct comparison was not made.

The BCNYC specifies how to configure standpipe systems, but does not specify minimum performance criteria for all situations. However, the BCNYC specifies that pressure-reducing valves at 2 ½ in. outlets should limit the discharge pressure to a maximum of 50 psi for a flow rate of 200 gpm. And pressure-reducing valves at 1 ½ in. hose stations should limit the discharge pressure to a maximum of 85 psi for a flow rate of 70 gpm.

NFPA 14 specifies the following minimum flow rate and pressure requirements for Class III standpipe systems. A flow rate of 500 gpm is required at the hydraulically most remote standpipe, and 250 gpm is required at each additional standpipe, up to a maximum combined flow rate of 1,250 gpm. NFPA 14 also identifies a maximum flow rate that is acceptable in buildings protected throughout with automatic sprinkler systems.

8.3.2 WTC 1 and WTC 2

The arrangement of the standpipe systems in WTC 1 and WTC 2 included a multiple supply configuration. Each water supply zone included three 6 in. diameter standpipes. The design of these systems included multiple 750 gpm fire pumps that could operate in parallel or in series. Refer to Fig. B–1. Two pumps on the B1 level were arranged in parallel, meaning that either pump could be used to supply water to the sub-grade loops and both towers. The pumps on the 7th, 41st, and 75th floors of each tower were configured in a series arrangement with the sub-grade loops and the B1 level pumps.

Hydraulic calculations were performed using the Hydraulic Analyzer of Sprinkler Systems (HASS) (HRS 2004) hydraulic calculation program for three specific configurations involving the operation of four, three, and two manual fire pumps. The first configuration involved the operation of three pre-connected hose valves on the 109th floor and one pre-connected hose valve on the 110th floor since these were the hydraulically most remote hose valve locations in the building. A flow rate of 250 gpm was specified at each hose valve. The results of the hydraulic calculations indicated that the standpipe systems were able to provide 250 gpm to the four hose stations with three or four pumps in operation. The calculation for four pumps provided 250 gpm to each hose valve at approximately 400 psi. The calculations for three pumps operating indicated that a flow of 250 gpm would be delivered to the four hose valves with a minimum pressure of 128 psi. Therefore, based on this analysis, it appears that the standpipe systems exceeded the requirements of NFPA 14 and the BCNYC. The calculations for two pumps operating indicated that 250 gpm could have supplied a single hose valve on the 110th floor.

The BCNYC required these systems to provide significantly less water than the pumps were designed to provide. Operating additional fire pumps or supplying water through a standard FDC or a single high-pressure FDC would further augment the performance of the standpipe systems. Calculations demonstrating that the Fire Department of The City of New York (FDNY) operations using the FDCs resulted in acceptable performance of the standpipe systems was independently confirmed in by Beyler (Beyler 2002). Therefore, it appears that excess pressure and flow were available to the standpipes and the pre-connected hose stations throughout WTC 1 and WTC 2 in the "normal" operating mode.

8.3.3 WTC 7

In WTC 7, the hose connections throughout the building were supplied from the combination wet pipe standpipe/sprinkler systems. Therefore, the primary supply zones to the hose connections were the same as for the sprinkler systems.

The primary supply to the high zone was the automatic booster pump located on the 46th floor. Section 27-945 (b)(5)(b.) of the BCNYC specified that the automatic fire pump must have had a capacity to provide at least 500 gpm at 25 psi to the highest hose outlet station supplied by the pump. The NFPA 14 requirements for Class III standpipe systems specified a flow rate of 500 gpm required at the hydraulically most remote standpipe/pre-connected hose outlet and 250 gpm at each additional outlet. The minimum pressure requirement was 100 psi, or 65 psi if approved by the authority having jurisdiction (AHJ).

Similarly to the analysis for WTC 1 and WTC 2, hydraulic calculations were performed to assess the standpipe systems for consistency with the provisions of NFPA 14 and the BCNYC. The calculations were performed for the most remote hose connections on the three standpipes of the high zone. These involved the hose connections on the 47th floor of riser R-7, 47th floor of riser R-8, 46th floor of riser R-9, and 47th floor of riser R-9.

The first calculation was conducted using the criteria established by the BCNYC with the primary water supply. The BCNYC criteria only required that 500 gpm flow at 25 psi at the most remote hose connections. The hose connection calculated was the 47th floor of riser R-9. The results indicated that the 500 gpm (55 psi head) booster pump would easily provide the 500 gpm flow at above the minimum required pressure.

NFPA 14 required that the minimum required flow and pressure be provided by an automatic source. However, the automatic booster pump present on the 46th floor was undersized to provide the flow and pressure that would have been required by NFPA 14. The booster pump was rated for 500 gpm, while the minimum required design flow for NFPA 14 would have been 1,000 gpm, or 200 percent of the rated pump capacity. Therefore, a second calculation was conducted using the criteria established by NFPA 14 utilizing the 750 gpm manual fire pump located in the first floor fire pump room. The results of this calculation indicated that the capacity of the 750 gpm manual fire pump was less than the minimum flow and pressure requirements in NFPA 14 for the high zone hose connections. In fact, the hydraulic calculations indicated that the manual fire pump could only provide a flow rate of 250 gpm to each hose connection at approximately 20 psi.

Based on these results, it appeared that the standpipe systems met or exceeded the requirements of the BCNYC, but were somewhat under-designed based on the requirements in NFPA 14.

8.4 SUMMARY OF TASK 4

The hydraulic analyses relied on the minimum delivered density and pressure requirements in NFPA 13 as the basic criteria for evaluating the fire control capacity of the sprinkler systems. It is important to recognize that in NFPA 13, the required densities and pressures are based on the assumption that an installed fire sprinkler system is designed to control a single fire. In addition, in the analyses performed here, small fires were assumed to be approximately the size of the area covered by a four-sprinkler array (approximately 750 ft^2). In fact, available performance history indicates that typical fires in high-rise office buildings are controlled or suppressed by less than four sprinklers, lending additional conservatism to the estimates of system capacity presented here. Finally, the calculations were based on availability of the primary water supplies only, without any consideration for fire department actions to provide a secondary water supply. In NYC such action is routine, and the secondary water supply is considered infinite in duration, with equivalent or higher capacity to the primary water supply. At the same time, due to the normal availability of a reliable, high capacity secondary water supply, duration of water supply was not included in this analysis.

Based on the analyses performed as part of this task, the installed sprinkler systems in WTC 1, 2, and 7 had the ability to simultaneously control or suppress multiple fires of varying sizes under “normally expected” operating conditions. The fires could have occurred at different locations on a single floor or on multiple floors. The results of extensive hydraulic calculations indicated that the water flow density and pressure associated with the installed sprinkler systems had the capacity to control fires on the order of two to three times the sprinkler system design area (1,500 ft^2), depending on the location in the building, and the systems would be expected to concurrently control at least four to six smaller fires similar in area to that protected by a four-sprinkler array (750 ft^2).

The calculations identified limits of performance, but these estimated limits were significantly greater than the limits associated with the requirements in NFPA 13. The available densities and pressures indicated that the installed systems generally exceeded the minimum requirements in NFPA 13 by significant margins. These systems would have been expected to control multiple small fires or fires up to three or four times the sprinkler system design area and would have been considered robust installations with considerable excess capacity. At the same time, if large fires were to open all of the sprinklers in an area equivalent to three to four times the design area of the sprinkler systems, the hydraulic capabilities of the system(s) would begin to degrade, and, although these fire areas would be considered relatively large (4,500 to 6,000 ft^2), they represented roughly 8 to 15 percent of the occupied floor areas in WTC 1, 2, and 7.

Flow restrictions existed at selected locations in WTC 1 and WTC 2, but the limits of available water flow were still considerably greater than those required in NFPA 13 for control of typical Light Hazard fire incidents.

While it is difficult to assess the performance capabilities of the standpipe/pre-connected hoses, hydraulic calculations indicated that the size of the standpipes and the capacity and number of fire pumps were consistent with the requirements for pressure and flow in the BCNYC. However, the booster pump on the 46th floor was undersized and could not provide the relatively higher minimum flow and pressure required in NFPA 14.

Chapter 9

TASK 5: SUPPRESSION SYSTEMS PERFORMANCE ON SEPTEMBER 11, 2001

9.1 GENERAL

The objective of the Task 5 analysis was to document to the extent possible the design and performance of the automatic fire sprinkler and standpipe systems in World Trade Center (WTC) 1, 2 and 7 on September 11, 2001. Given the design and intended operation of the fire protection systems, an attempt was made to address specific questions related to the performance of these systems. These questions included:

- What initially happened to the operational condition of systems as a result of each major event?
- How was the performance of the systems impacted by each event? and,
- At what point in the sequence of events were the systems lost?

This section of the report outlines the sequence of major events and the impact to the critical fire protection system components resulting from each event.

The estimates of performance relied on the detailed information and analyses documented in the preceding sections of this report, along with relevant evaluations performed by others (i.e., McAllister 2002; Beyler 2002).

9.2 SEQUENCE OF EVENTS

An evaluation was conducted of the operational readiness and performance of the automatic sprinkler and standpipe/pre-connected hose systems and the associated water supplies. The evaluation was based on estimates of conditions in the buildings at the time of each major event in the sequence of impacts and building collapses. The timeline for these events is presented in Table 9–1, along with the departure times of the two flights.

Table 9–1. Timeline and summary of major events.

Time	Event
7:59 a.m.	AA flight 11 departs from Logan
8:14 a.m.	UA flight 175 departs from Logan
8:46 a.m.	Initial aircraft strike: WTC 1
9:03 a.m.	Initial aircraft strike: WTC 2
9:58 a.m.	Collapse of WTC 2
10:29 a.m.	Collapse of WTC 1
5:21 p.m.	Collapse of WTC 7

9.3 BASIS FOR ESTIMATING SYSTEMS DAMAGE

The extent of damage to the water supply, automatic sprinklers, and the standpipe systems on each individual floor was estimated using structural damage estimates prepared by the National Institute of Standards and Technology (NIST) (see Figs. 9–1 and 9–2) as part of the baseline structural performance and aircraft impact damage analysis. The exact extent of suppression systems damage could not be accurately determined due to the collapse of all three structures. Therefore, the initial damage to system components was assumed to correspond to areas associated with initial structural damage. This approach was considered a reasonable first approximation, particularly considering the limited information available regarding the status and performance of the suppression systems on September 11. The sprinkler and standpipe system components were overlaid on diagrams of the preliminary impact damage estimates prepared by NIST as part of the baseline structural performance and aircraft impact damage analysis. Then, it was assumed that if the components were located within the initial impact damage areas, the integrity of system components was compromised or lost. Based on the proximity of the critical components to the initial impact area, additional assessments were made regarding the integrity and operability of the primary and secondary water supplies, standpipes, sprinkler system infrastructure, and the sprinkler systems on individual floors. Estimates of the available sprinkler water density and duration of supply were based on analyses documented in Chapters 6 through 8.

The preliminary damage estimates included floors 94 through 96 in WTC 1 and floors 78 through 81 in WTC 2. These estimates were subsequently revised by NIST as additional analyses were completed. The result was to extend the initial damage estimates to include areas on floors 93 through 99 in WTC 1 and floors 77 through 85 in WTC 2.

Comparison of the preliminary and more recent damage estimates was performed in order to determine if the damage estimates associated with the suppression systems would be changed significantly based on the newer impact damage estimates in NIST NCSTAR 1-2.[3] Based on this comparison, it was determined that the primary changes in the damage estimates involved additional floors, outside the core areas of the buildings. Since the primary areas of damage of relevance to the suppression systems involved the core areas of the buildings, the estimates of damage to the suppression systems resulting from use of the preliminary impact damage estimates were considered valid approximations. Therefore, it was not necessary to repeat the analysis of the damage estimates that was already completed based on the initial damage assessment.

9.3.1 WTC 1 Aircraft Strike

A rough estimate of the initial damage that resulted from the impact of the aircraft on WTC 1 was based on the extent of damage illustrated in Fig. 9–1. The sprinkler system component locations were compared to the initial structural damage estimates. The integrity and operability of system components were assumed to be compromised if they were located within the primary area of damage. Figure 9–1 shows the primary damage in WTC 1 that occurred on floors 94 through 96.

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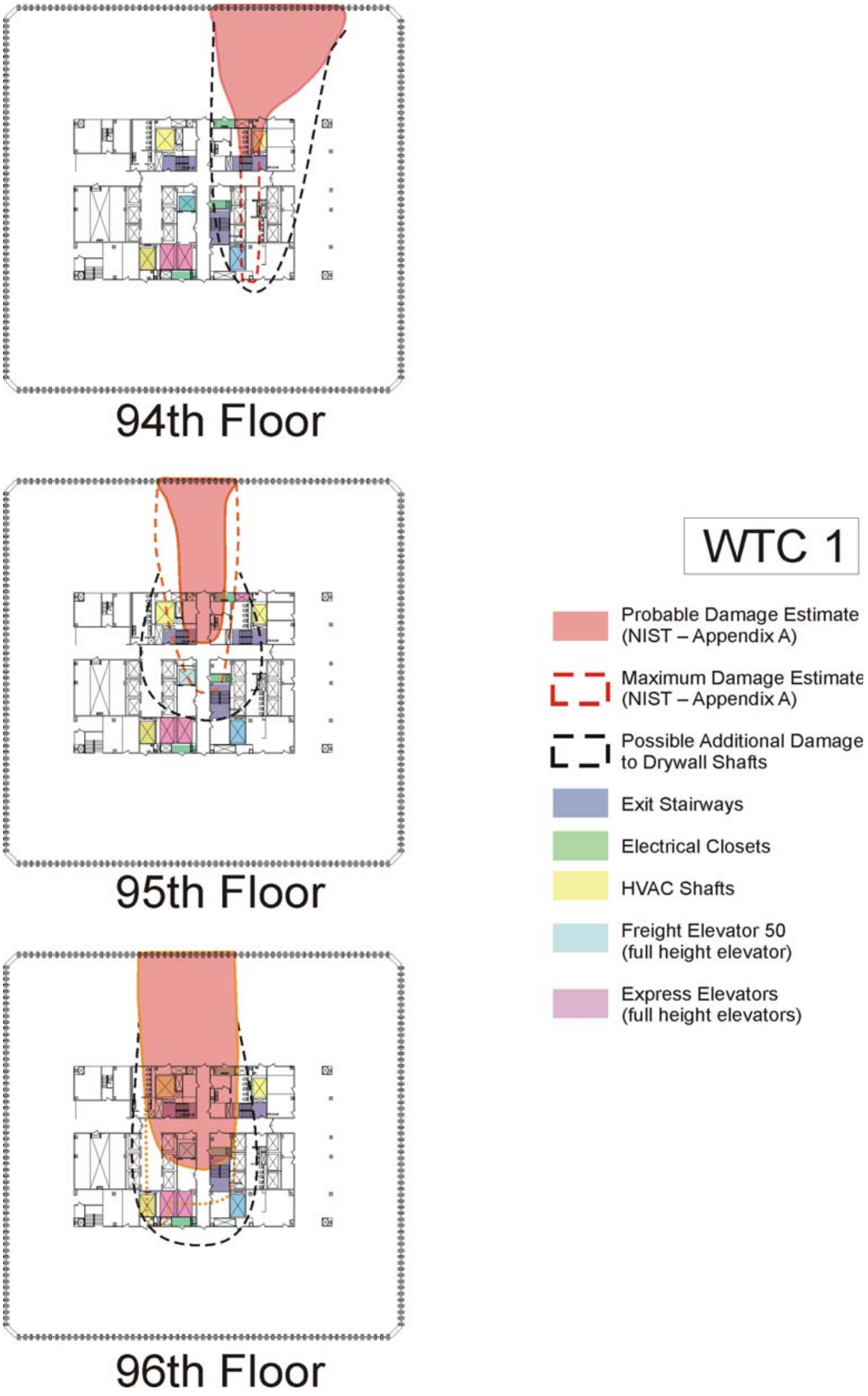
[3] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.



Source: Adopted from McAllister 2002. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 9–1. NIST damage estimates, WTC 1.

The sprinkler system on floor 96 was within the area of significant impact damage at the northwest quadrant of the building. It is unlikely that the aircraft would have avoided the sprinkler system on this floor. However, the system was supplied with water from riser B, which was located in the janitor's closet immediately south of stair 3, the southernmost stair enclosure. Based on the initial damage estimates it did not appear that initial damage was sustained to riser B. The other sprinkler risers (A and C) did not pass through this floor and were assumed to be unaffected by the initial impact.

A portion of stair 3 was located within the initial impact area, exposing riser FS-F1 to sustained damage at the 96th floor. Stair 2 was located in the northwest quadrant of the core area and was entirely within the initial impact area. Therefore, the high zone standpipe riser FS-F2 was severed and inoperable as a result of the initial impact.

Stair 1 was located in the northeast quadrant of the core area and sustained damage. It is possible that standpipe riser FS-F3 was damaged, however, it was located outside of the immediate damage area. Table 9–2 provides a summary of the initial damage estimates to the sprinkler and standpipe systems on the 96th floor.

Based on the initial damage estimates, it appeared that the sprinkler system on the 96th floor was compromised at the north side of the building. A portion of the structure at the center of the floor on the north side sustained significant damage as a result of the impact. It is likely that the sprinkler system on this floor was in the direct path of the aircraft. This system was also supplied from riser B which remained intact and operable.

Stair 3 and standpipe riser FS-F1 were outside the initial impact area and appear to be unaffected on the 95th floor. A portion of stair 2 was located in the initial impact area. It is possible that riser FS-F2 was damaged. Stair 1 and standpipe riser FS-F3 were most likely unaffected since they were located outside of the immediate damage area. Table 9–3 provides a summary of initial damage estimates to the sprinkler and standpipe systems on the 95th floor.

Table 9–2. Summary of estimated initial damage, sprinkler and standpipe systems, 96th floor, WTC 1.

Component	Location	Initial Impact Damage Estimate
Sprinkler system	Northwest quadrant	Significant damage to sprinkler system.
Sprinkler riser A	Did not pass through this floor.	
Sprinkler riser B	Core–janitor's closet located adjacent to stair 3 to the south.	No initial damage to the riser on this floor.
Sprinkler riser C		Did not pass through this floor.
Standpipe riser FS-F1	Core–stair B (3)–south	A portion of the stair enclosure was within the initial impact area. Possible damage to the riser.
Standpipe riser FS-F2	Core–stair C (2)–northwest	The entire stair was within the initial impact area; loss of riser likely.
Standpipe riser FS-F3	Core–stair A (1)–northeast	A portion of the stair enclosure was within the initial impact area. Possible damage to the riser.
Stored water supplies	None located on this floor	No initial damage.

Table 9–3. Summary of estimated initial damage, sprinkler and standpipe systems, 95th floor, WTC 1.

Component	Location	Initial Impact Damage
Sprinkler system	North side	Significant damage to sprinkler system likely.
Sprinkler riser A	Did not pass through this floor.	
Sprinkler riser B	Core–janitor's closet located adjacent to stair 3 to the south	No initial damage to the riser on this floor.
Sprinkler riser C		Did not pass through this floor.
Standpipe riser FS-F1	Core–stair B (3)–south	No initial damage to the riser on this floor.
Standpipe riser FS-F2	Core–stair C (2)–northwest	A portion of the stair enclosure was within the initial impact area. Possible damage to the riser.
Standpipe riser FS-F3	Core–stair A (1)–northeast	No initial damage to the riser on this floor.
Stored water supplies	None located on this floor	No initial damage

At the northeast corner of the 94th floor on the north side, the building sustained significant damage as a result of the impact. The sprinkler system on the 94th floor was also in the direct path of the aircraft and sustained extensive damage. It was noted that this system was supplied with water from riser B, which did not sustain direct initial damage, so while the floor level systems in the vicinity of the 94th floor were not functional, the water supply was maintained for some period of time.

Stair 3 was located in the immediate initial impact area on the 94th floor (refer to Fig. 9–1). The standpipe riser FS-F1 was in the initial impact area and was damaged. Stairs 1 and 2 were unaffected since they were located outside of the immediate estimated damage area. Therefore, risers FS-F2 and FS-F3 were undamaged at the 94th floor as a result of the aircraft impact. Table 9–4 provides a summary of initial damage estimates to the sprinkler and standpipe systems on the 94th floor.

Table 9–4. Summary of estimated initial damage, sprinkler and standpipe systems, 94th floor, WTC 1.

Component	Location	Initial Impact Damage
Sprinkler system	Northeast quadrant	Significant damage to sprinkler system likely.
Sprinkler riser A	Did not pass through this floor.	
Sprinkler riser B	Core–Janitor's closet located adjacent to stair 3 to the south	No initial damage to the riser on this floor.
Sprinkler riser C	Did not pass through this floor.	
Standpipe riser FS-F1	Core–stair B (3)–south	A portion of the stair enclosure was within the initial impact area. Possible damage to the riser.
Standpipe riser FS-F2	Core–stair C (2)–northwest	No initial damage to the riser on this floor.
Standpipe riser FS-F3	Core-stair A (1)–northeast	No initial damage to the riser on this floor.
Stored water supplies	None located on this floor	No initial damage.

The stored water supply tanks for the sprinkler and standpipe systems were located on the 110th, 76th, 42nd, and 20th floors. The initial impact damage to the standpipe risers likely caused the 5,000 gal water storage tank FSP 110A to drain. The water supplies on the other floors were unaffected by the initial impact because these tanks were located below the impact zone. Damage initially sustained by the standpipe risers reduced or interrupted water flow availability from the manual fire pumps and FDCs to the standpipe and sprinkler systems above the 32nd floor. Damage sustained to the sprinkler systems on the 94th, 95th, and 96th floors caused the 10,000 gal of sprinkler reserve water storage to drain from the tanks, reducing the effectiveness of the sprinkler systems on the 32nd through 107th floors. Damage to the booster pump would have occurred after the water tanks were drained, resulting in failure of the pump.

The fire protection systems in WTC 2 and WTC 7 were basically unaffected by the impact of the aircraft that crashed into WTC 1. The standpipe systems below the high zone in WTC 1 continued to be operational. The high zone standpipe system was partially intact but would have required manual intervention to reinstate service. The low zone sprinkler systems were unaffected by the impact. The high and mid-level zone sprinkler systems were adversely affected by a decreased water supply capacity and duration as a result of the damage sustained to the standpipe riser and sprinkler systems on the 94th through 96th floors. The effectiveness of the sprinkler systems in the high and mid-level zones was reduced as a result of the damage to the sprinkler systems on the 94th through 96th floors. However, these sprinkler systems located away from the immediate impact zone, were capable of containing a number of small isolated fires on multiple floors for some time until the water supply was lost as demonstrated in the analysis described in Chapter 8. However, large fires on multiple floors that significantly exceeded the design areas of the sprinkler systems would have overwhelmed the sprinkler systems.

In summary, the following effects on the operational status of the standpipe and sprinkler systems were determined, based on system damage estimates resulting from the initial aircraft impact on WTC 1:

- Loss of standpipe riser FS-F1, FS-F2.
- Possible loss of standpipe riser FS-F3.
- Loss of standpipe system water supply after a limited amount of time as a result of the damage to the standpipe risers.
- Loss of the sprinkler systems on the 94th through 96th floors.
- The effectiveness of the sprinkler systems in the high and mid-level zones was reduced, however, the systems were capable of containing small fires on multiple floors.
- Possible loss of the sprinkler systems on other floors immediately above the 96th floor and below the 94th floor.
- Loss of sprinkler system water supply after a limited amount of time as a result of the damage to the standpipe risers.

9.3.2 WTC 2 Aircraft Strike

An estimate of the initial damage to the standpipes and sprinkler systems in WTC 2 that resulted from the second aircraft impact was based on the preliminary structural damage estimates in Fig. 9–2. Figure 9–2 illustrates that extensive initial damage in WTC 2 occurred on floors 78 through 81. No evidence was found to indicate that the fire protection systems in WTC 1 or WTC 7 were affected in any way by the initial impact of the aircraft that crashed into WTC 2.

Table 9–6. Summary of estimated initial damage, sprinkler, and standpipe systems, 80th floor, WTC 2.

Component	Location	Initial Impact Damage
Sprinkler system	East side of building from south face	Significant damage to sprinkler system likely.
Sprinkler riser A	Did not pass through this floor.	
Sprinkler riser B	Core–janitor’s closet located adjacent to stair 3 to the east.	No initial damage to the riser on this floor.
Sprinkler riser C	Did not pass through this floor.	
Standpipe riser FS-F1	Core–stair B (3)–east	No initial damage to the riser on this floor.
Standpipe riser FS-F2	Core–stair C (2)–southwest	No initial damage to the riser on this floor.
Standpipe riser FS-F3	Core–stair A (1)–northwest	No initial damage to the riser on this floor.
Stored water supplies	None located on this floor	Initial damage as a result of impact on 79th floor.

The standpipe risers on the 79th floor did not appear affected by the initial impact. There were no water storage tanks or pumps located on this floor. Table 9–7 provides a summary of the initial damage estimates for the 79th floor sprinkler and standpipe systems.

The sprinkler system on the 78th floor of WTC 2 was most likely extensively damaged by the impact of the aircraft. A large part of the sprinkler system at the south side of the building was damaged, significantly compromising its effectiveness. In addition, the sprinkler system on the 78th floor was supplied with water from riser B. Although there was no damage to this riser on the 78th floor, the damage incurred at the 79th floor compromised the integrity of all of the sprinkler systems within the high and mid-level zones. The damage to the sprinkler riser likely drained the water storage tanks on the 110th floor within 20 to 35 min. (Note: These calculated times are based on the flow limitation of 440 gpm reported in the Chapter 6 analysis and assumes that the supplemental refill connection was not operational.)

Table 9–7. Summary of estimated initial damage, sprinkler and standpipe systems, 79th floor, WTC 2.

Component	Location	Initial Impact Damage
Sprinkler system	East side of building from south face.	Significant damage to sprinkler system likely.
Sprinkler riser A	Did not pass through this floor.	
Sprinkler riser B	Core–janitor’s closet located adjacent to stair 3 to the east.	Damage sustained to riser B was likely.
Sprinkler riser C	Did not pass through this floor.	
Standpipe riser FS-F1	Core–stair B (3) –east	No initial damage to the riser on this floor.
Standpipe riser FS-F2	Core–stair C (2)–southwest	No initial damage to the riser on this floor.
Standpipe riser FS-F3	Core–stair A (1)–northwest	No initial damage to the riser on this floor.
Stored water supplies	None located on this floor	Initially damaged.

The standpipe risers on the 78th floor of WTC 2 were unaffected by the aircraft impact. There were no water storage tanks or pumps located on this floor. Table 9–8 provides a summary of the initial damage estimates for the 78th floor sprinkler and standpipe systems.

Table 9–8. Summary of estimated initial damage, sprinkler and standpipe systems, 78th floor, WTC 2.

Component	Location	Initial Impact Damage
Sprinkler system	East side of building from south face	Significant damage to sprinkler system likely.
Sprinkler riser A	Did not pass through this floor.	
Sprinkler riser B	Core–Janitor's closet located adjacent to stair 3 to the east	No initial damage to the riser on this floor.
Sprinkler riser C	Did not pass through this floor.	
Standpipe riser FS-F1	Core–stair B (3)–east	No initial damage to the riser on this floor.
Standpipe riser FS-F2	Core-stair C (2)–southwest	No initial damage to the riser on this floor.
Standpipe riser FS-F3	Core–stair A (1)–northwest	No initial damage to the riser on this floor.
Stored water supplies	None located on this floor	Initial damage as a result of impact on 79th floor
Other–Fire carts	Cores–78th, 44th floors and concourse level	No initial damage.

The likely damage to riser B would have compromised the integrity of the sprinkler system infrastructure for the mid-level and high zones. The impact of the loss of riser B on the 79th floor is significant since this riser supplied the sprinkler systems on the 32nd through 98th floors. The damage to riser B would have prevented adequate pressure and flow from being provided to the sprinkler systems above the 79th floor, as well as significantly compromising the water supply to the sprinkler systems on floors 32 through 78.

Riser B was supplied with water from the sprinkler and standpipe storage tanks located on the 110th floor. The damage to riser B resulted in the loss of integrity of the water supply to the high zone sprinkler systems and the high zone standpipe system. The 10,000 gal sprinkler reserve water storage tanks and the 5,000 gal standpipe tank likely drained as a result of the impact. The booster pump that supplied the high zone sprinkler systems would have sustained damage after the tanks drained unless supplemental water was provided through the fire department connections (FDCs).

The low zone sprinkler systems were unaffected by the initial impact and should have been operational. The high zone sprinkler systems were compromised by decreased water supply capacity and duration as a result of the damage sustained to the standpipe riser and sprinkler systems on the 94th through 96th floors.

The standpipe systems below the high zone were not directly affected and remained operational. The high zone standpipe system was intact, and it is likely that the fire cart located on the 78th floor was intact. The amount of time that water was available was limited due to the failure of sprinkler riser B.

In summary, the following adverse effects on the standpipe and sprinkler systems in WTC 2 were likely caused by the initial aircraft impact on WTC 2:

- Loss of sprinkler riser B, although the other standpipe system risers remained operable.
- Loss of sprinkler and standpipe system water supplies after a limited amount of time as a result of the damage to sprinkler riser B.
- Loss of the sprinkler systems on the 78th through 81st floors.
- Loss of water supply to the sprinkler systems on floors 32 through 78.
- The effectiveness of the sprinkler systems above the 79th floor was significantly reduced as a result of the loss of riser B.
- Possible loss of the sprinkler systems on other floors immediately above the 96th floor and below the 94th floor.
- Use of manual fire pumps and FDCs was possible.

9.3.3 WTC 2 Collapse

There was no significant damage to WTC 7 reported as a result of the collapse of WTC 2. However, there was significant damage to the 12 in. supply main in the utility rack on the sub-grade level and the distribution system in the surrounding area of WTC 2 (Beyler 2002). The power supply for the two B1 level standpipe pumps was supplied by a single circuit which was likely damaged as a result of the collapse, rendering the B1 level pump beneath WTC 1 inoperable. Significant damage to the concourse and B1 sprinkler and standpipe loops was also likely.

The configuration of the sub-grade loops included isolation valves to prevent major water supply interruption due to broken pipe segments. FDCs were located between each series of isolation valves, allowing water to be pumped through the FDCs to the sprinkler and standpipe systems in WTC 1 after the collapse of WTC 2.

The low zone sprinkler systems in WTC 1 and WTC 2 were interconnected. The water supply for the WTC 1 low zone systems would have drained until the manual tower-isolating valve was closed. This would have isolated the WTC 1 sprinkler systems from the damaged portions of the system infrastructure resulting from the collapse of WTC 2. The FDCs for the low zone could have been used to supply water to these systems (Beyler 2002). However, once WTC 2 collapsed, accessibility to isolation valves and FDCs was significantly reduced.

9.3.4 WTC 1 Collapse

The collapse of WTC 1 resulted in extensive damage to the below grade water supply for the WTC complex. Although the redundant water supplies to WTC 7, located under Washington Street, most likely survived the collapses of WTC 1 and 2 (Beyler 2002), multiple fires were reported in WTC 7 as a result of burning debris and structural materials from the WTC 1 collapse (NIST 2003). Photographic and videographic records, along with eyewitness accounts, indicated that extensive fires were burning throughout WTC 7 for a number of hours before the building collapsed (NIST 2003).

9.3.5 WTC 7 Collapse

No fire department actions were taken to suppress the fires in WTC 7 once the building was evacuated (Smith 2002). Insufficient documentation existed to allow determination of the performance of the suppression systems in WTC 7. However, it is unlikely that the sprinklers provided more than nominal protection once multiple fires were burning on different floors.

The analysis of the WTC 7 sprinkler system design indicated that the sprinkler systems were capable of controlling multiple fires, or a fire which exceeded the sprinkler system design areas, for some period of time. However, photographic records indicated that the fires were extensive on multiple floors (Averill et al. 2005; McAllister et al. 2005). For example, a fire on the 12th floor burned for several hours, and eventually burned out; the sprinkler systems were not able to suppress this fire. In addition, the water supply to the upper floors (floors 21 through 47) consisted of a stored water source and risers connected to the FDCs. The stored water provided, at the most, 20 to 30 minutes of supply before reliance on the fire department for continued supply became acute. Therefore, once multiple fires occurred in WTC 7 and the fire department was unable to support the water demand from the street, the sprinkler systems would have been quickly overwhelmed.

An eyewitness account indicated that at some point there was no water to the standpipes in WTC 7 (Smith 2002). The cause of this is unknown, but could have resulted from a loss of power to the fire pumps, diversion of the water from the standpipes for other fire department operations (Smith 2002), and/or the documented fact that the fire department was unable to supplement the water supply to WTC 7 through the FDCs (Smith 2002). In addition, combustible liquids storage and supply piping existed at the first floor, as well as on floors 5, 7, and 8. Analyses of the areas associated with the fuel storage tanks on the first floor detected no fuel residual, indicating that the fuel contributed to the fires in WTC 7 (McAllister et al. 2005). The automatic sprinkler systems were not designed to protect a combustible liquids hazard. The sprinklers would likely have provided some control, depending on the extent of the fuel spill fire areas, for a limited amount of time. However, even if the sprinkler systems were fully operational at this point, with the limited duration of the stored water supply and the absence of supplemental water from the FDCs to the sprinkler systems, the result would have been failure of the sprinkler systems to control the fires, leading to extensive fire spread on multiple floors.

9.4 SUMMARY OF TASK 5

Preliminary structural damage estimates provided by NIST were used to determine the extent of damage to and related operability of the fire suppression systems in WTC 1 and WTC 2 resulting from the incidents on September 11, 2001. Initial damage to the standpipe and sprinkler systems in WTC 1 as a result of the aircraft strike was primarily on floors 94 through 96. Based on review of the damage estimates, photographic and video records, and documented eyewitness accounts, the effects of the impact on the operability of the suppression system was estimated to include the following:

- Loss of standpipe riser FS-F1 and FS-F2.

- Possible loss of standpipe riser FS-F3.
- Loss of standpipe risers Loss of standpipe system water supply after a limited amount of time as a result of the damage to the standpipe risers.
- Loss of the sprinkler systems on the 94th through 96th floors.
- The effectiveness of the sprinkler systems in the high and mid level zones was reduced, however the systems were capable of containing small fires on multiple floors.
- Possible loss of the sprinkler systems on other floors immediately above the 96th floor and below the 94th floor.
- Loss of sprinkler system water supply after a limited amount of time as a result of the damage to the standpipe risers.

Floor control valves on floors 94 through 96 of WTC 1 for these suppression as well as standpipe isolation valves on the 88th and 99th floors could potentially have been used to isolate the initial impact zone, but, such an action would have required immediate, precise information and would not have prevented building collapse. It is unlikely that the sprinkler and standpipe systems in WTC 2 or WTC 7 were immediately damaged by the aircraft strike on WTC 1.

The damage to WTC 2 as a result of the second aircraft strike was concentrated on floors 78 through 81. The resulting effects on the condition and operability of the standpipe and automatic sprinklers in WTC 2 were estimated to include the following:

- Loss of sprinkler riser B.
- Operability of the standpipe system risers not lost due to initial impact.
- Loss of sprinkler and standpipe system water supplies after a limited amount of time as a result of the damage to sprinkler riser B.
- Loss of the sprinkler systems on the 78th through 81st floors.
- Loss of water supply to the sprinkler systems on floors 32 through 78.
- The effectiveness of the sprinkler systems above the 79th floor was significantly reduced as a result of the loss of riser B.
- Possible loss of the sprinkler systems on other floors immediately above the 96th floor and below the 94th floor.
- Use of manual fire pumps and FDCs was possible.

The damage to sprinkler riser B was significant and could not be bypassed by closing one or more isolation valves. Considerable efforts would have been required to reinstate service to riser B.

The collapse of WTC 2 damaged the sub-grade sprinkler and standpipe loops and portions of the water distribution system in the surrounding area. It is also possible that vibration and pressure waves caused additional damage to the systems in WTC 1.

The collapse of WTC 1 caused extensive damage to the below grade water distribution system for the WTC complex. It was reported that burning debris from the collapse of WTC 1 caused multiple fires in WTC 7 (Smith 2002). WTC 7 burned for nearly 7 h before collapse (Smith 2002). Although the Task 2 and Task 4 analyses demonstrated that the sprinkler systems in WTC 7 were robust, multiple fires were reported in the building, and several areas of the building that contained electrical transformers, generators, fuel day tanks, and pressurized fuel piping were either not protected by automatic sprinklers or sprinklers in those areas were not designed to control such hazards.

Limited documentation was available regarding the performance of the suppression systems in WTC 7. However, even though the installed sprinkler and riser/standpipe systems, as well as the water supplies, were robust, multiple factors led to failure of the suppression systems and the eventual collapse of WTC 7. These factors included the following:

- Multiple fires occurred on different floors as a result of burning debris from the collapse of WTC 1. Many of these fires extended beyond the sprinkler system design areas and involved most of the floor areas.
- The stored water supply on the 47th floor of WTC 7 would have provided, at most, 20 to 30 min of supply to the sprinkler systems.
- The inability of the fire department to supplement the water supply for the upper floors significantly reduced the performance of the sprinkler systems.
- The sprinkler systems were not designed to protect a combustible liquids hazard.

Chapter 10
SUMMARY AND LIMITATIONS

10.1 SUMMARY

The following is a summary of this report. Descriptions of the fire protection systems were based on extensive review of original design drawings and specifications, operations and maintenance manuals, and other related documents maintained by The Port Authority of New York and New Jersey (PANYNJ). Limited factual information or eyewitness accounts were found regarding the performance of the fire suppression systems on September 11, 2001. Therefore, estimates of the damage to the fire suppression systems and the effects on operability were largely based on review of structural damage impact estimates and available investigative reports. The use of anecdotal input or “hearsay” information was generally avoided unless such information was later corroborated by an independent source.

10.1.1 Scope

The scope of this effort included investigation of the suppression features in World Trade Center (WTC) 1, 2, and 7. This effort focused on (1) documentation of the installed fire suppression features, and (2) examination of the expected performance of the suppression features under a range of fire incident scenarios, including the incidents that occurred on September 11, 2001. Five tasks were performed as part of this work, including the following:

- Task 1: Documentation of the design and installation of the fire sprinkler, standpipe, and pre-connected hose systems, and comparison of the designs to applicable codes and standards requirements

- Task 2: Documentation of the design and capacity of the water supply to the suppression systems, including provisions for redundancy

- Task 3: Identification and documentation of the differences in the design of the water supply, fire sprinkler systems, standpipe systems and pre-connected hoses among WTC 1, 2, and 7

- Task 4: Documentation of the normal operation and effect of fully functional fire sprinkler, standpipe and pre-connected hose systems for fire control

- Task 5: Documentation of the performance of the sprinklers, standpipes, and pre-connected hoses on September 11, 2001, in WTC 1, 2, and 7

10.1.2 Applicable Codes/Standards

The WTC was constructed and maintained under the jurisdiction of PANYNJ. Although PANYNJ was not subject to the provisions of the Building Code of the City of New York (BCNYC), the PANYNJ voluntarily adopted the provisions within the BCNYC for the design and construction of WTC 1, 2, and 7. In addition, certain reference standards (RS) identified in the BCNYC were adopted. The reference

September 11, 2001. Initial damage to the standpipe and sprinkler systems in WTC 1 as a result of the aircraft strike was primarily on floors 94 through 96. In WTC 2 the initial damage to the suppression systems was on floors 78 through 81. Based on review of the damage estimates, photographic and video records, and documented eyewitness reports, the adverse effects of the impacts on the operability of the suppression systems were extensive.

The collapse of WTC 1 caused extensive damage to the below grade water distribution system for the WTC complex. Although the primary water supplies to WTC 7 apparently survived the collapse of WTC 1 and WTC 2, it was reported that burning debris from the collapse of WTC 1 caused multiple fires in WTC 7. Some of these fires, identified through review of photographic and video records and eyewitness accounts, started in areas of WTC 7 that contained electrical transformers, fuel day tanks, and pressurized fuel piping. These areas were either not protected by automatic sprinklers or the sprinklers in these areas were not designed to control such hazards.

Primary and backup power was provided in all three buildings, but the absence of remote redundancy of the power transmission lines to the emergency fire pumps would have affected the operability of the sprinkler and standpipe systems once primary power was lost.

Based on the available information it appears that several factors could have led to the extensive fire spread and eventual collapse of WTC 7. Multiple fires occurred on different floors of WTC 7, started by burning debris from WTC 1. Several of these fires spread beyond the design areas for the sprinkler system(s) and involved most of the floor areas. The stored water in WTC 7 would have provided, at most, 20 to 30 min of supply to the sprinkler systems. The inability of The Fire Department of New York (FDNY) to supplement the water supply for the upper floors or provide the primary supply to the lower floors dramatically reduced the potential effectiveness of the sprinkler systems, assuming the systems were not critically damaged by the collapse of WTC 1. And finally, the sprinkler systems were not designed to protect combustible liquid hazards.

Water Supply

The primary source of water for the WTC complex was the New York City water distribution system. A complex grid of 20 in. and 12 in. mains surrounded the WTC complex, forming a very robust water supply with an average steady state system-wide pressure of 50 psi. The WTC complex was provided with two separate supply connections at Vesey and Liberty Streets with isolation valves to permit independent operation. WTC 7 was provided with two connections from the 12 in. main under Washington Street, about 12 ft apart.

The water supply components in WTC 1, 2, and 7 included water storage tanks, fire pumps, and fire department connections (FDS). The primary water supplies for the automatic sprinkler and standpipe systems for the most part consisted of gravity tanks and booster pumps, with secondary or back up supplies directly from the underground water distribution system.

Three separate 5,000 gal water storage tanks were provided for the high and mid-level zone sprinkler and standpipe systems at the tops of WTC 1 and WTC 2. A single 5,000 gal tank was provided on the 41st floor of each tower. The tanks were interconnected through a 4 in. main. Each tank was provided with a separate refill connection. As supplements to the gravity tanks, the maintenance and engineering staff supplied water to the fire suppression systems from the city water distribution system using manually operated fire pumps. The fire department could also supply water through the fire department connections located at the street level throughout the complex.

The systems in WTC 7 included one automatic and two manually operated water supplies. The combined systems were provided with a single automatic fire pump for the low zone. The high and mid-level zones were supplied from two water storage tanks located on the 47th floor. The high zone also included a booster pump. A single 750 gpm fire pump supplied the secondary water. The FDNY could also supply water to the systems using the fire department connections. The water supply tanks located in the upper water supply zone of WTC 7 did not service the lower floors. Rather, the primary and secondary water supply for floors 1 through 20 were the two parallel service connections to the 12 in. main under Washington Street and associated FDCs.

Standpipe/Riser Systems

Standpipes supplied the pre-connected hoses in WTC 1 and WTC 2. The sprinkler systems were supplied separately by risers. In WTC 7, the standpipes and risers were combined into a single system.

The standpipe systems in WTC 1 and WTC 2 were interconnected at the top of each zone with check valves that prevented downward flow in two of the three risers. This arrangement permitted upward flow through all three risers while operating in the secondary supply modes using the manual fire pumps or the fire department connections. The standpipe systems in WTC 7 did not have a similar interconnection at the top of the standpipe zones.

The standpipe/pre-connected hose systems in WTC 1 and WTC 2 were supplied by storage tanks and the underground loop. The hose stations were Class III hose stations with 125 ft of hose and a nozzle for use by the fire brigade and/or the FDNY. Operating pressures were maintained by manually operated fire pumps with primary power and backup power generators located on the B6 level. Fire department connections were available to supplement the flow and pressure for the standpipe systems.

The standpipe/riser systems in all three buildings were installed in stairwells with hose stations at each floor as well as at other locations on specific floors.

No information was found to indicate if the dependence of the low zone standpipe system arrangement in WTC 7 on the two feeders located only 12 ft apart under Washington Street had a significant adverse impact on the performance of the sprinkler and standpipe systems in WTC 7 on September 11, 2001. The standpipe system in WTC 7 was reportedly used to supply water to fight other nearby fires. This, along with any damage to the Washington Street supply mains due to the collapse of WTC 1 and WTC 2, would have significantly reduced the effectiveness of the sprinkler and standpipe systems to the lower floors of WTC 7 h before WTC 7 collapsed.

While it is difficult to assess the performance capabilities of the standpipe/pre-connected hoses, hydraulic calculations indicated that the size of the standpipes and the capacity and number of fire pumps were adequate to meet the requirements for pressure and flow contained in the BCYNC. However, the booster pump on the 46th floor of WTC 1 and WTC 2 was undersized, and could not provide the minimum pressure and flow requirements of NFPA 14.

In WTC 1 and WTC 2, if the maintenance or engineering staff failed to operate the manual fire pumps, or the fire department was delayed in supplementing the water supply through one of the fire department connections, water available for the sprinkler systems and manual firefighting in the buildings would be limited to the stored water tanks**.** While this arrangement was consistent with the BCNYC at the time of installation, more recent editions of NFPA 14 require automatic or semi-automatic operation of fire pumps. The use of automatic fire pumps would have also been consistent with "best practices" at the time of installation.

Manual fire pumps and booster pumps maintained the systems operating pressures. Backup power to the pumps was supplied by emergency generators located on several floors of WTC 7.

The installation of the supply piping from the storage tanks on the 110th floor in WTC 1 and WTC 2 resulted in restricted flow capacity to several floors in the mid-level water supply zones in both buildings. While the flow capacity was sufficient to supply the sprinkler and standpipe systems, the installation was not consistent with engineering "best practices" at the time of the installation.

The standpipe/pre-connected hose systems were consistent with the applicable requirements in the BCNYC. They were not consistent with the flow rates and durations required in NFPA 14. These differences would manifest themselves if the standpipe systems were used simultaneously at multiple locations throughout the building (i.e., very high demand) and the fire department failed to use the FDCs to back up the water supply. No information was found to indicate that the standpipes were in excessive use on September 11.

Sprinkler Systems

Wet pipe automatic sprinkler systems were installed throughout WTC 1 and WTC 2, with exception of a few areas, including the mechanical spaces on the 108th through the 110th floors and the electrical rooms throughout the buildings. In these areas, either sprinkler systems were not required under the BCNYC or the spaces were provided with alternative special suppression systems. The systems were "control" type sprinkler systems and were phased in from 1983 to early 2001 (Note that some systems were installed in the sub-grade levels when the buildings were built, and others were installed around 1976 to protect core areas, maintenance areas, and select tenant spaces of the buildings.) The sprinkler systems in WTC 1 and WTC 2 were supplied by vertical risers located in the stairwells. In WTC 7, the risers were located in janitor's closets and wet columns supplied from gravity fed storage tanks above each of four supply zones. The supply to all three buildings was supplemented by the underground water supply main that looped the WTC complex.

In WTC 7 wet-pipe, "control" type automatic sprinkler systems were installed in most areas and were supplied by a combined standpipe/riser system. Certain areas were not protected by sprinklers, including electrical equipment areas (switchgear, networking, and switchboard rooms), generator rooms, and bathrooms. Sprinklers were not installed on most of the 5th floor nor on the 7th floor, which housed the OEM generators and fuel day tanks. A dry-pipe sprinkler system was installed to protect the fuel storage tanks on the 1st floor that supplied the high pressure fuel lines that serviced the emergency generators.

WTC 7 contained fuel oil powered generators and day tanks located on the fifth, seventh, eighth, and ninth floors. The suppression protection varied for each component of the fuel oil supply system. A dry-pipe sprinkler system was provided for protection of two 12,000 gal fuel oil tanks located under the loading berths on the south side of the building, adjacent to Vesey Street. An Inergen suppression system was provided for the 6,000 gal fuel oil storage tank room located on the mezzanine, eight feet above the elevator storage area on the first floor. The area below this room was protected by a wet pipe sprinkler system. The fuel pumps were located on the 1st floor near the loading dock and were protected by a dry-pipe sprinkler system. The generator and day tank enclosures were not protected by automatic sprinklers. These omissions of sprinkler coverage were consistent with the BCNYC.

The sprinkler systems installed in WTC 1, 2, and 7 exceeded the required performance levels under the BCNYC and NFPA 13 for protection of high-rise office buildings by considerable margins. Based on historical incident data, systems having such characteristics would be expected to extinguish, rather than control, most fires that occur in these types of buildings.

The installed sprinkler systems in WTC 1, 2, and 7 had the ability to simultaneously control or suppress multiple fires of varying sizes under “normally expected” operating conditions. The fires could have occurred at different locations on a single floor or on multiple floors. Water flow density and pressure associated with the installed systems had the capacity to control a single fire on the order of two to three times the sprinkler system design area, depending on the location in the building, and, the systems would be expected to concurrently control at least four to six fires similar in area to that protected by a four-sprinkler array (i.e., 750 ft^2). While these systems were considered very robust, a coverage area of two or three times the design area of the sprinkler system constituted less than 15 percent of the floor area of a typical single floor in these buildings.

The intensity and extent of the initial fires in WTC 1 and WTC 2 on September 11, 2001, were considerably greater than two to three times the specified design areas and involved multiple floors. While there was no way to confirm the extent of the initial fires, it is likely that had the systems remained operable, a large number of sprinklers would have been opened on multiple floors. Once the number of open sprinklers exceeded an area equivalent to two or three times the design areas, the system’s ability to control the fire would have been reduced and the duration of the primary water supply rapidly degraded. Furthermore, the likely damage to the suppression systems in WTC 1 and WTC 2 due to the aircraft impacts and the subsequent failures of structural components virtually ensured that significant parts of the systems were rendered inoperable, regardless of the extent of the initial fires.

Although consistent with the BCNYC, the typical floor level sprinkler system was installed with only one connection to the infrastructure riser. This arrangement provided a single point of failure of the water supply to the floor level sprinklers.

Even if the sprinkler systems had been designed to protect much higher hazard levels (i.e., Ordinary Group II or Extra Hazard), the magnitude of the fires experienced in these buildings and accompanying impact damage would have most likely resulted in the fires not being controlled.

10.2 LIMITATIONS

There was very little eyewitness or communications information regarding the performance of the fire suppression systems on September 11, 2001. The descriptions of the systems and their inherent operational capabilities described in this report are considered reasonably accurate. The performance of the individual suppression systems on September 11, 2001, was based on review of the incident information accumulated by NIST, analysis of the likely initial impact effects on the systems, and historical performance records for automatic sprinklers. Where possible, significant events and/or effects were determined based on information from more than one source. However, due to the fragmentation of available information regarding the events of September 11, this could not always be accomplished.

Descriptions of suppression systems, likely events or actions, and subsequent effects were based on, and/or deduced from, available information. Events or effects that were considered “likely” or “probable,” based on the accumulated information, were considered appropriate for inclusion.

Appendix A
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Appendix B
FIGURES

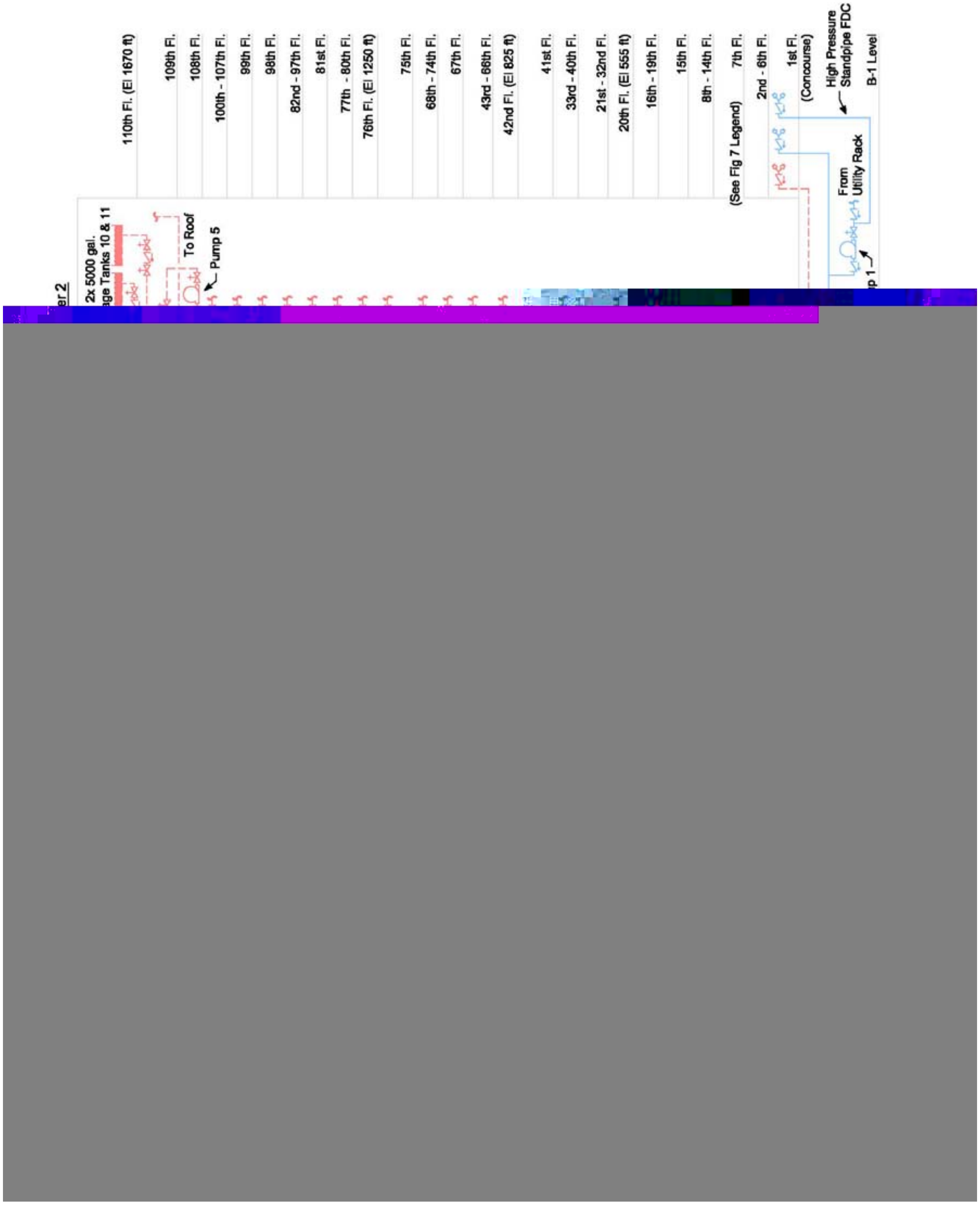

Figure B–1. Riser diagram, tower sprinkler and standpipe systems.

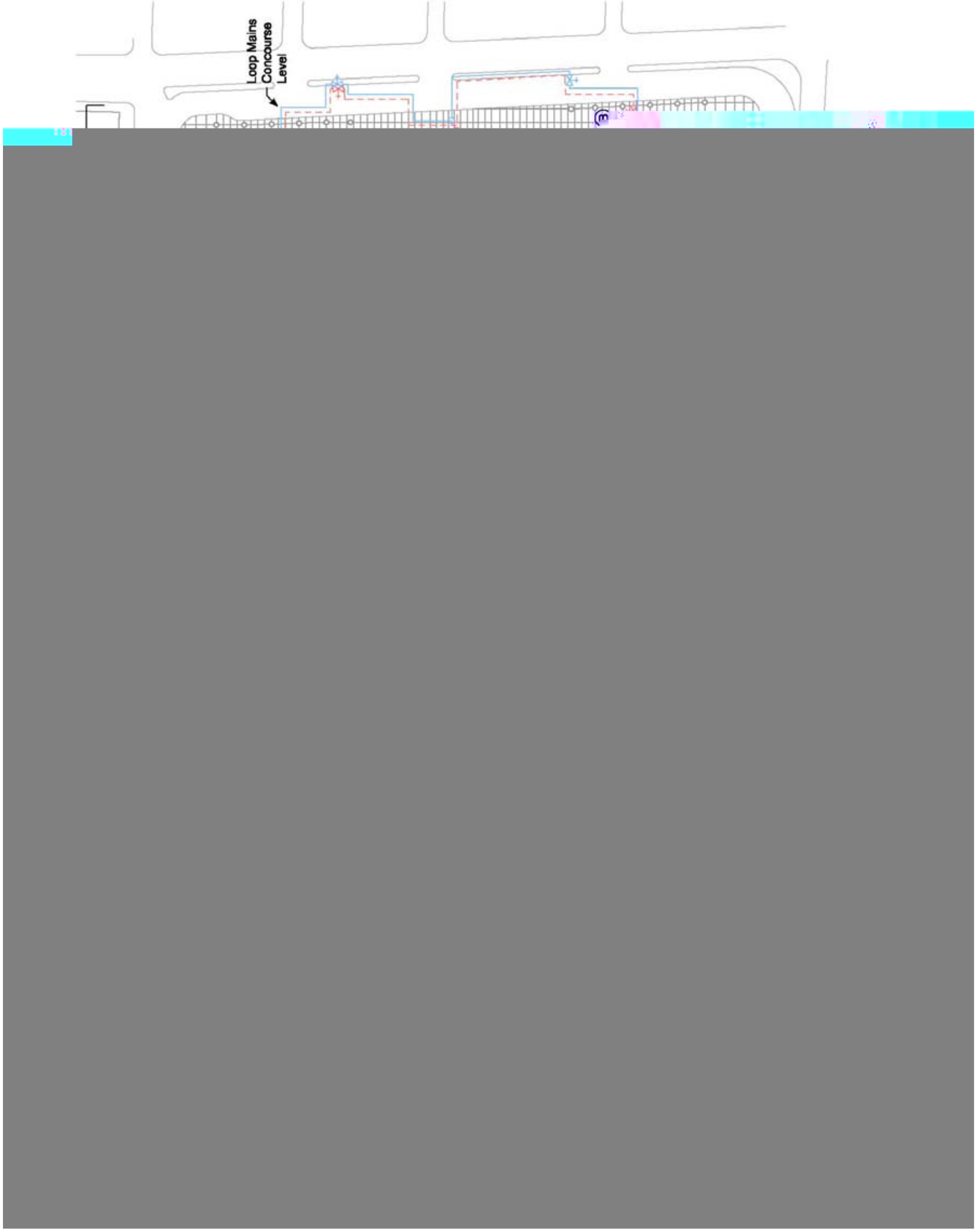

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Figure B–2. Layout of the WTC complex fire department connections.

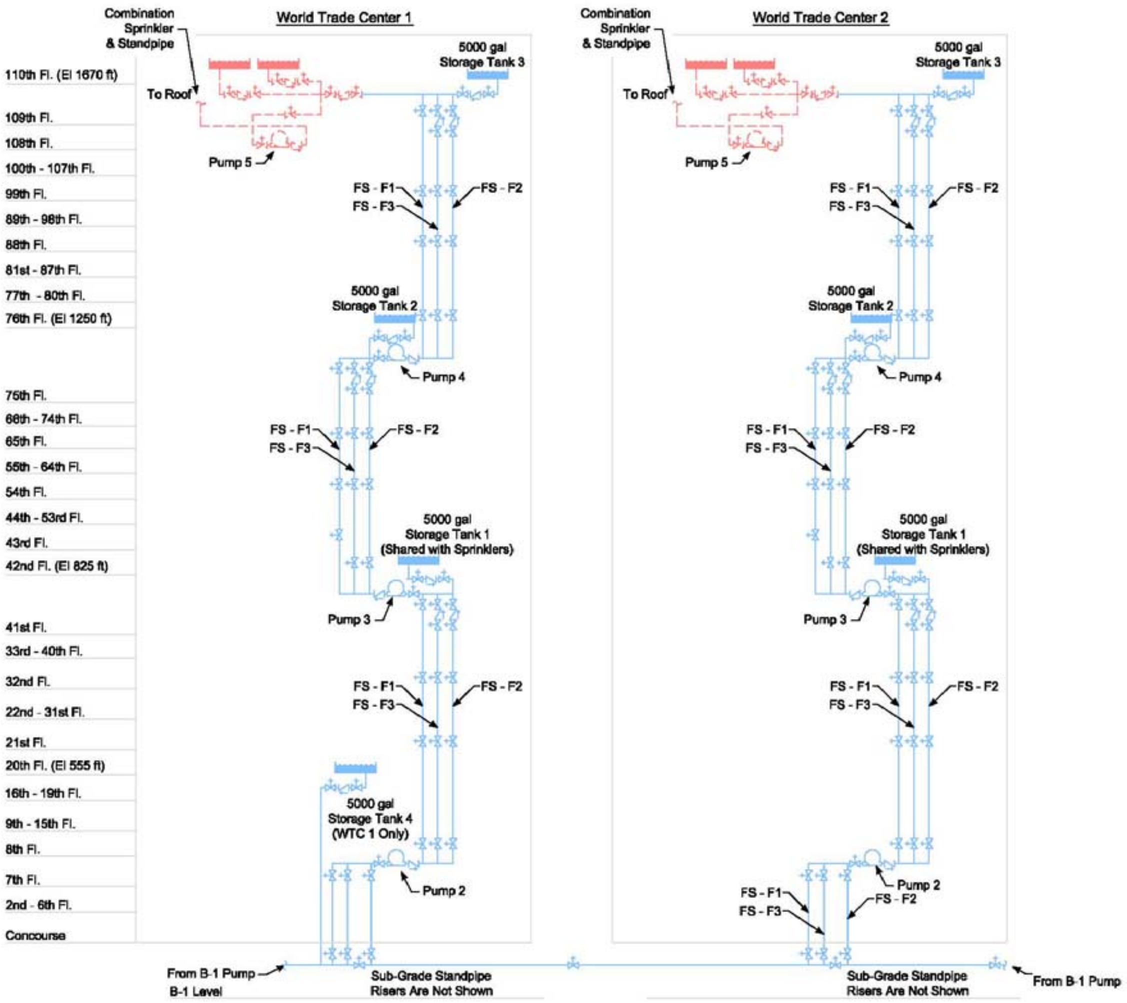

Figure B–3. Riser diagram, tower standpipe systems, WTC 1 and WTC 2.

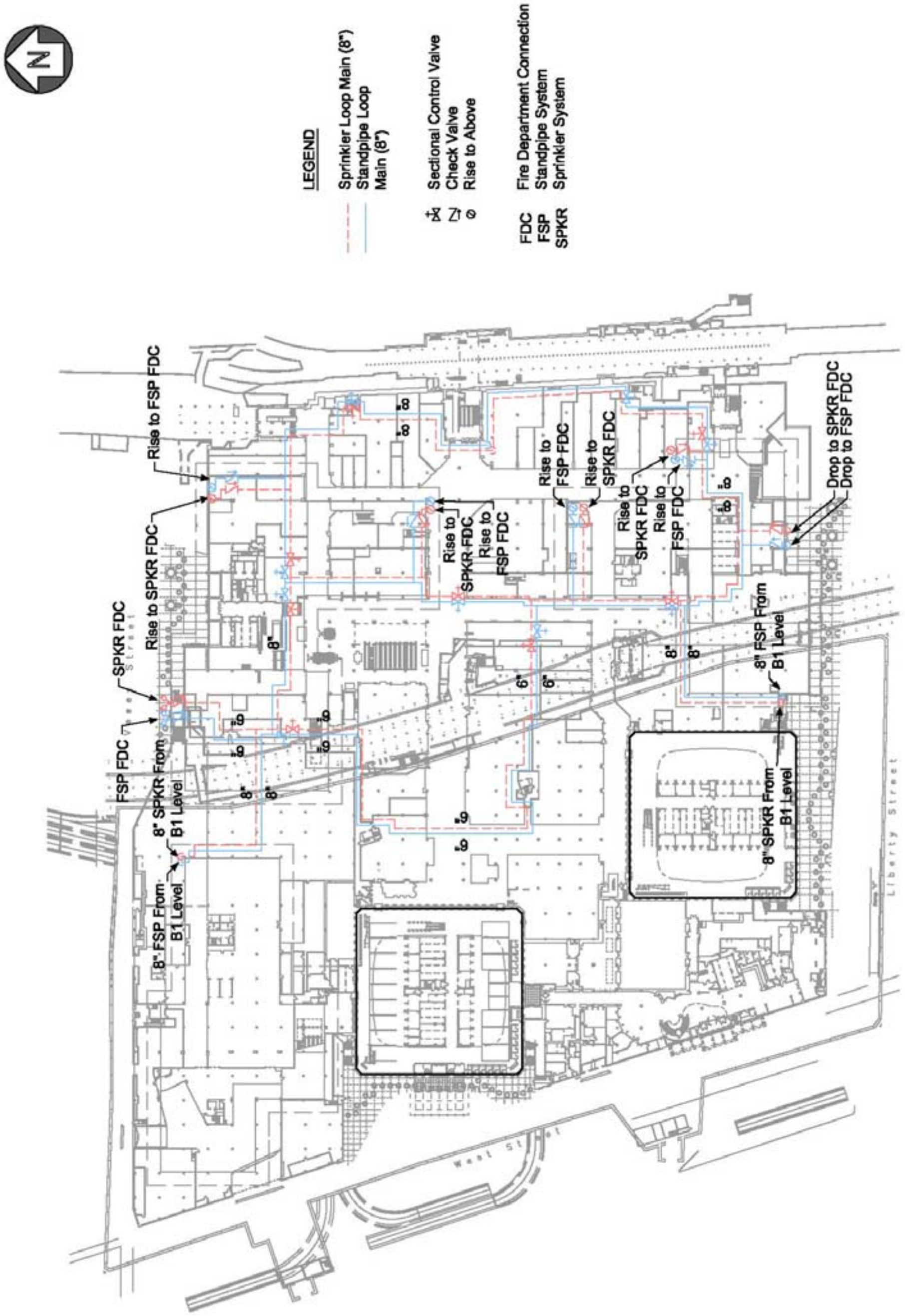

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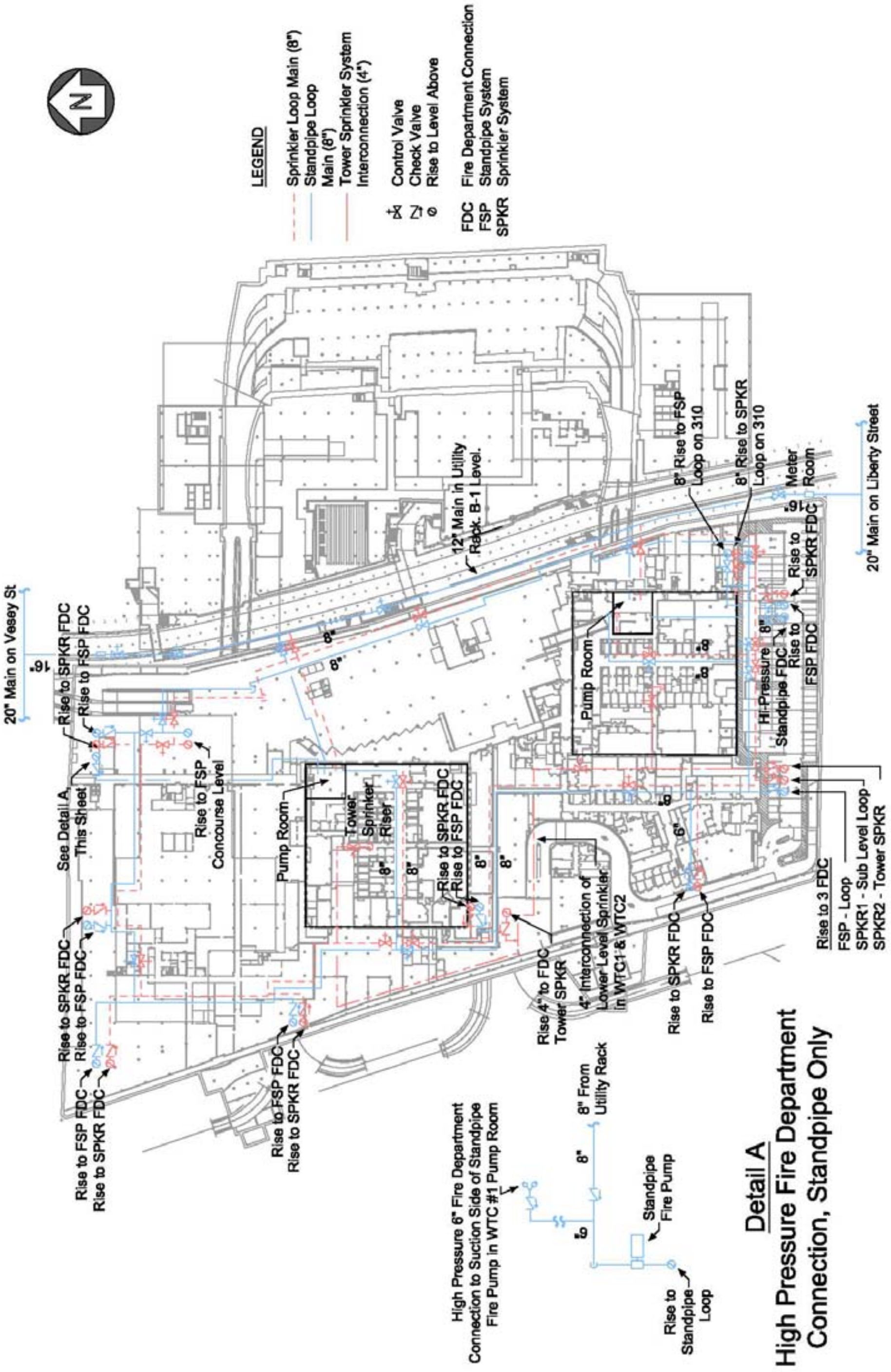
Figure B–4. Standpipe and sprinkler loops, concourse level.



Source: Reproduced with permission of The Port of Authority of New York and New Jersey.

Figure B–5. Standpipe and sprinkler loops, B1 level.

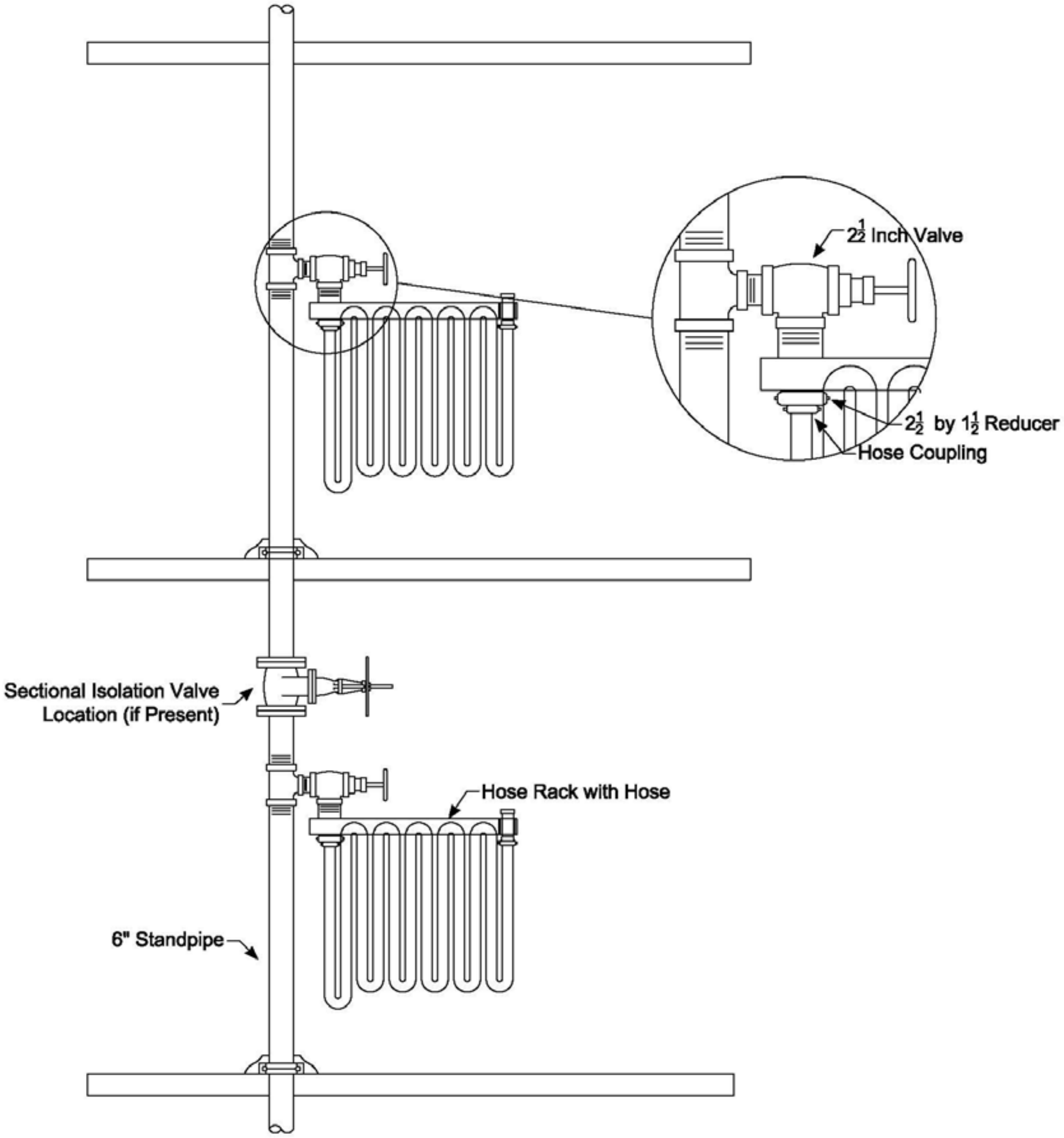
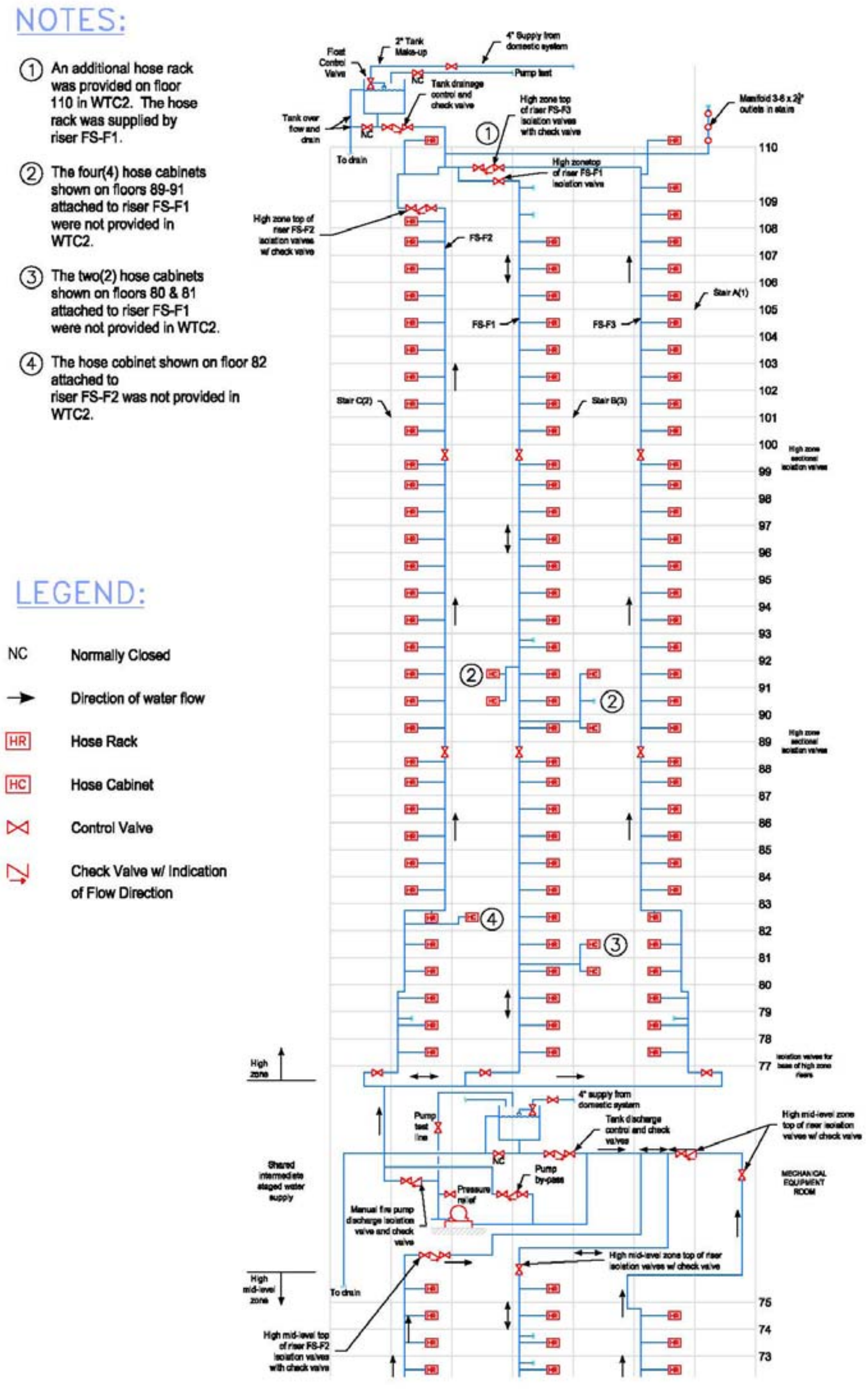


Figure B–6. Typical hose rack arrangement.



NOTES:

① An additional hose rack was provided on floor 110 in WTC2. The hose rack was supplied by riser FS-F1.

② The four(4) hose cabinets shown on floors 89-91 attached to riser FS-F1 were not provided in WTC2.

③ The two(2) hose cabinets shown on floors 80 & 81 attached to riser FS-F1 were not provided in WTC2.

④ The hose cobinet shown on floor 82 attached to riser FS-F2 was not provided in WTC2.

Figure B–7. WTC 1 high zone standpipe system and noted differences in WTC 2.

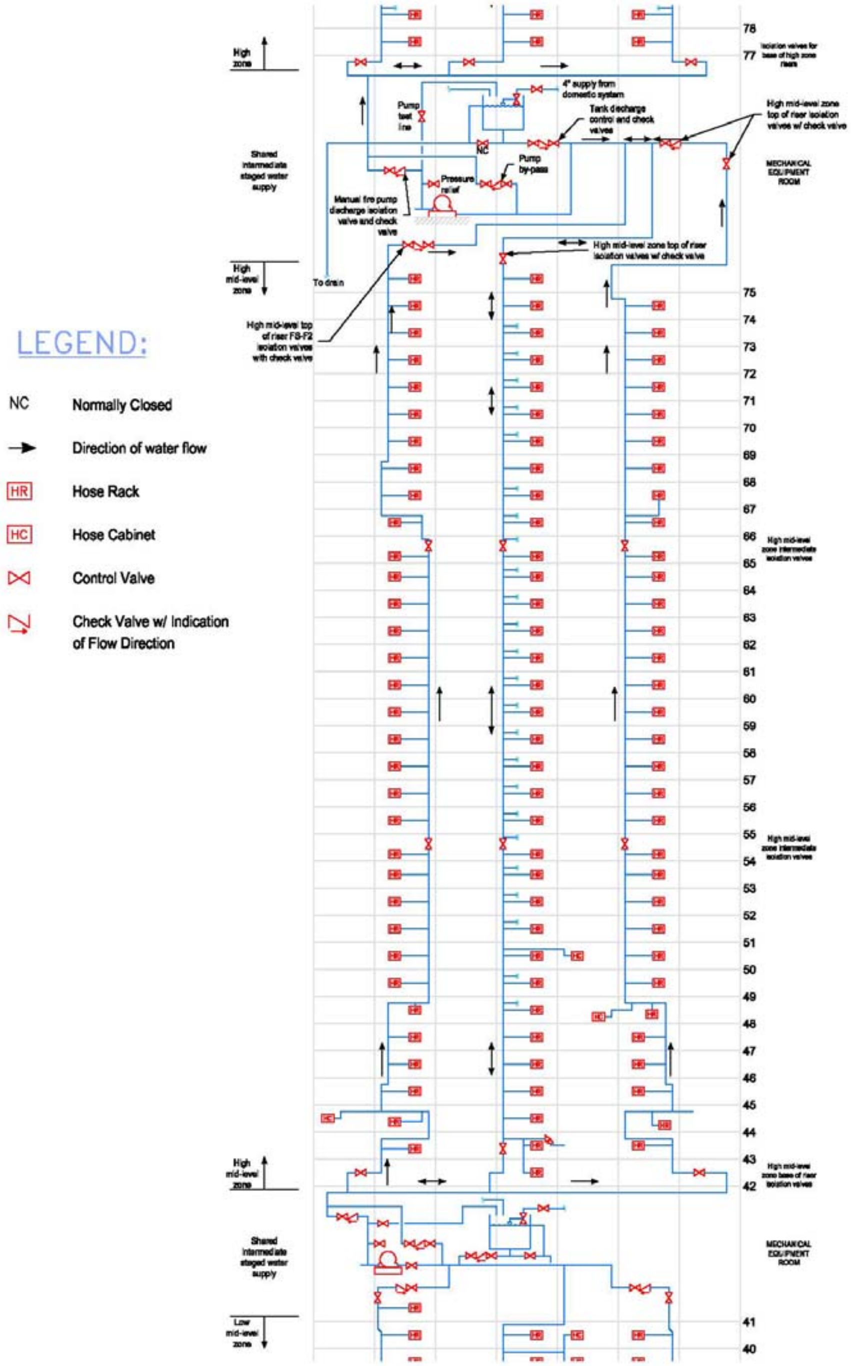
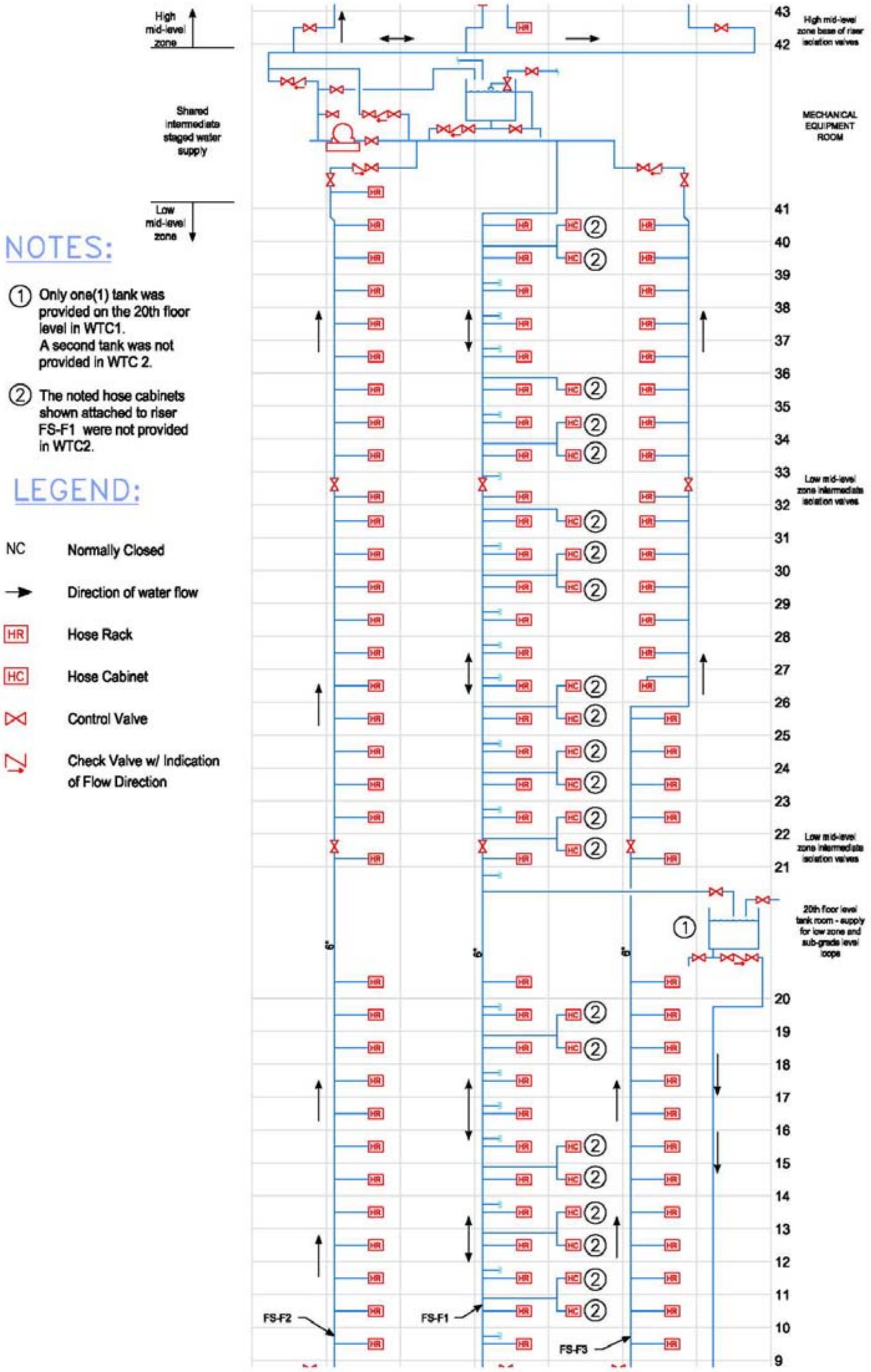


Figure B–8. WTC 1 upper mid-level zone standpipe system and noted differences in WTC 2.



NOTES:

① Only one(1) tank was provided on the 20th floor level in WTC1. A second tank was not provided in WTC 2.

② The noted hose cabinets shown attached to riser FS-F1 were not provided in WTC2.

LEGEND:

NC	Normally Closed
→	Direction of water flow
HR	Hose Rack
HC	Hose Cabinet
⋈	Control Valve
↘	Check Valve w/ Indication of Flow Direction

Figure B–9. WTC 1 lower mid-level zone standpipe system and noted differences in WTC 2.

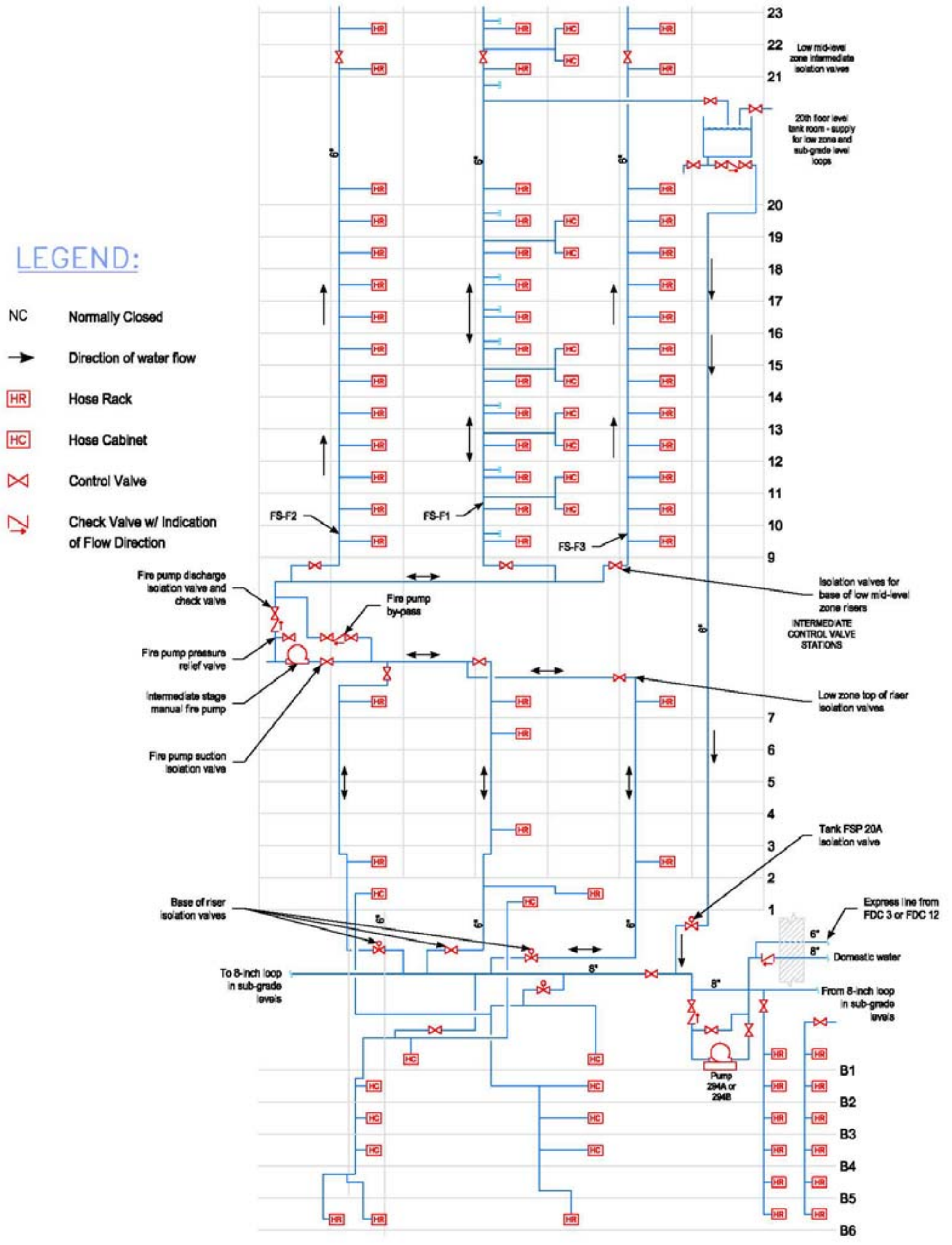


Figure B–10. WTC 1 low zone standpipe system and noted differences in WTC 2.

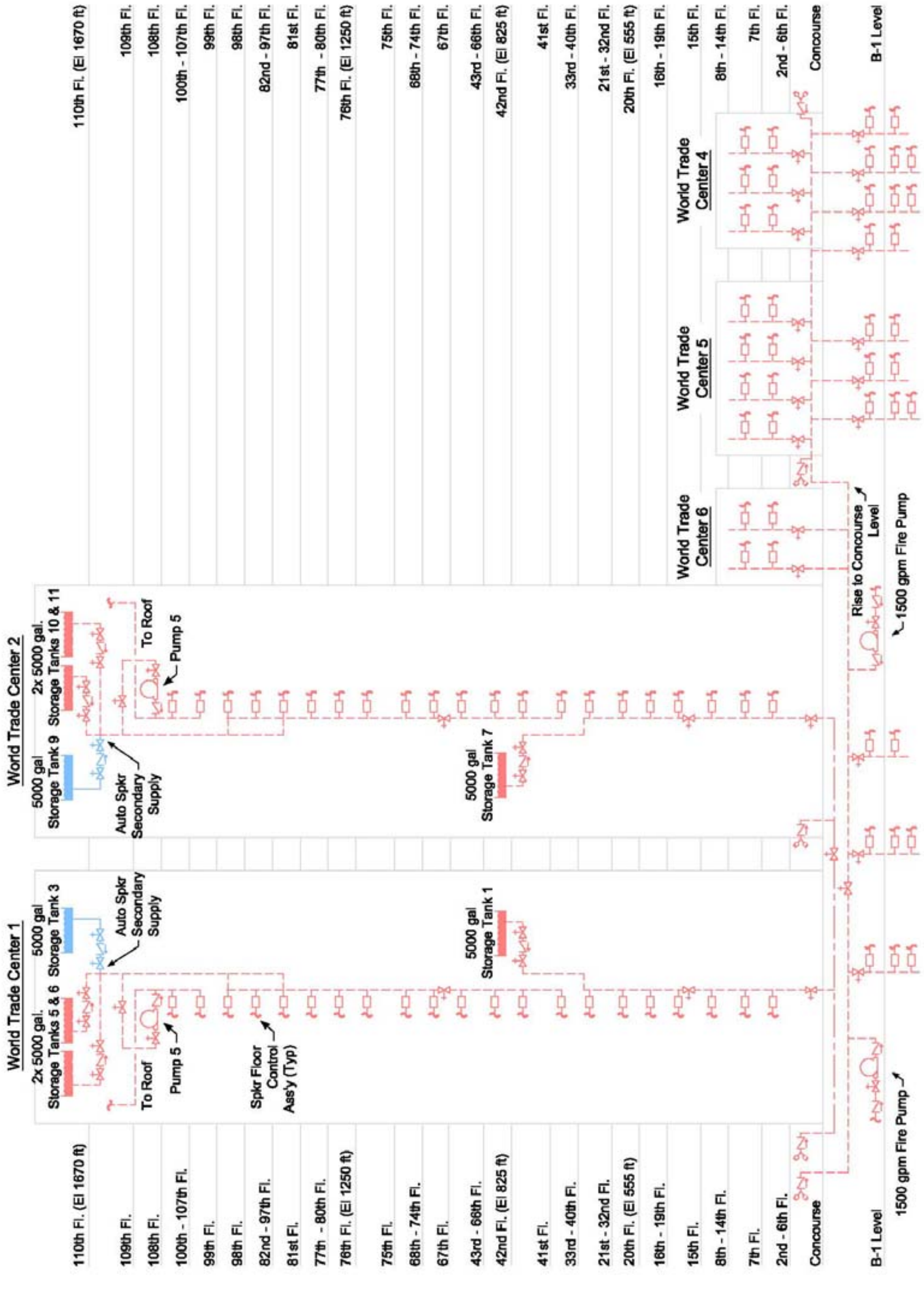


Figure B–11. Riser diagram, tower sprinkler systems, WTC 1 and WTC 2.

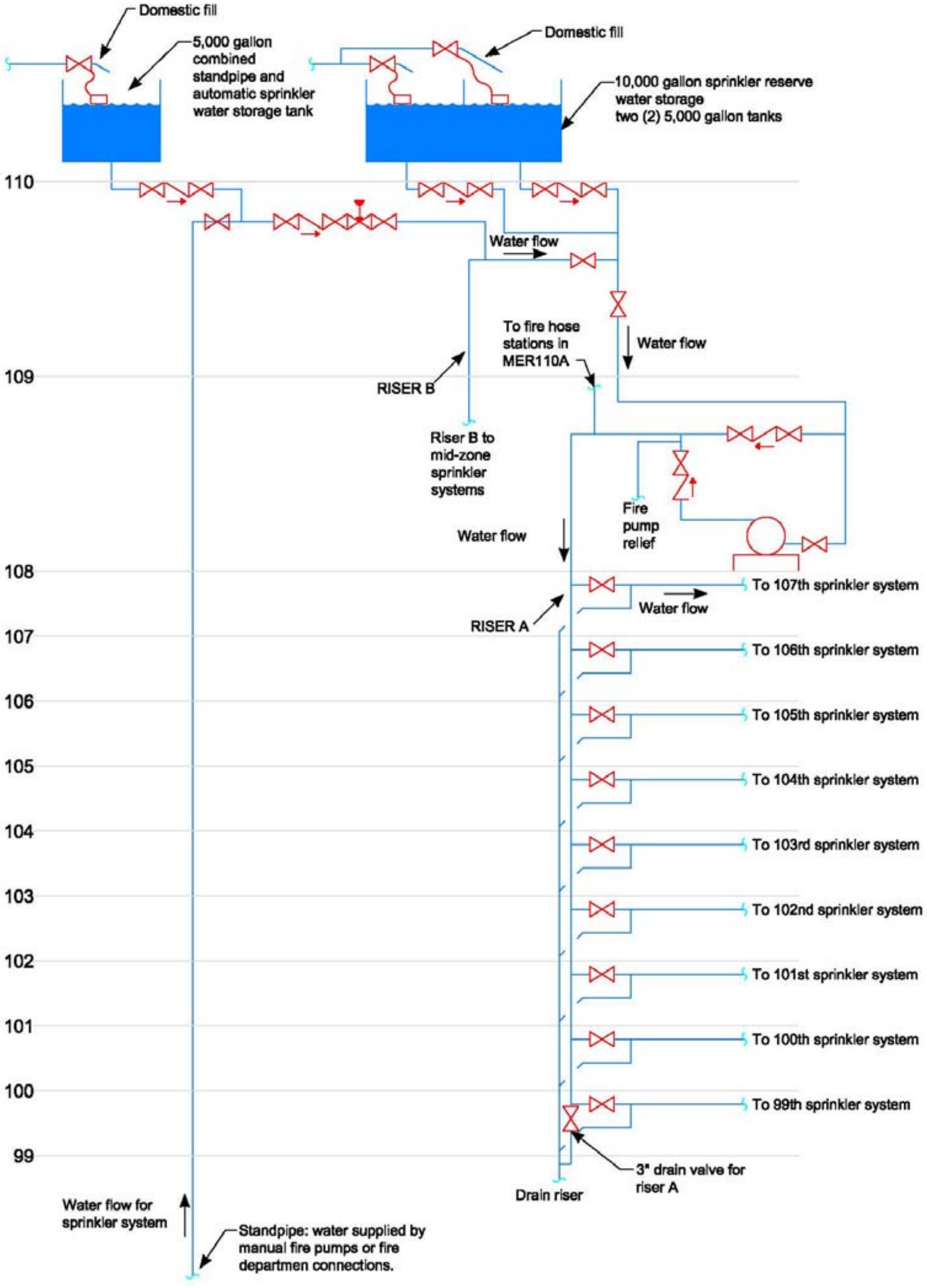


Figure B–12. High zone sprinkler systems, WTC 1 and WTC 2.

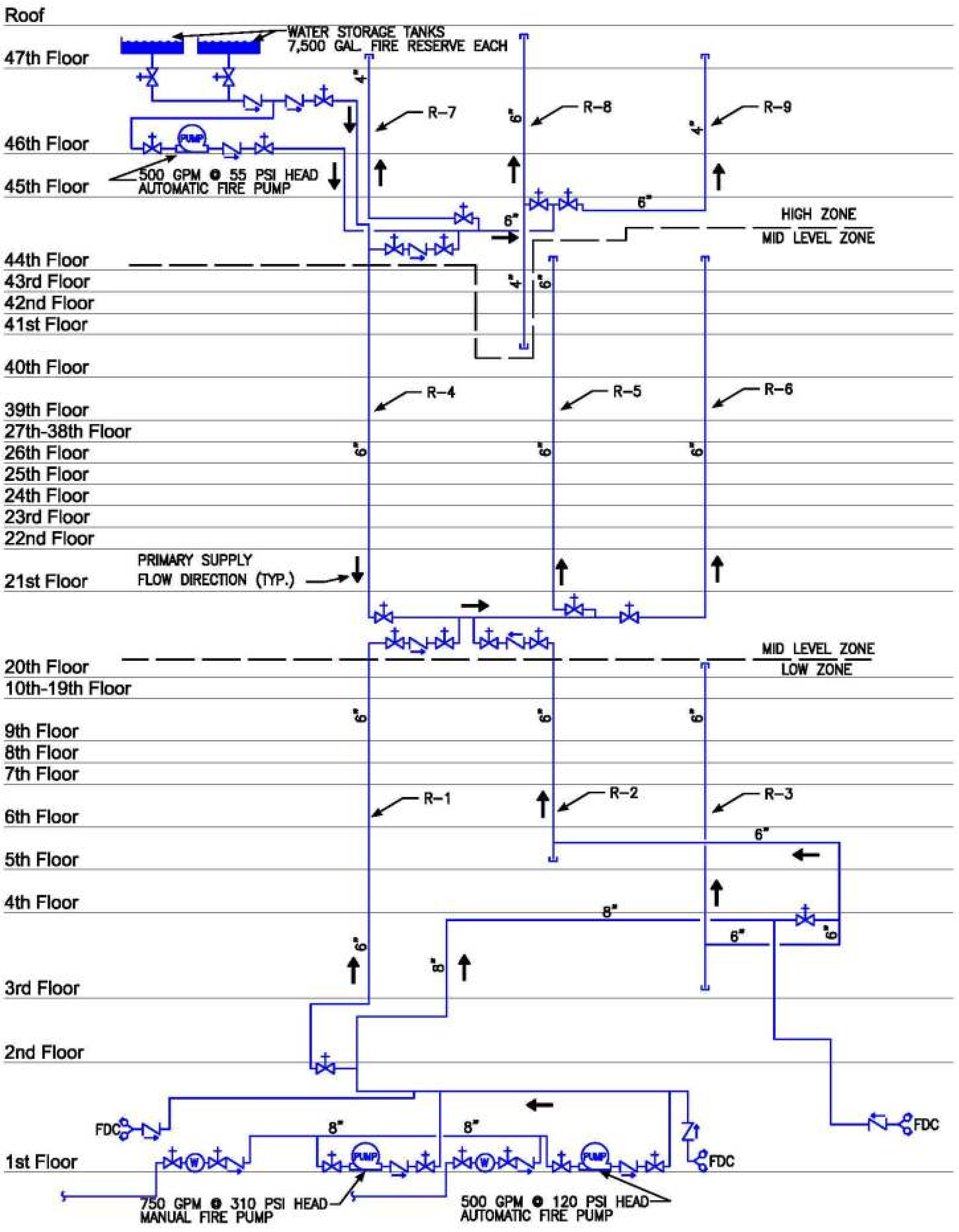


Figure B–13. Supply riser schematic, WTC 7.

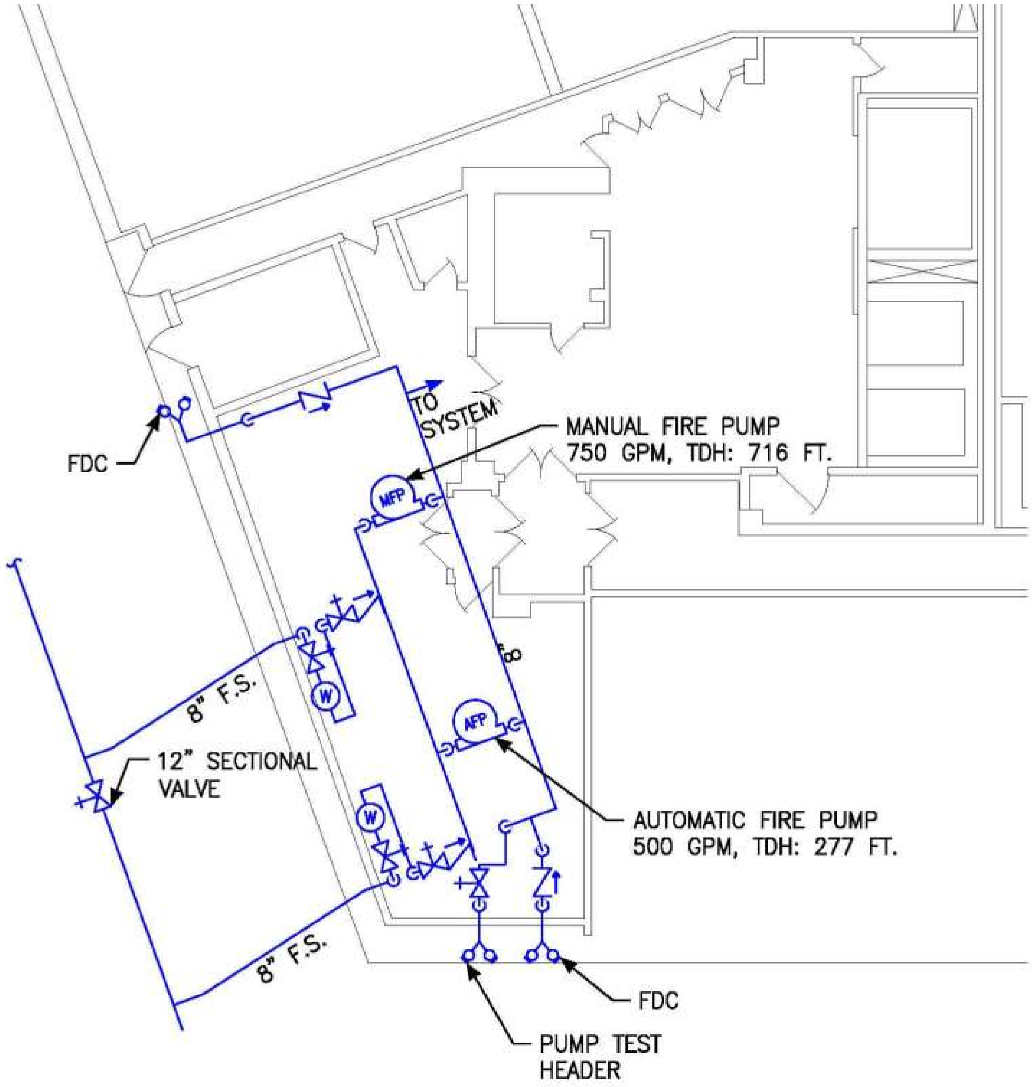


Figure B–14. First floor fire pump room, WTC 7.

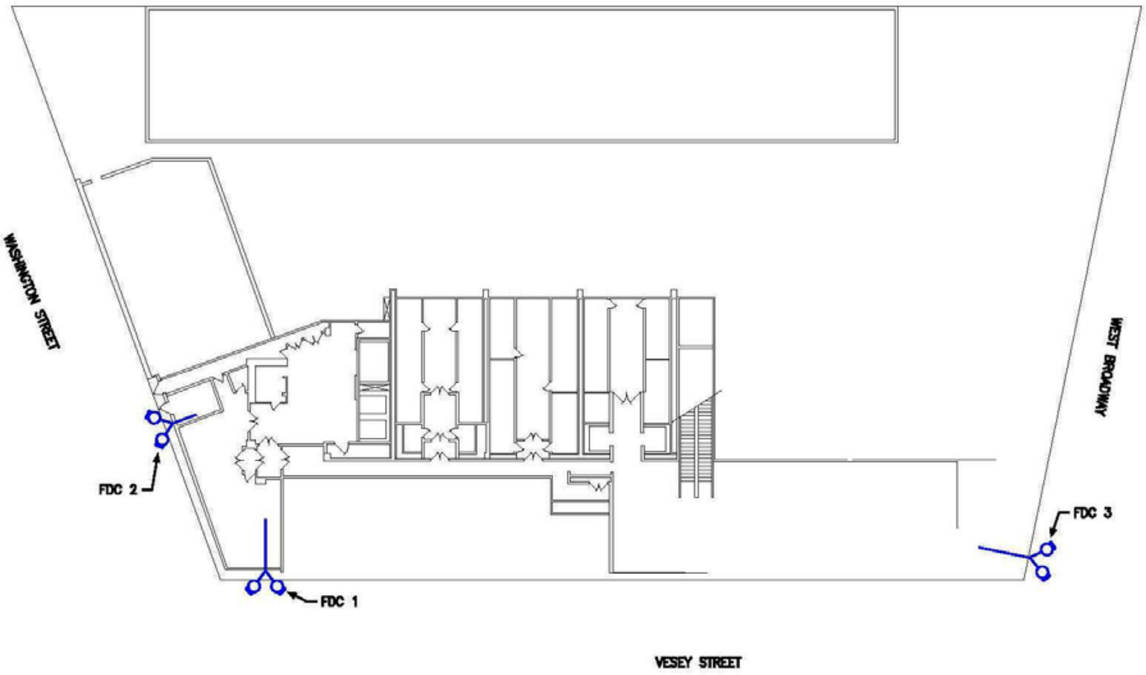


Figure B–15. Fire department connection locations, WTC 7.

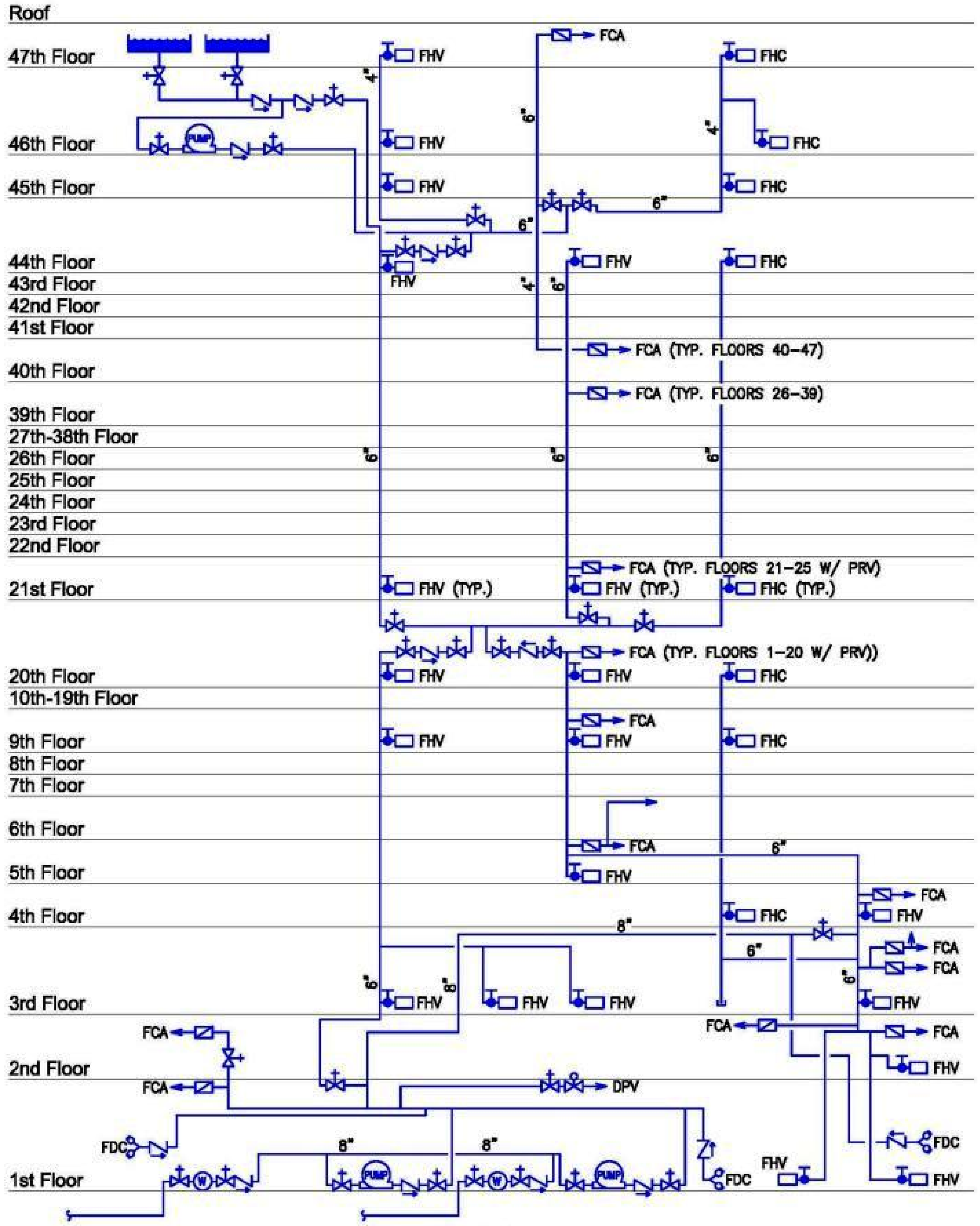
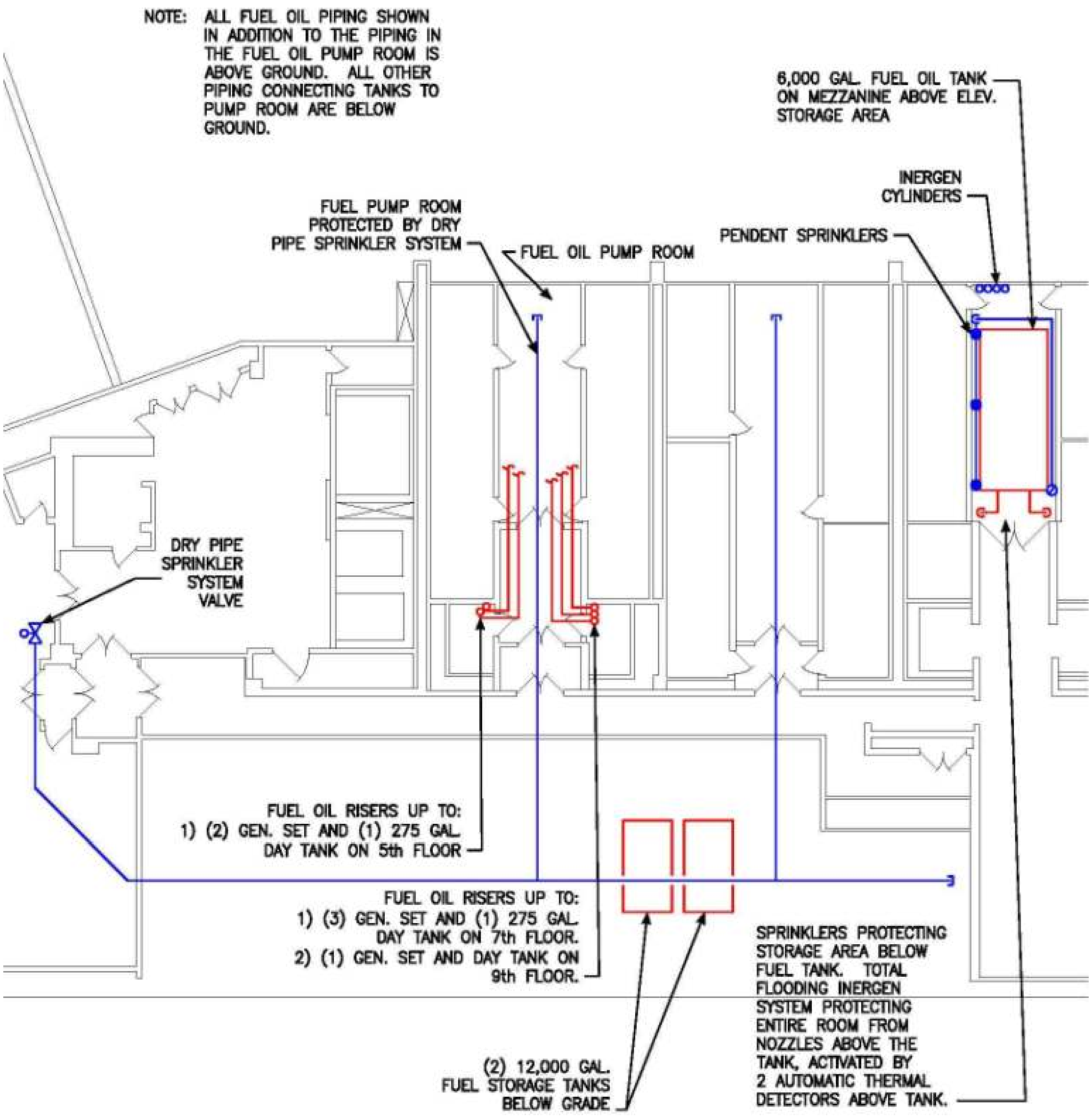
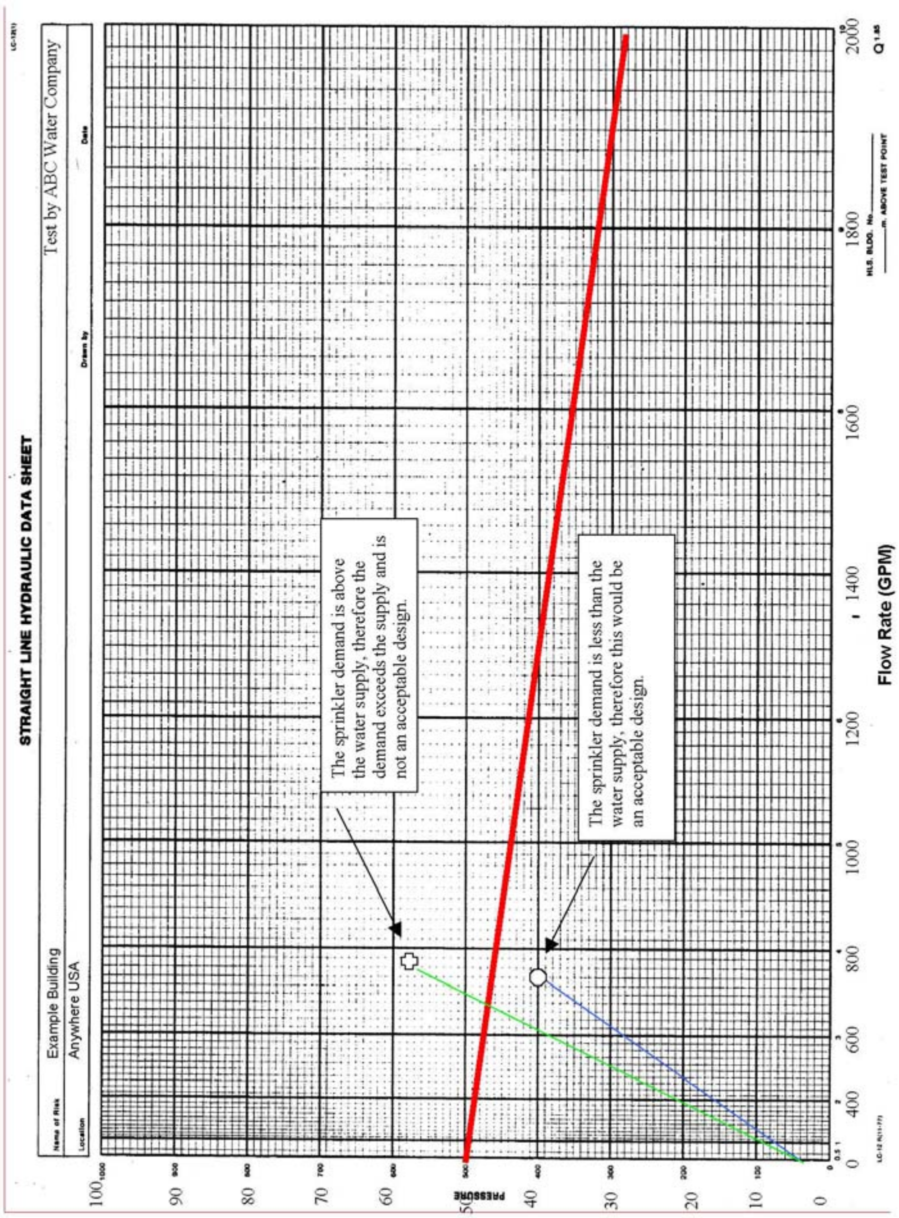


Figure B–16. Floor control valve and fire hose valve/cabinet locations, WTC 7.



Source: Reproduced with permission of Swanke et al. 1998.

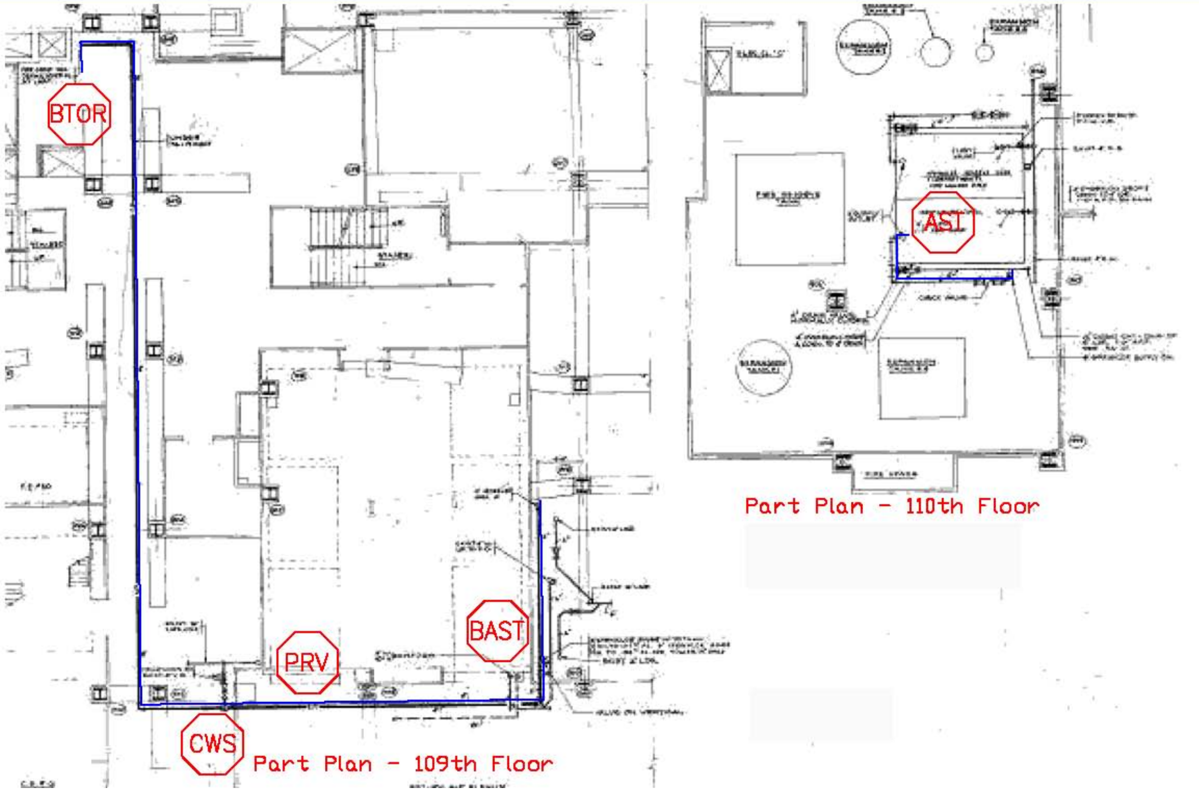
Figure B–17. Fuel oil system and suppression protection schematic, WTC 7.



The sprinkler demand is above the water supply, therefore the demand exceeds the supply and is not an acceptable design.

The sprinkler demand is less than the water supply, therefore this would be an acceptable design.

Figure B–18. Example water supply graph with pass and fail sprinkler system demands.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–19. Hydraulic node layout, 110th floor tank and supply mains, 109th floor.

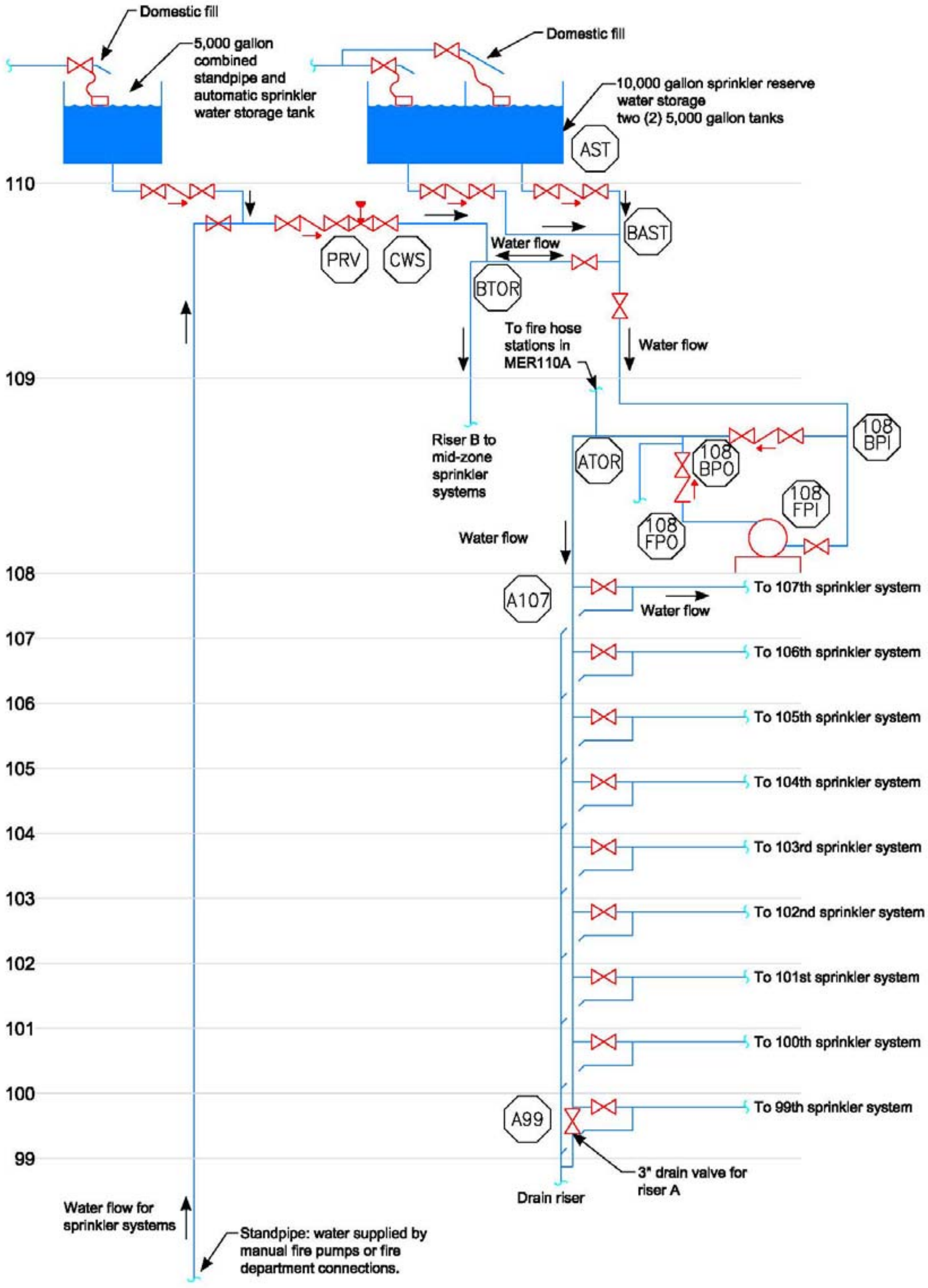
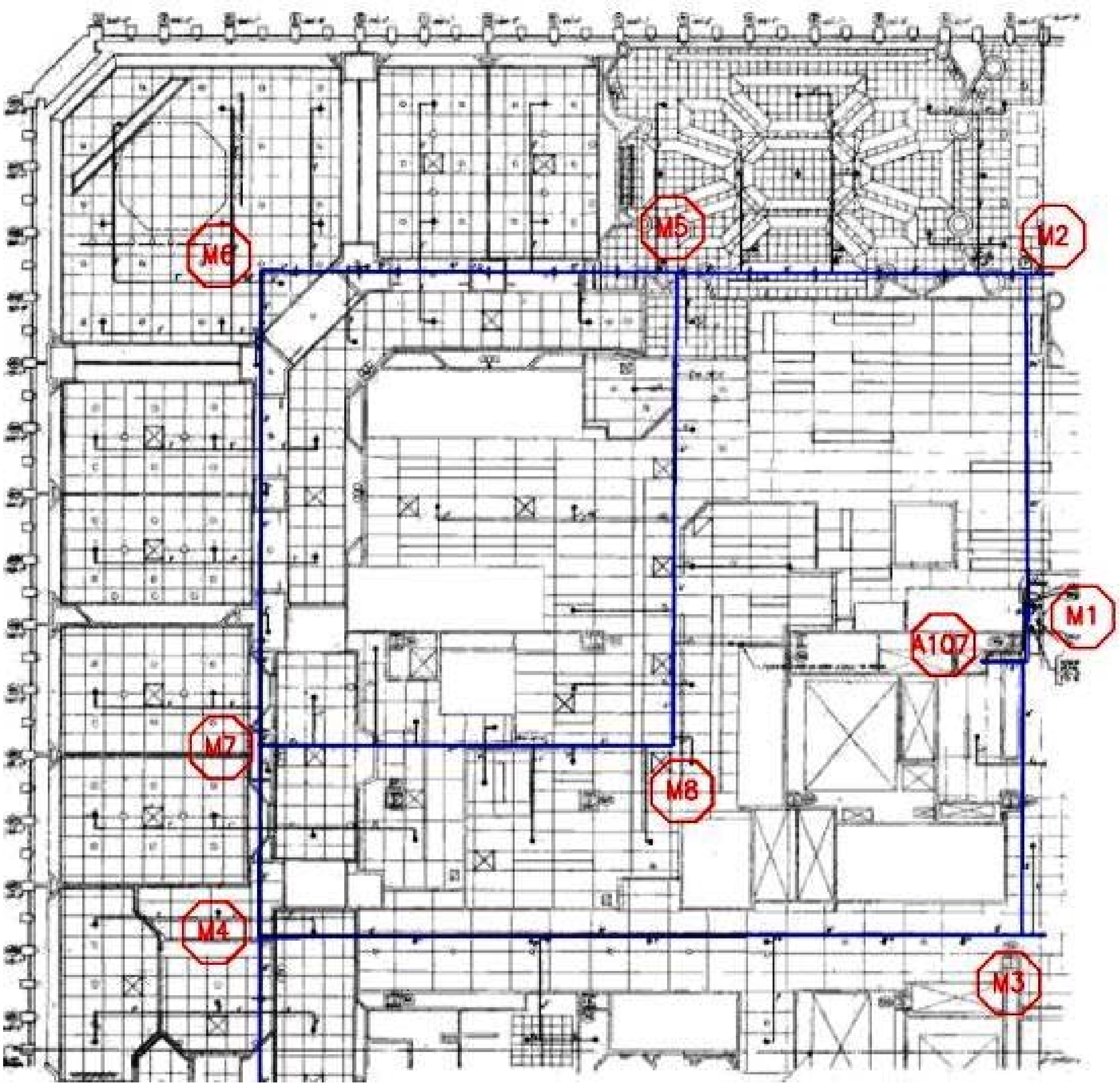
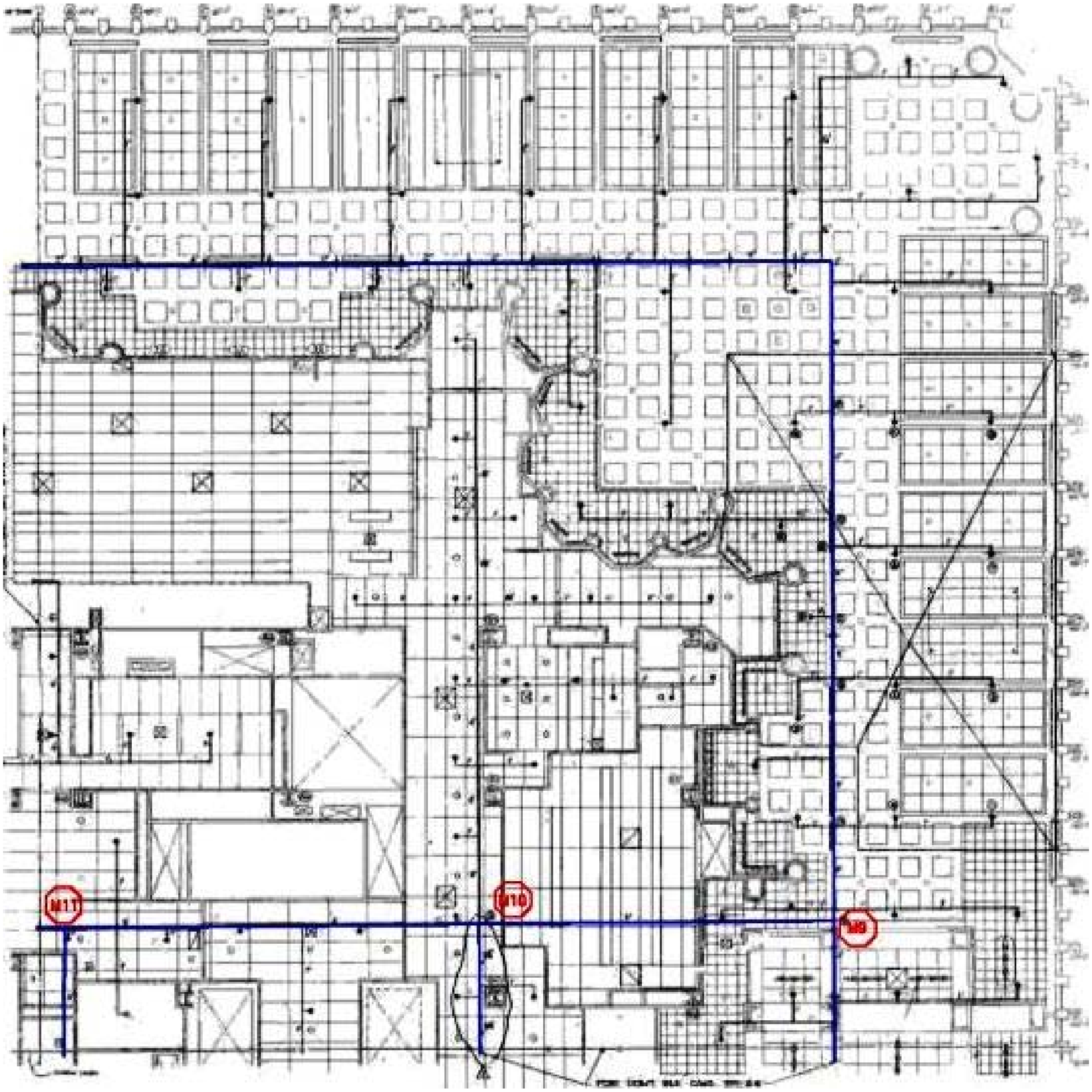


Figure B–20. Hydraulic node layout, high zone riser A.



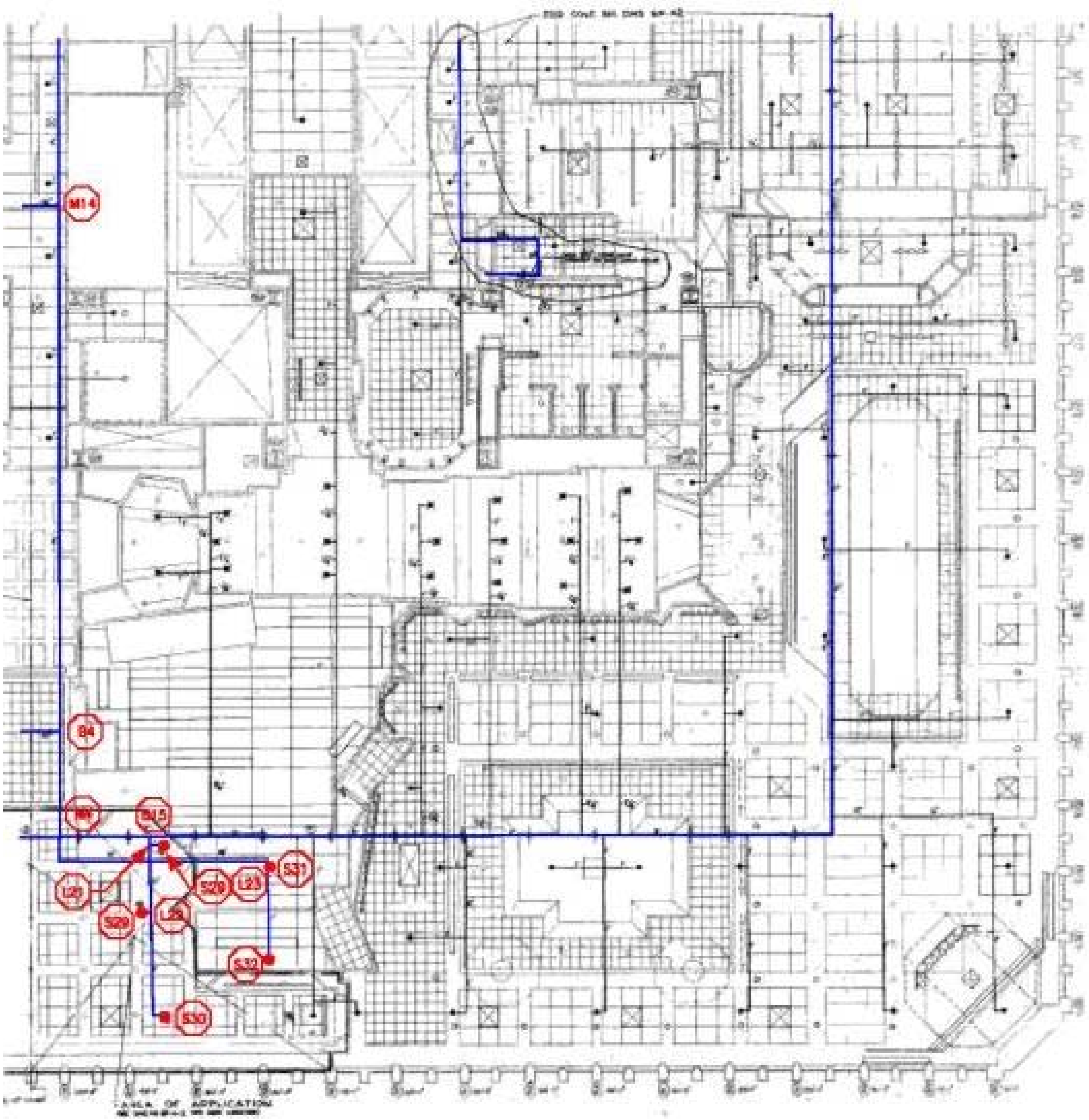
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–21. Hydraulic node layout, 107th floor NW quad., WTC 1.



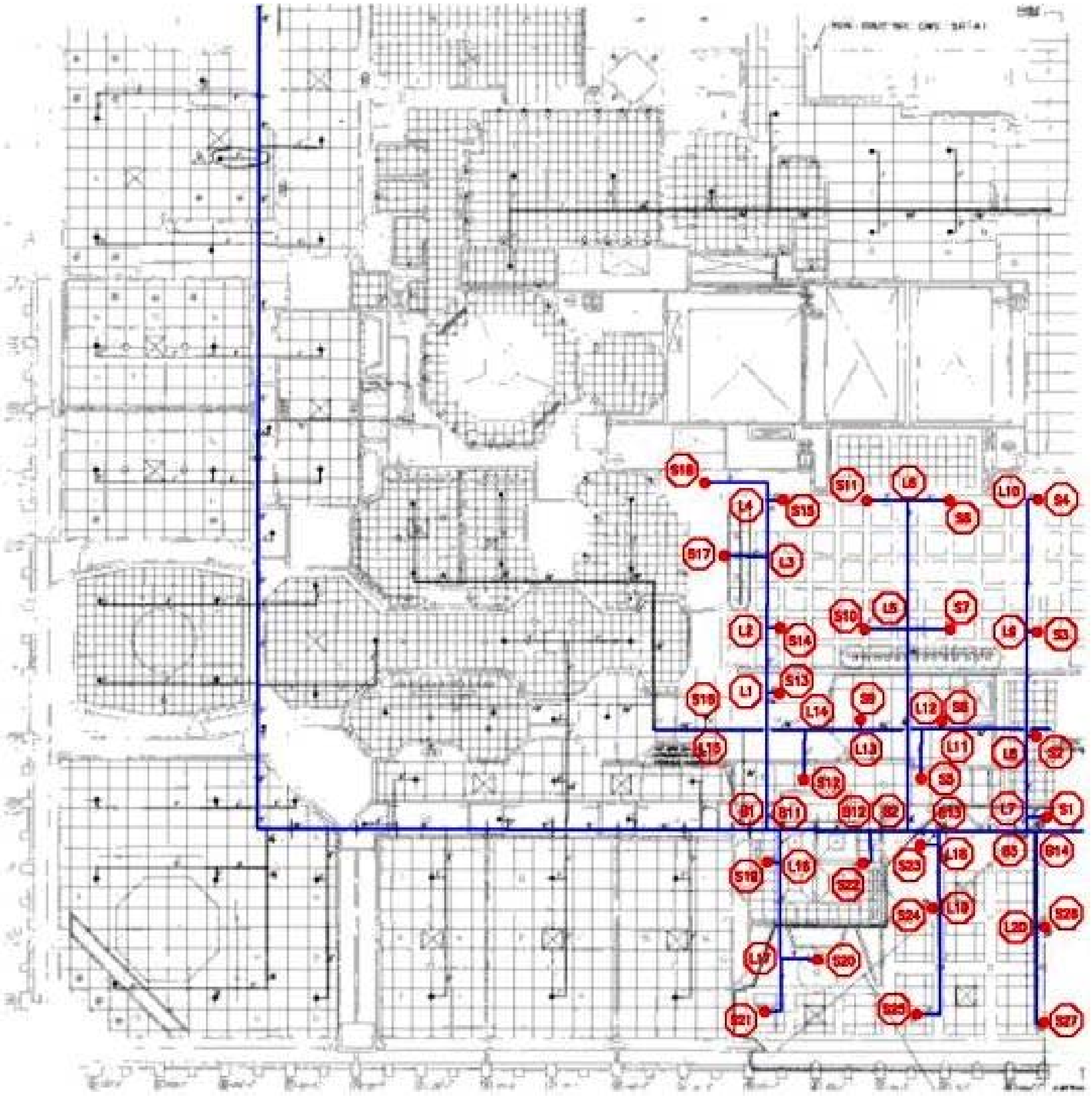
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–22. Hydraulic node layout, 107th floor NE quad., WTC 1.



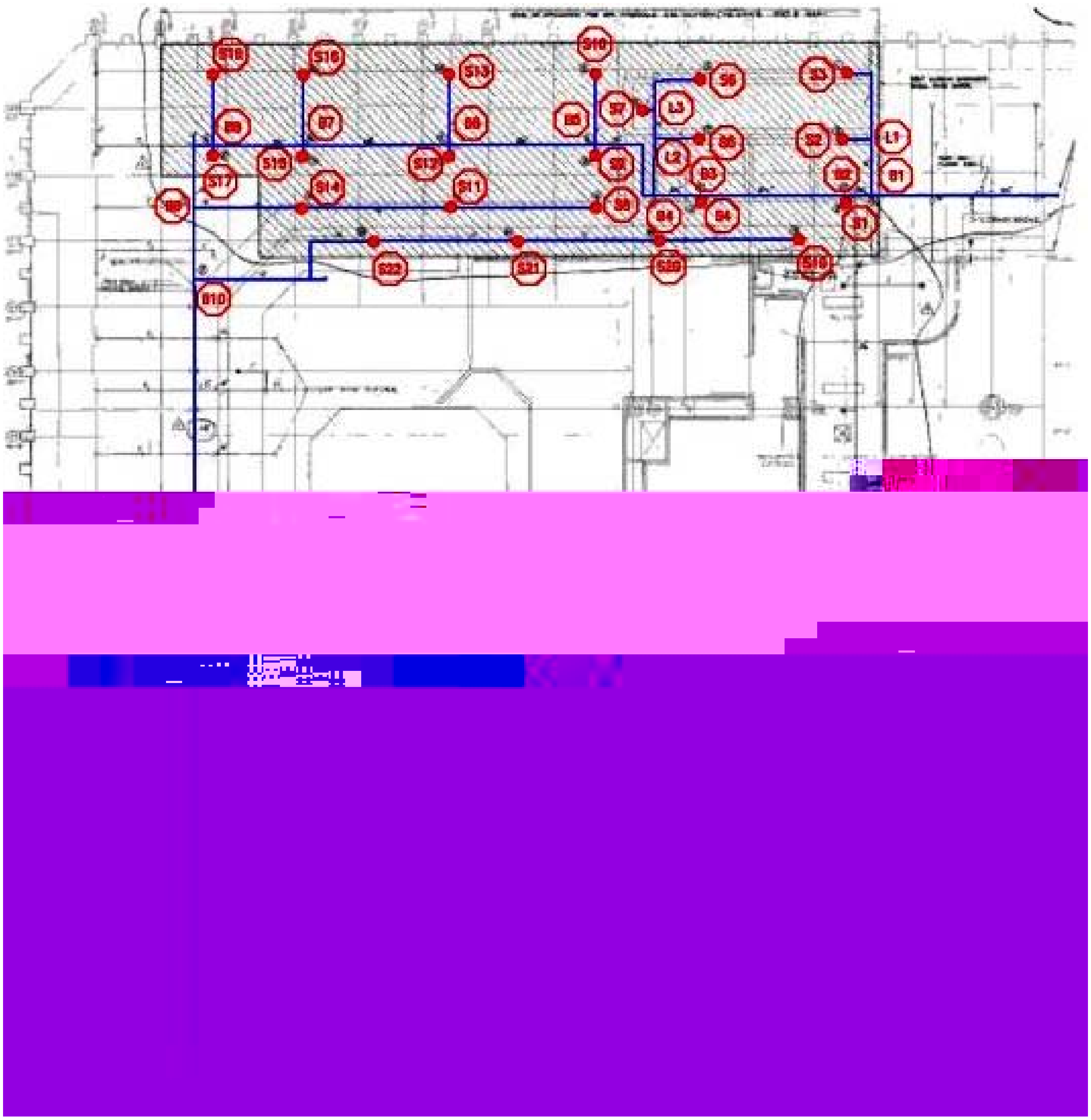
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–23. Hydraulic node layout, 107th floor SE quad., WTC 1.



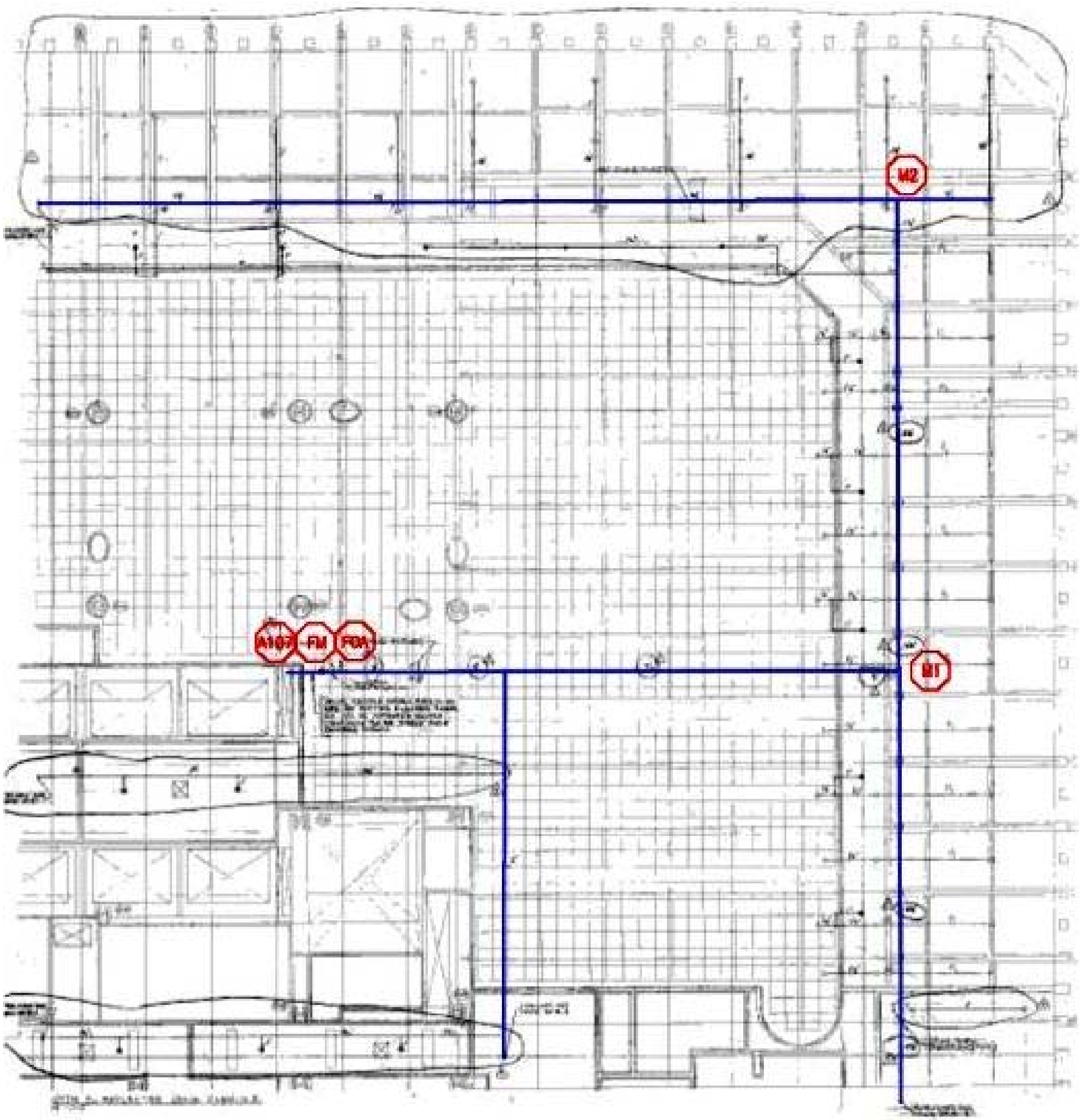
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–24. Hydraulic node layout, 107th floor SW quad., WTC 1.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–25. Hydraulic node layout, 107th floor NW quad., WTC 2.

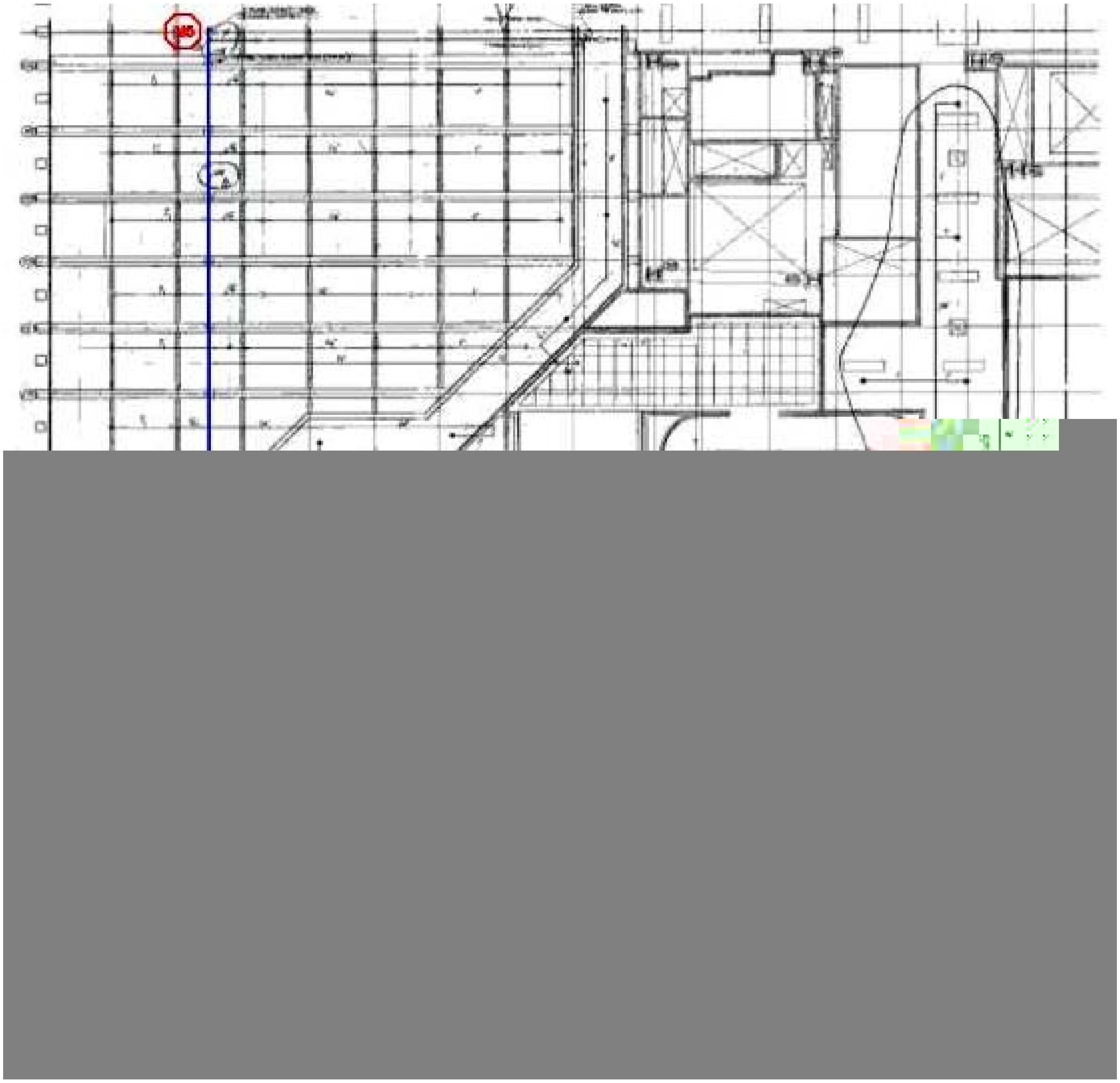


Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–26. Hydraulic node layout, 107th floor NE quad., WTC 2.

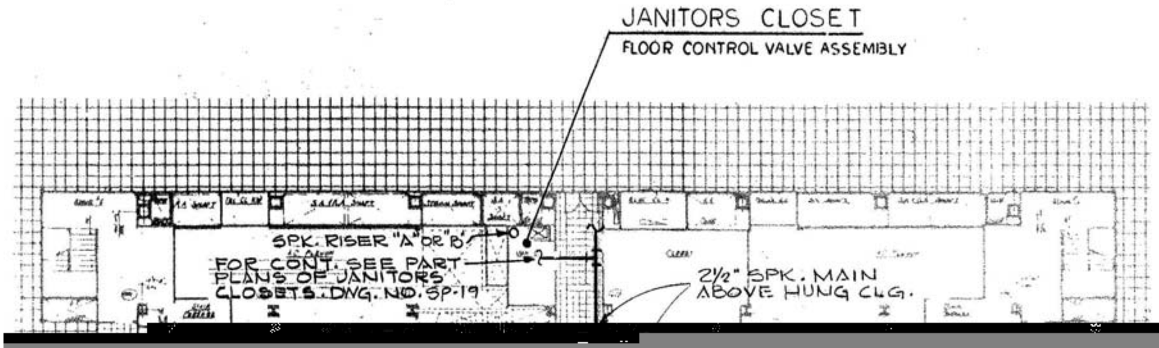
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–27. Hydraulic node layout, 107th floor SE quad., WTC 2.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–28. Hydraulic node layout, 107th floor SW quad., WTC 2.



[redacted]

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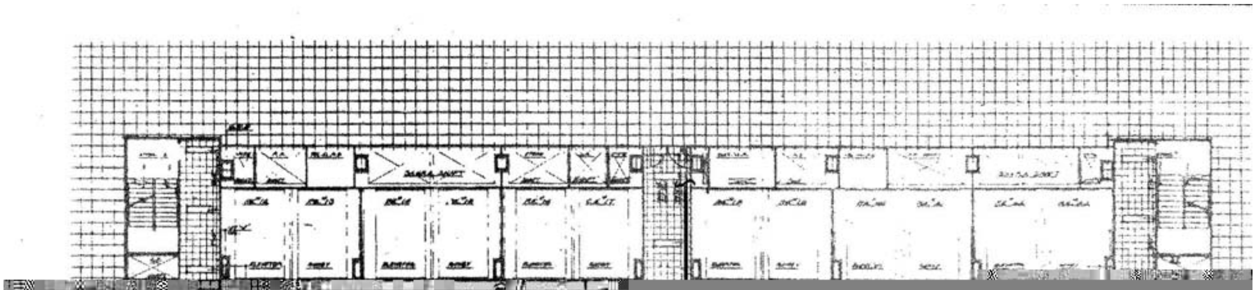
Figure B–29. Typical high zone sprinkler system core layout.



[redacted]

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Figure B–30. Typical mid-level zone sprinkler system core layout.

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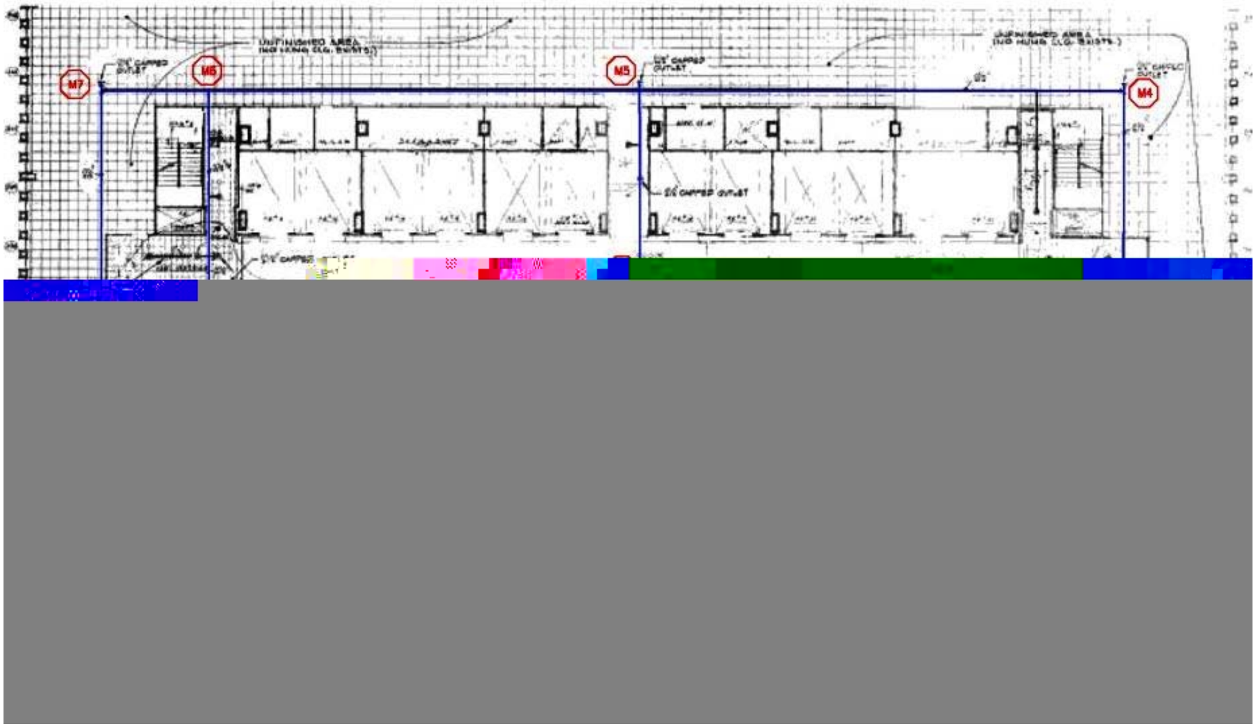
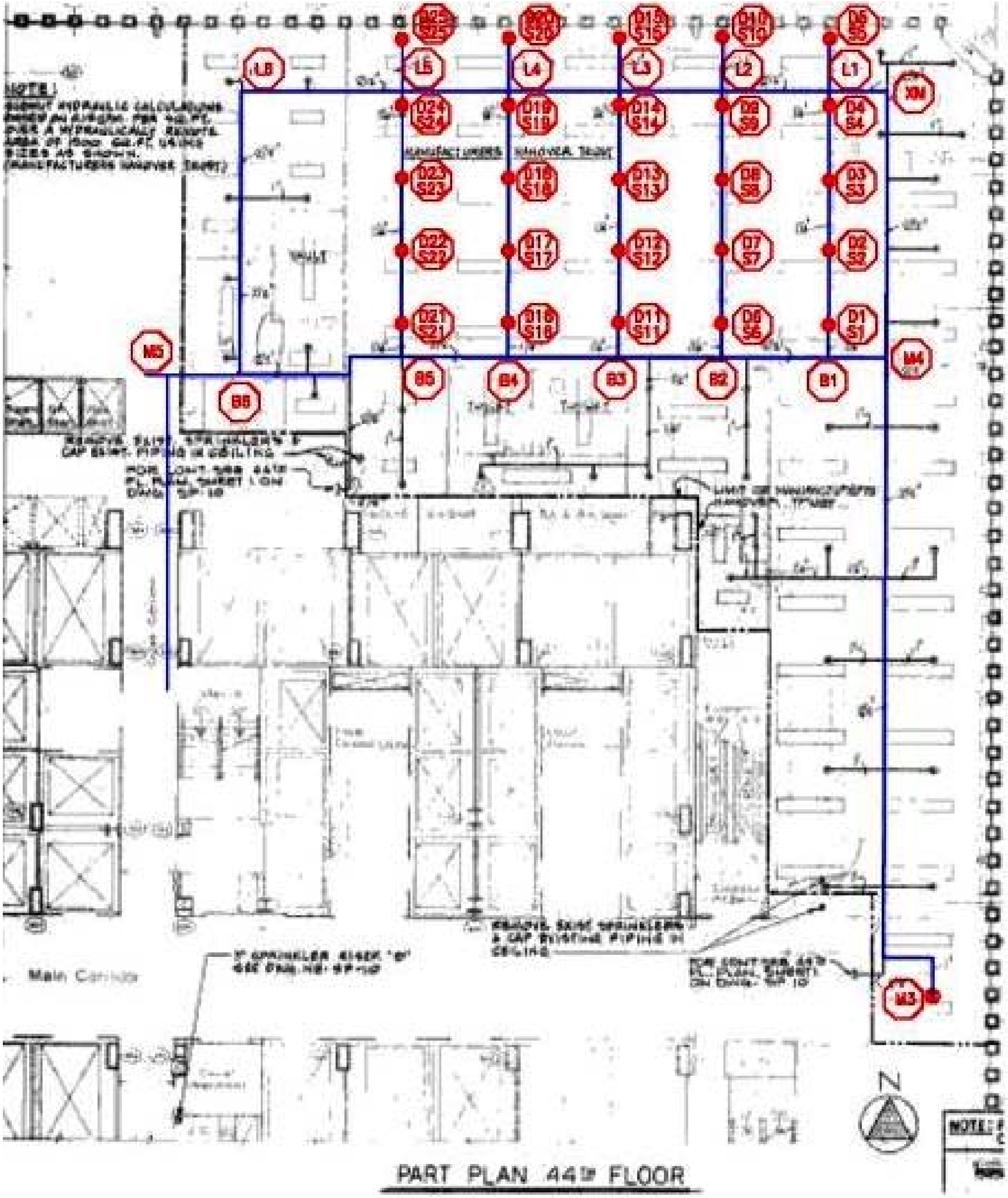
Figure B–31. Typical low zone sprinkler system core layout.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–32. Typical looped sprinkler main layout.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–33. Typical Ordinary Hazard grid sprinkler system layout.

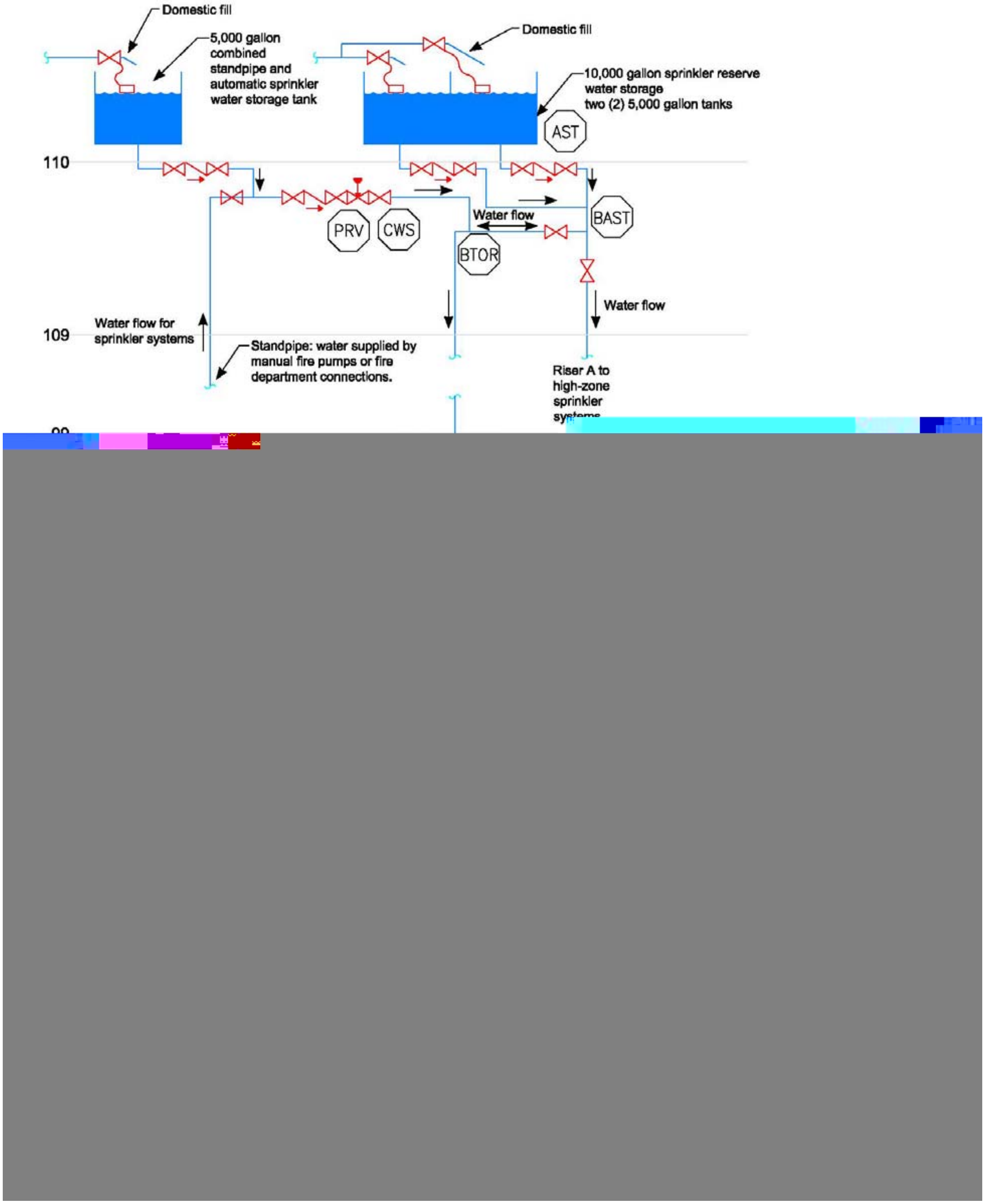
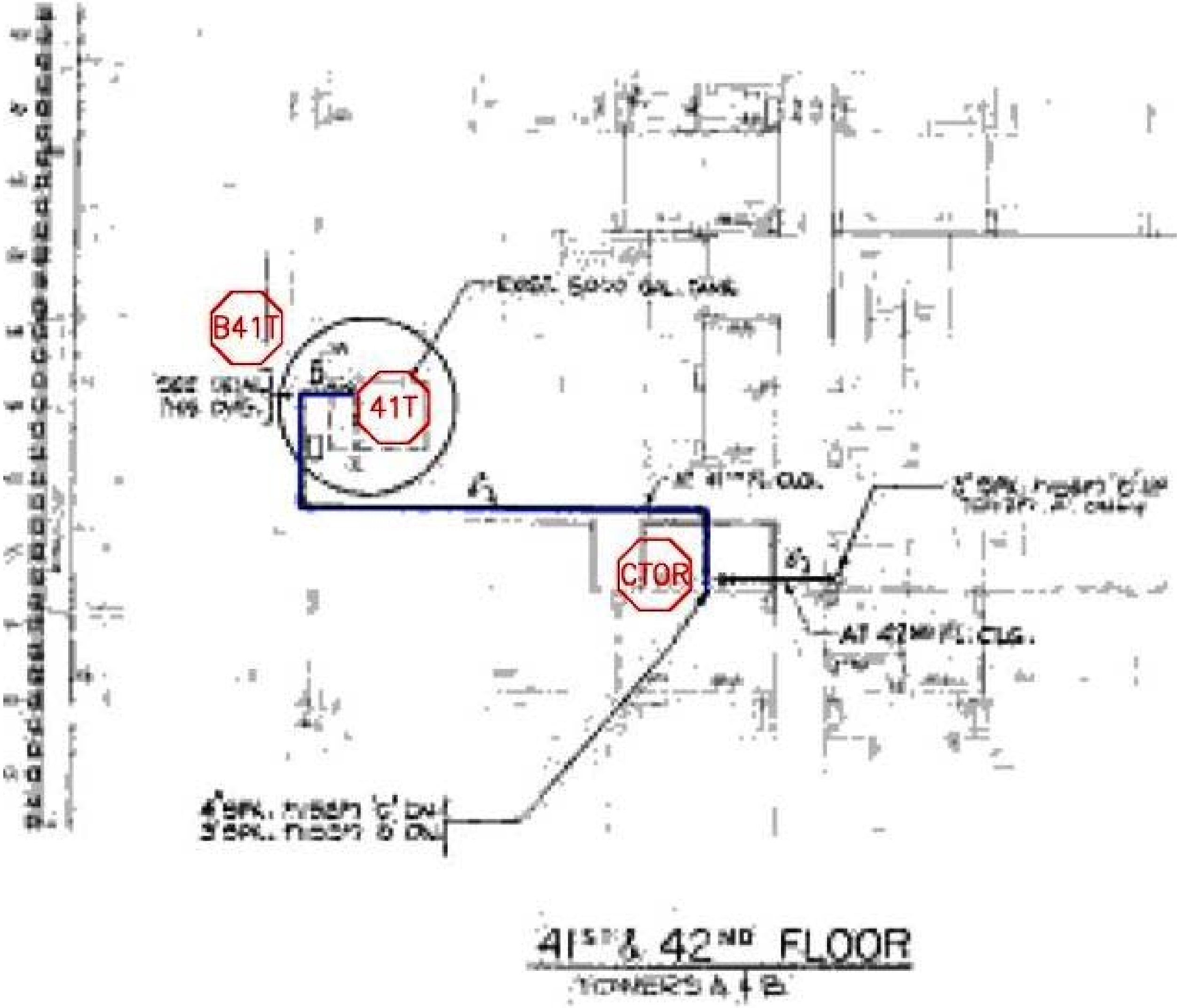


Figure B–34. Hydraulic node layout, mid-level zone riser B.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–35. Low zone water storage tank arrangement, 41st and 42nd floors.

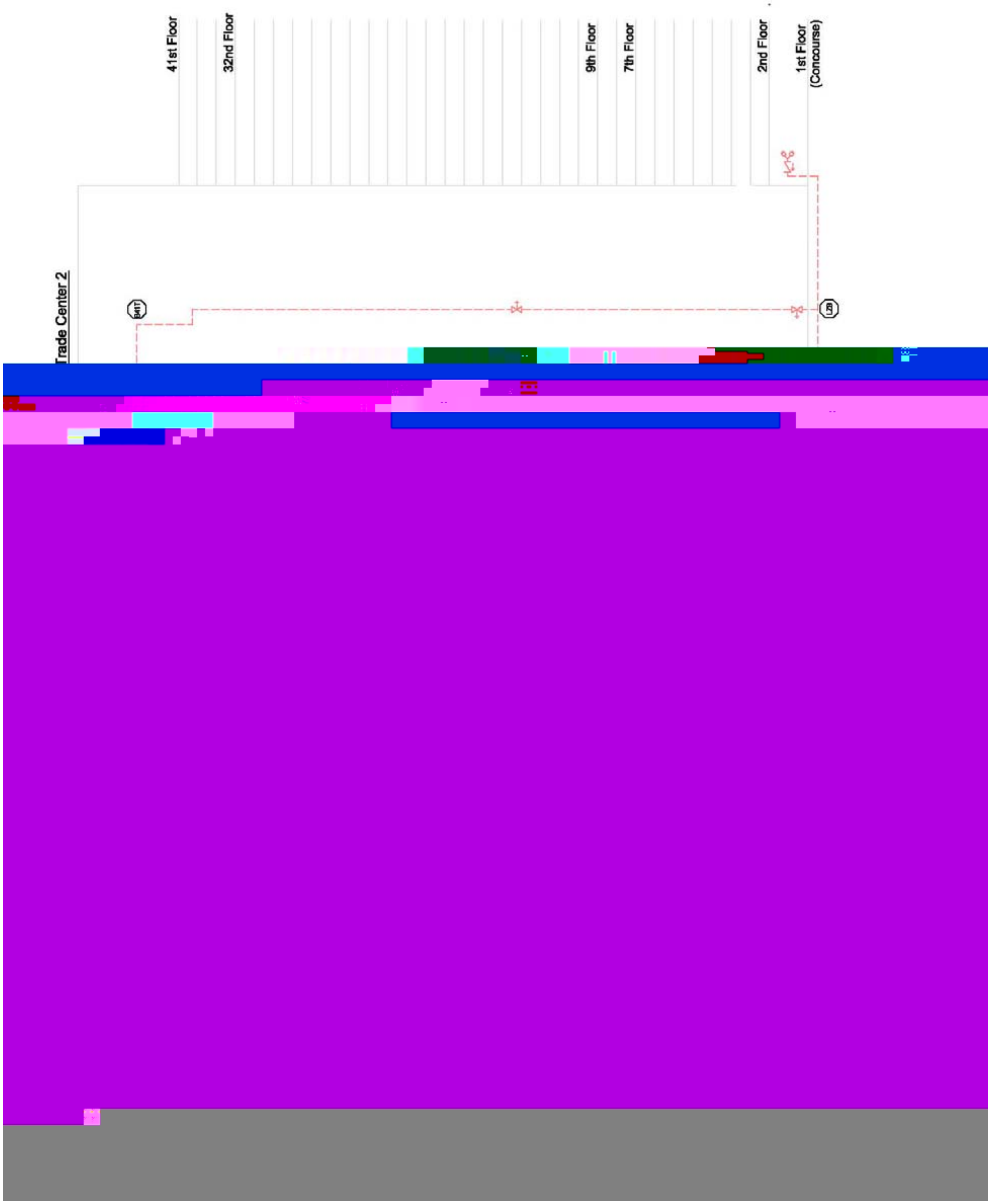
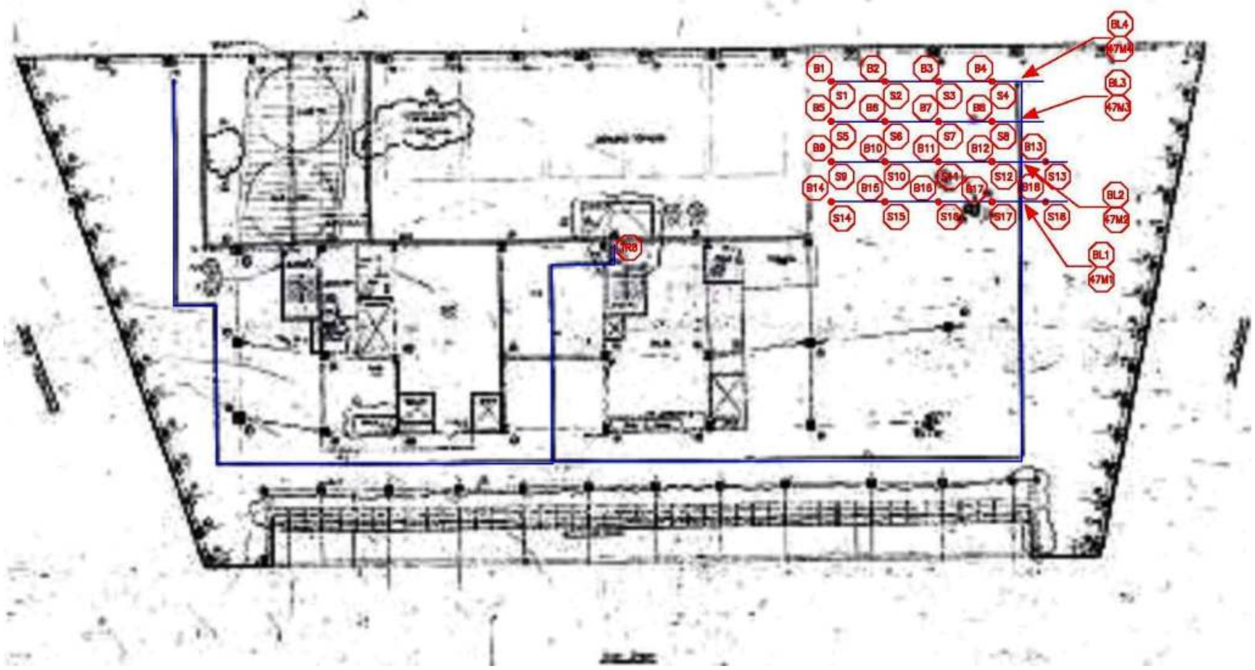
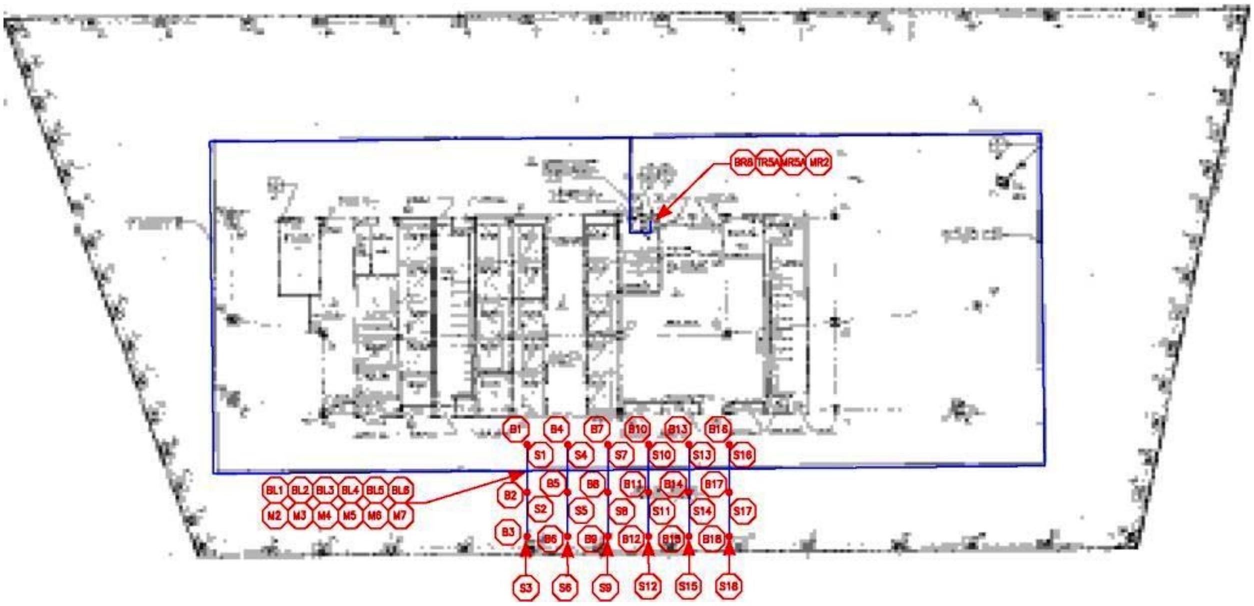


Figure B–36. Hydraulic node layout, low zone riser C.



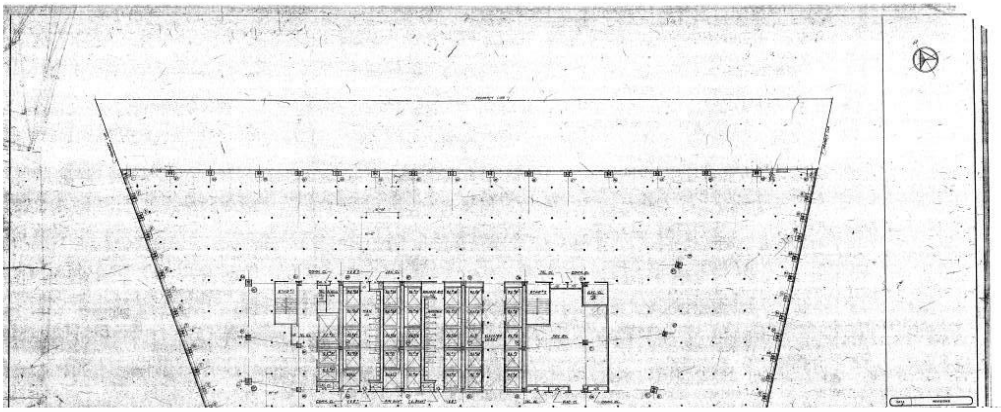
Source: Reproduced with permission of Syska & Hennessy 1984.

Figure B–37. Hydraulic node layout, 47th floor, WTC 7.



Source: Reproduced with permission of Syska & Hennessy 1984.

Figure B–38. Typical floor hydraulic node layout, WTC 7.



Source: Syska & Hennessy 1984. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–39. Typical sprinkler layout, floors 7 to 23, WTC 7.

Source: Syska & Hennessy 1984. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–40. Typical sprinkler layout, floors 7 to 23, WTC 7.

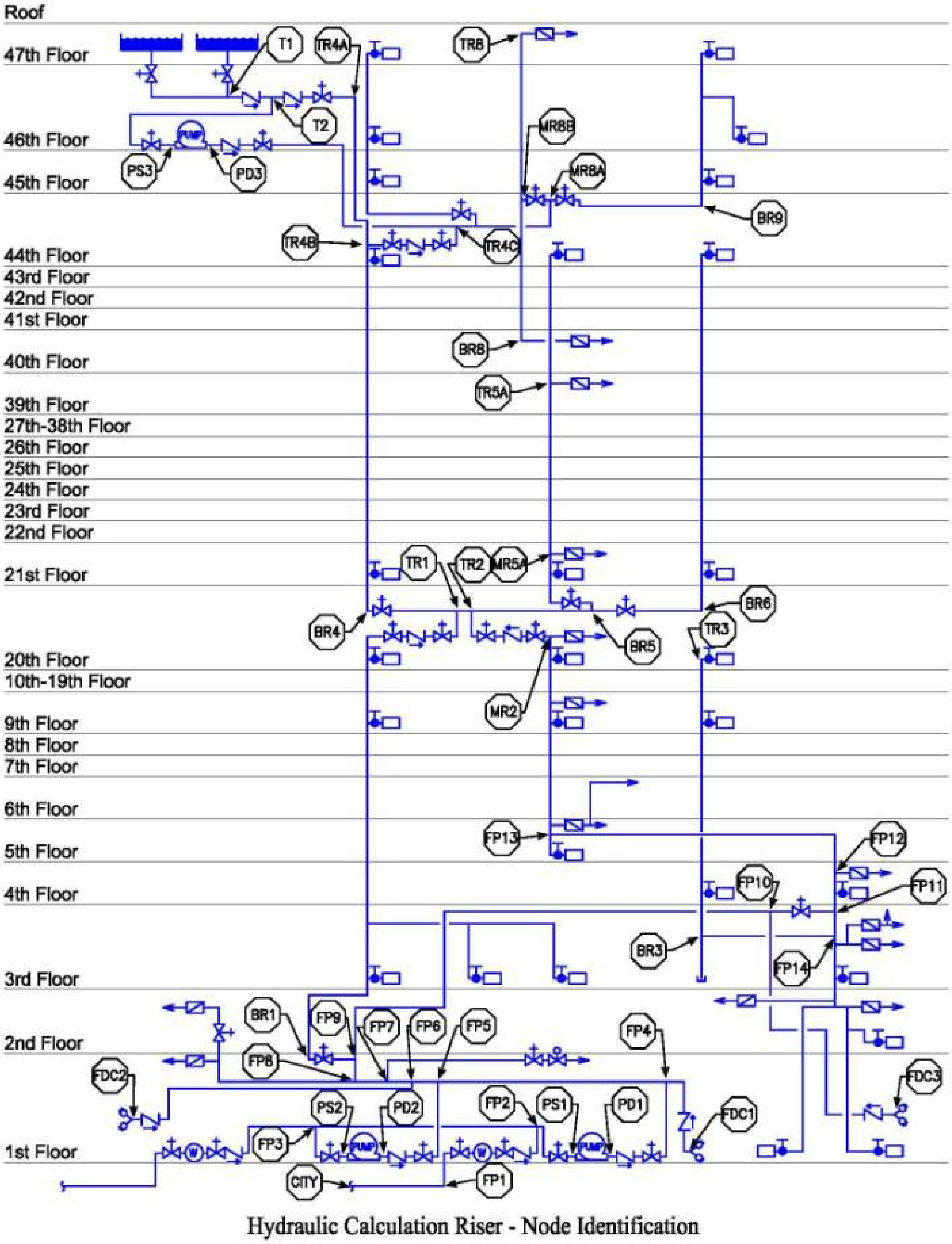


Figure B–41. Hydraulic calculation node riser, WTC 7.

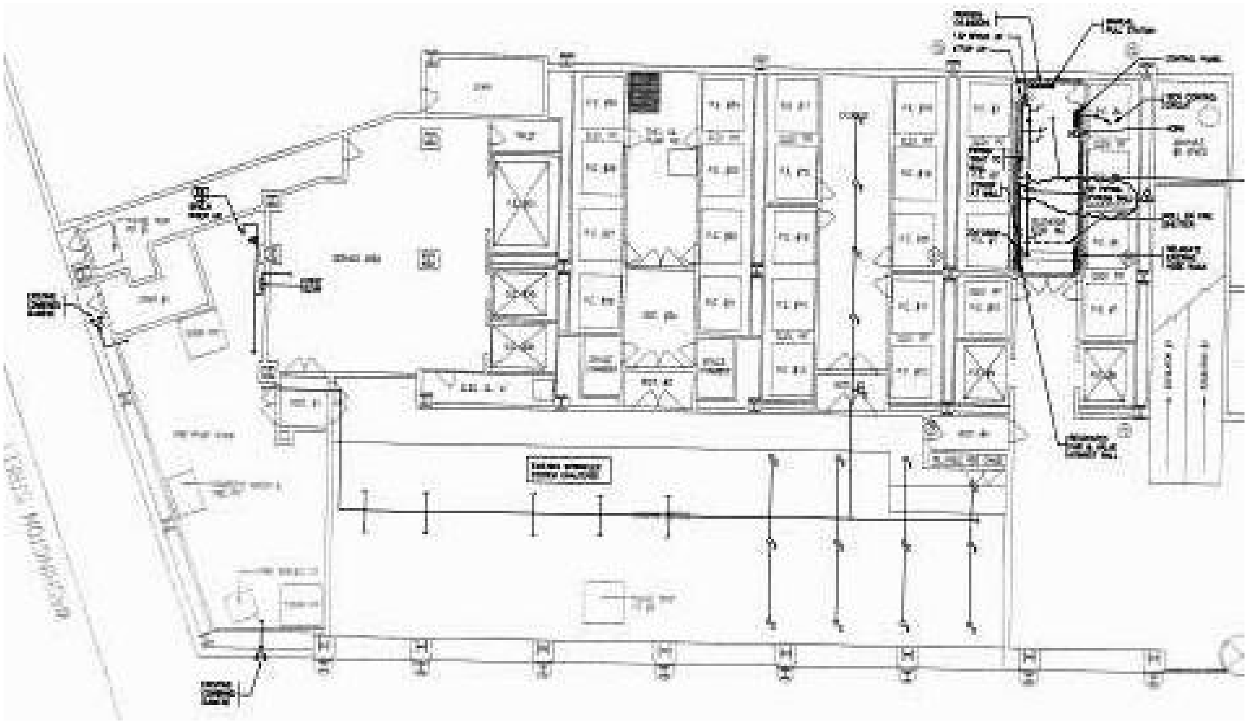


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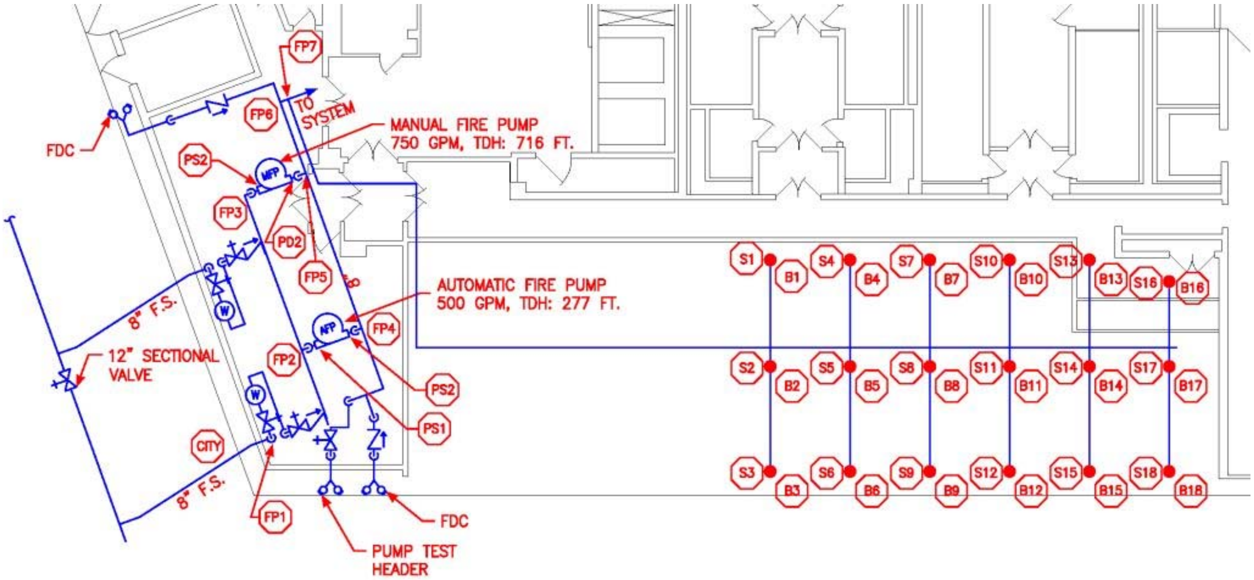
Figure B–42. First floor loading dock sprinkler configuration, WTC 7.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure B–43. First floor and fire pump room hydraulic node layout, WTC 7.

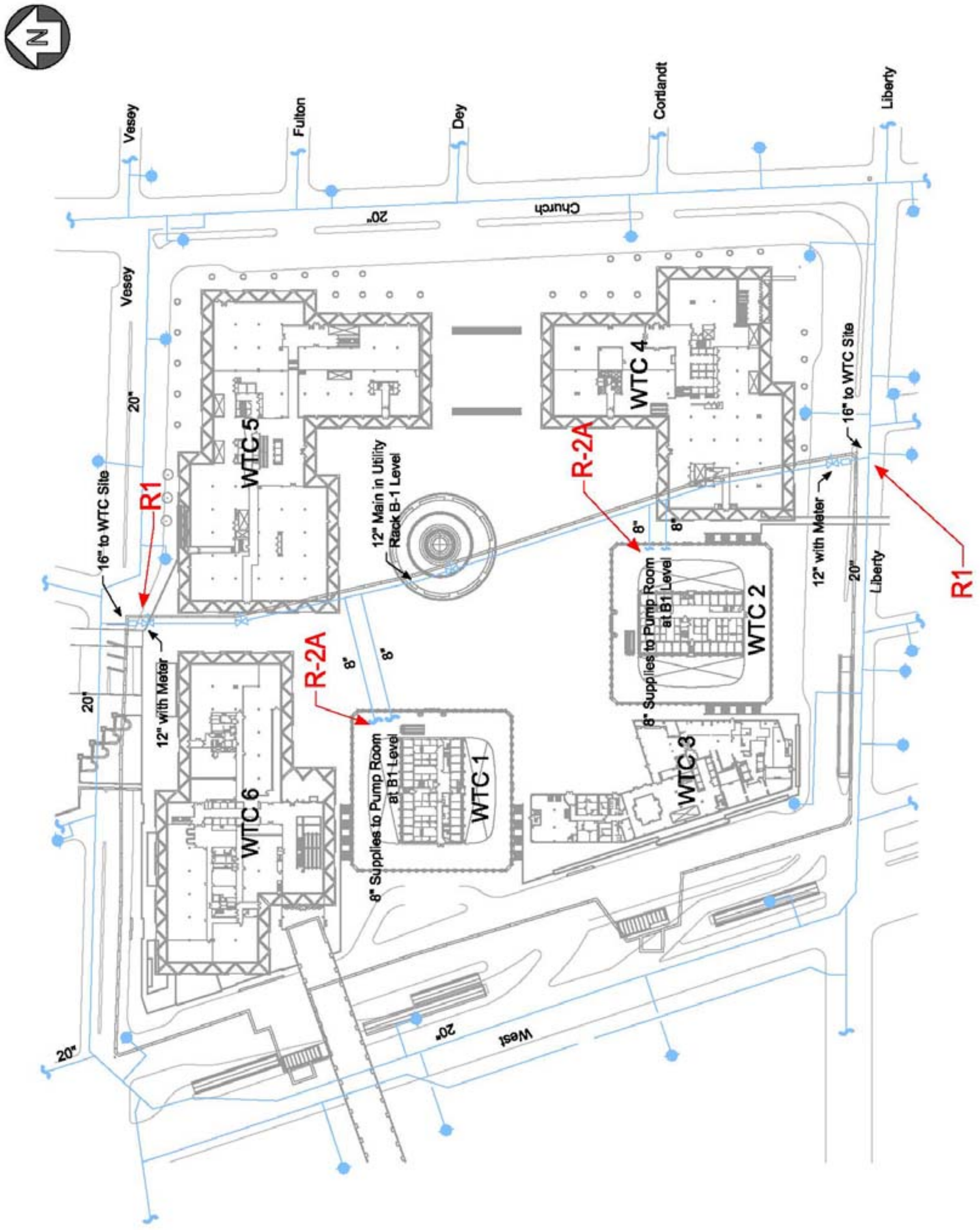


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Figure B–44. Redundancies associated with the WTC complex water supply.

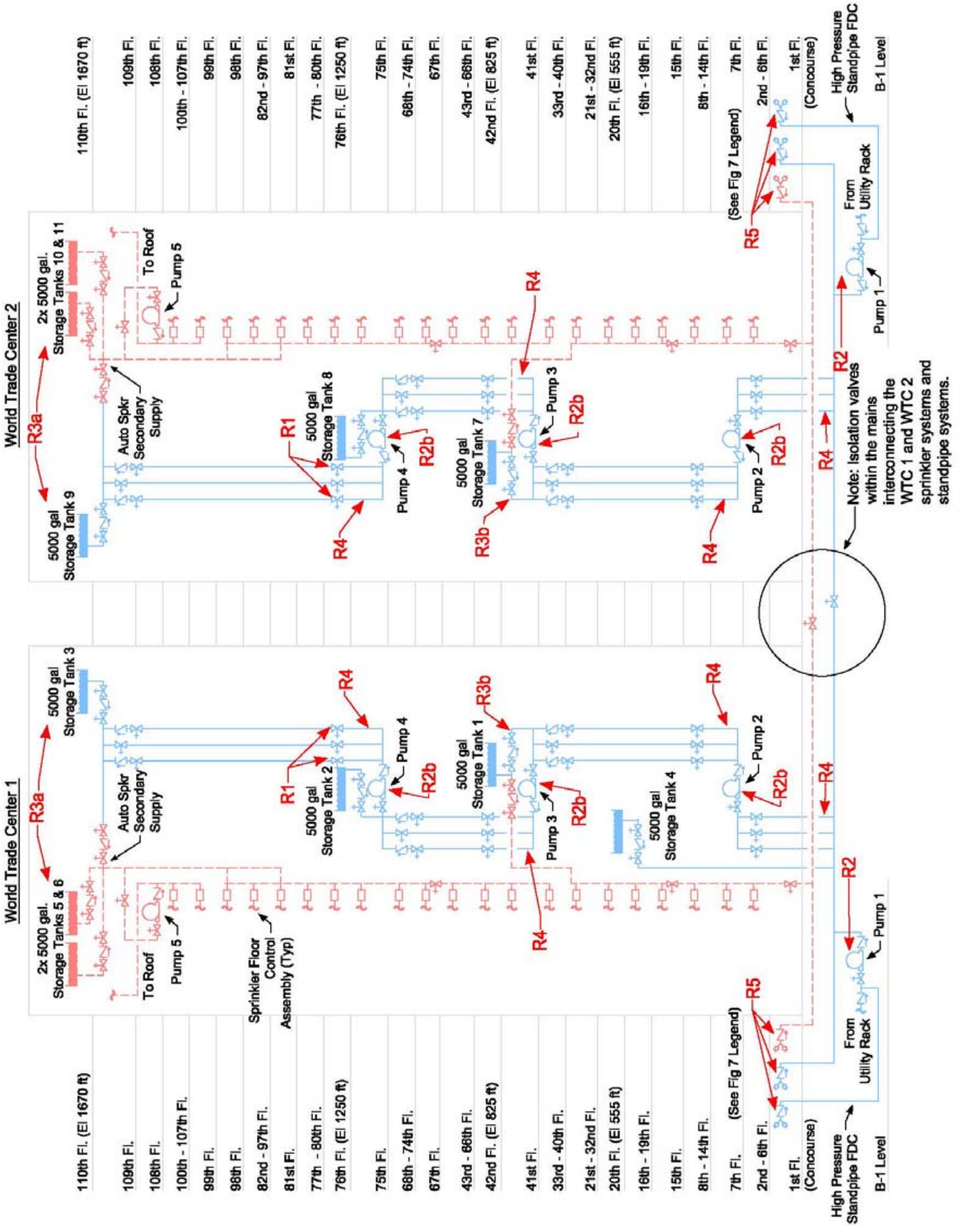


Figure B–45. Redundancies associated with the sprinkler and standpipe systems.

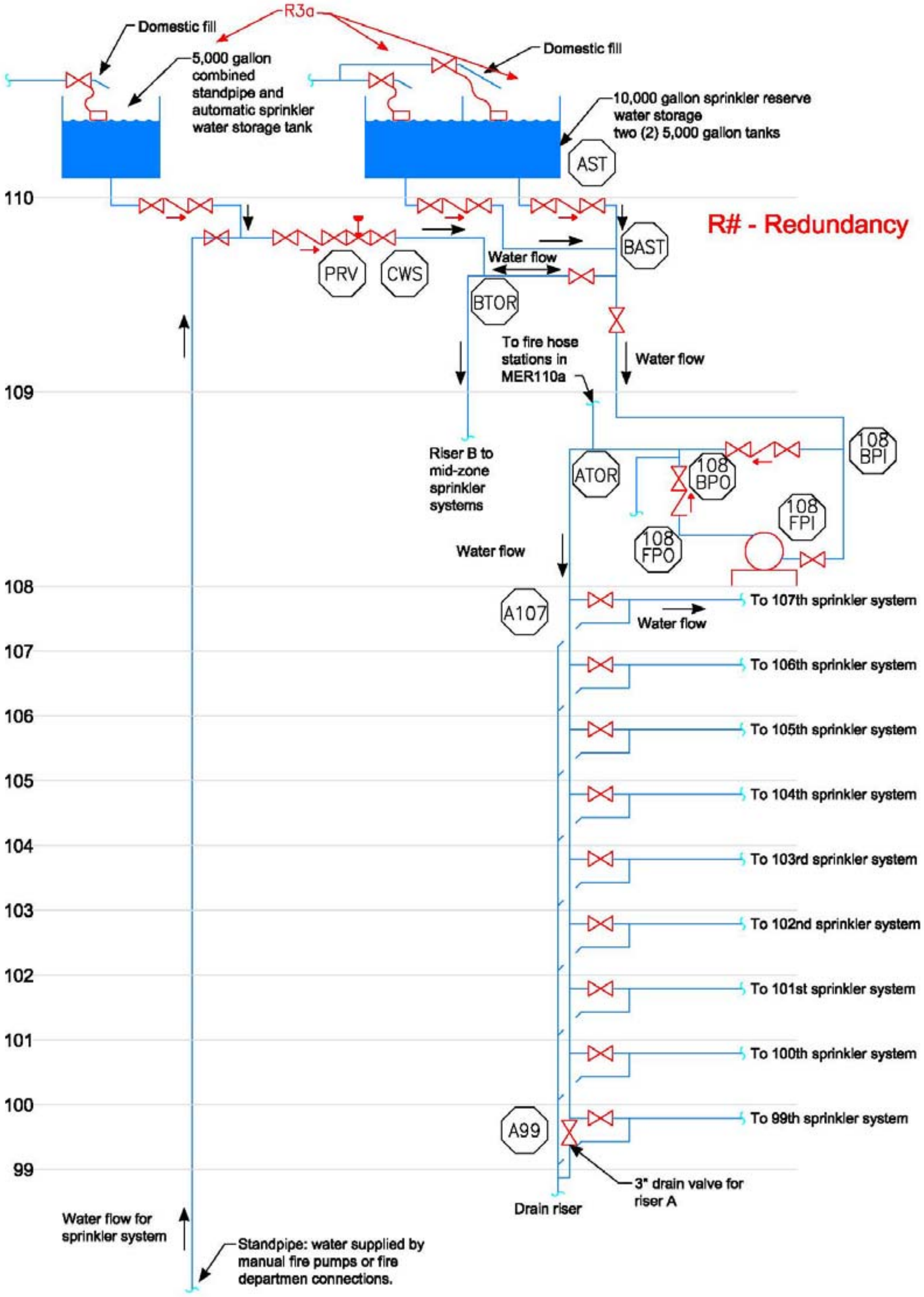


Figure B–46. Redundancies associated with high zone sprinkler system riser A.

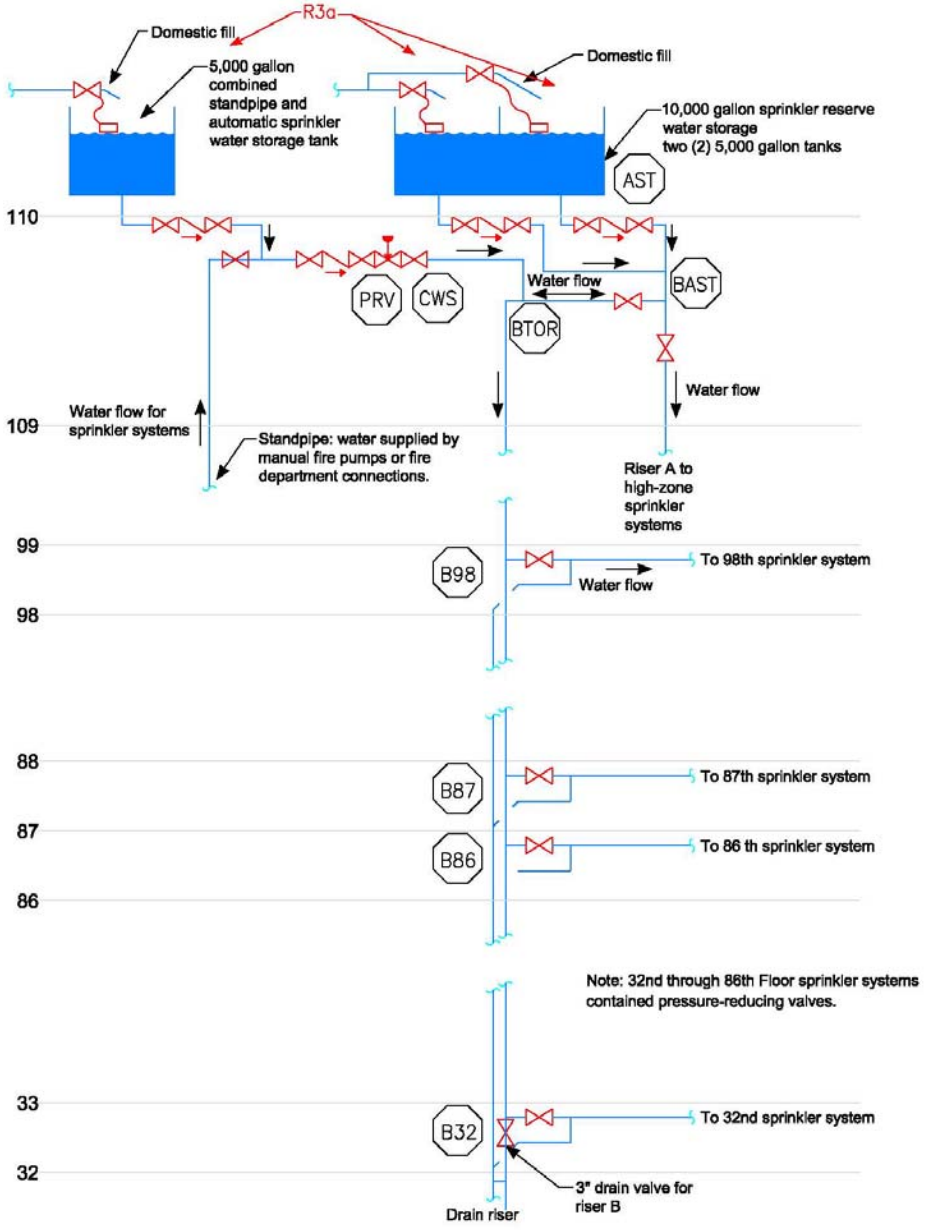


Figure B–47. Redundancies associated with mid level zone sprinkler system riser B.

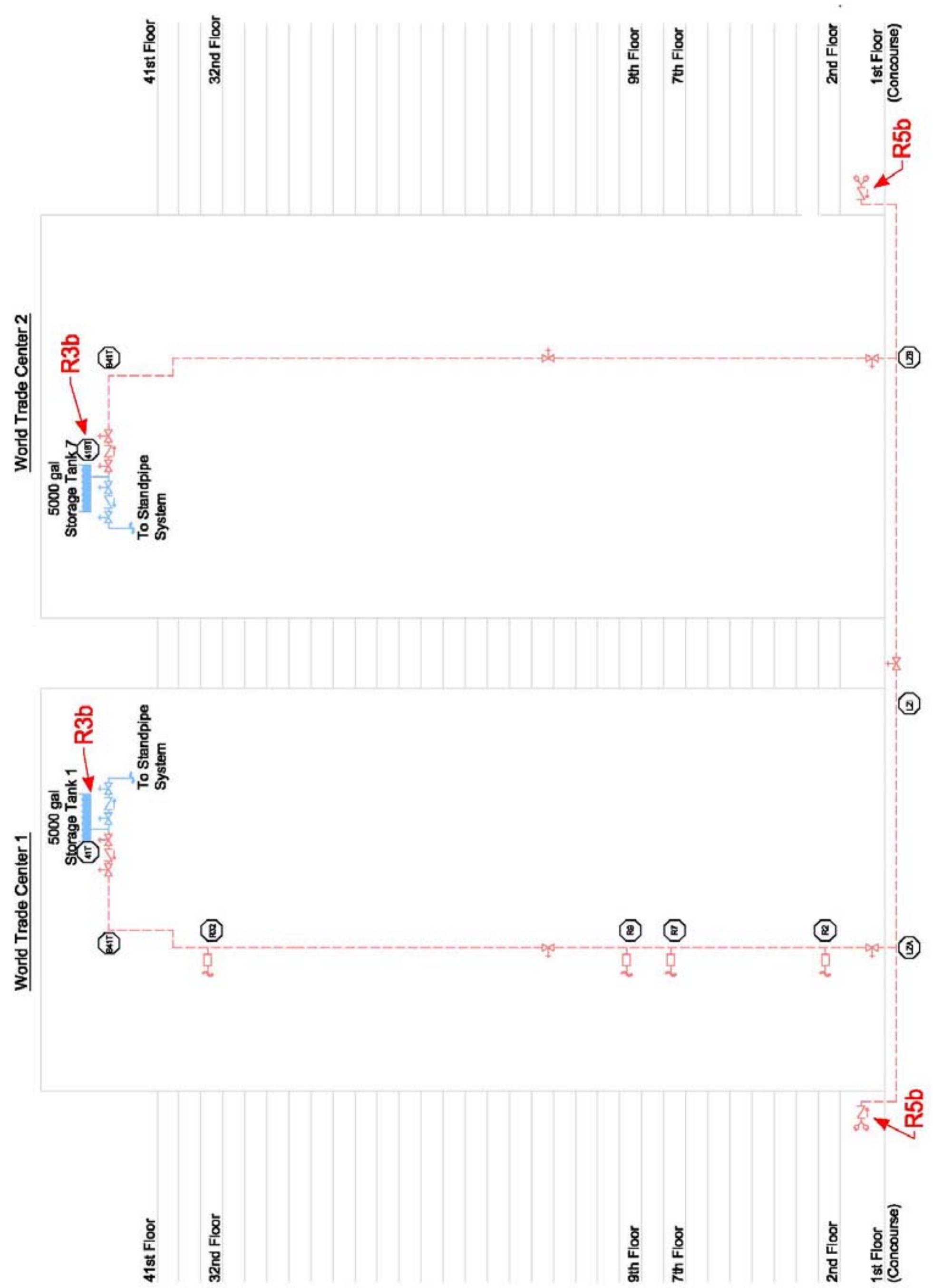
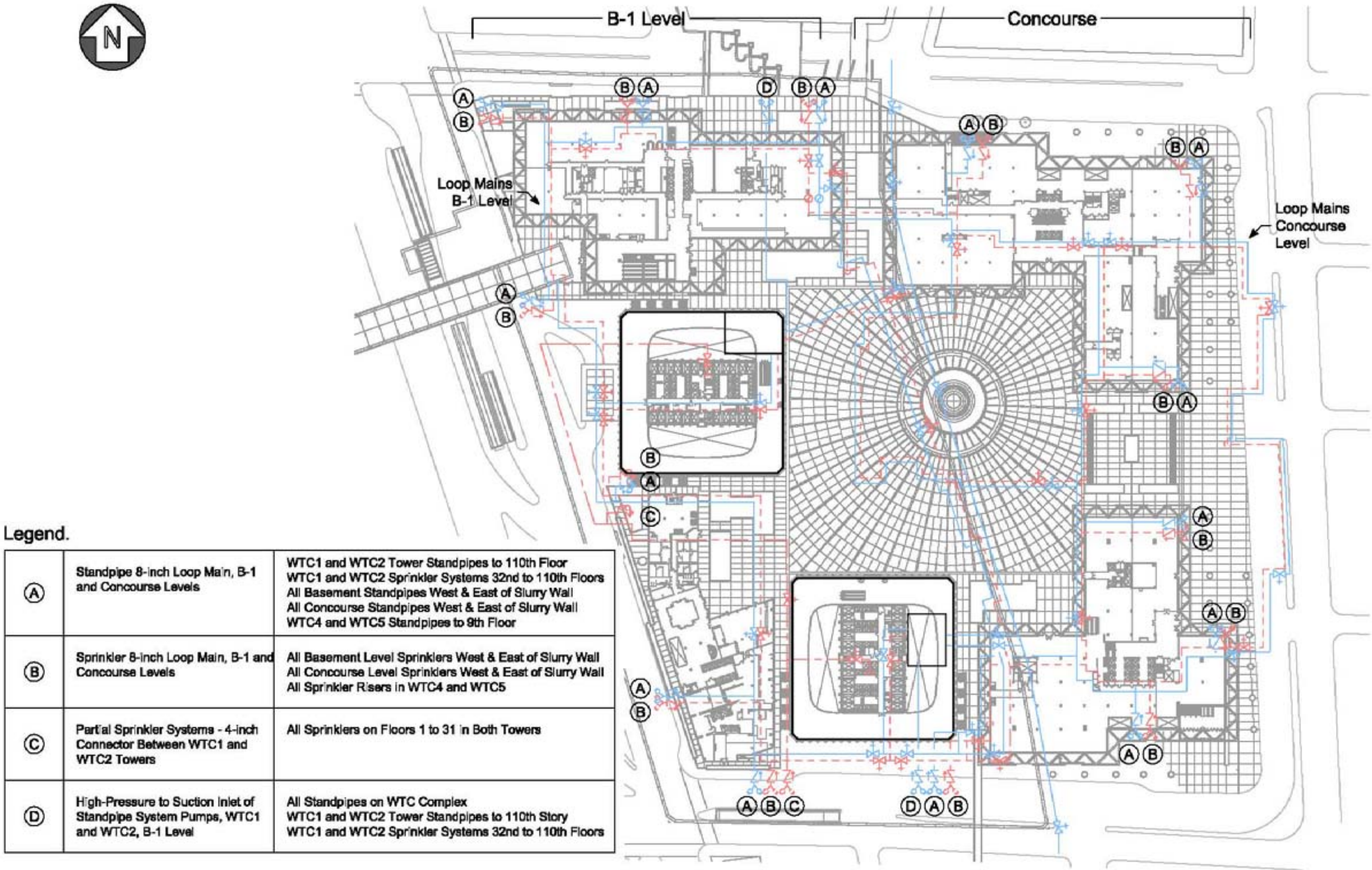


Figure B–48. Redundancies associated with low zone sprinkler system riser C.



Legend.

Ⓐ	Standpipe 8-inch Loop Main, B-1 and Concourse Levels	WTC1 and WTC2 Tower Standpipes to 110th Floor WTC1 and WTC2 Sprinkler Systems 32nd to 110th Floors All Basement Standpipes West & East of Slurry Wall All Concourse Standpipes West & East of Slurry Wall WTC4 and WTC5 Standpipes to 9th Floor
Ⓑ	Sprinkler 8-inch Loop Main, B-1 and Concourse Levels	All Basement Level Sprinklers West & East of Slurry Wall All Concourse Level Sprinklers West & East of Slurry Wall All Sprinkler Risers in WTC4 and WTC5
Ⓒ	Partial Sprinkler Systems - 4-inch Connector Between WTC1 and WTC2 Towers	All Sprinklers on Floors 1 to 31 in Both Towers
Ⓓ	High-Pressure to Suction Inlet of Standpipe System Pumps, WTC1 and WTC2, B-1 Level	All Standpipes on WTC Complex WTC1 and WTC2 Tower Standpipes to 110th Story WTC1 and WTC2 Sprinkler Systems 32nd to 110th Floors

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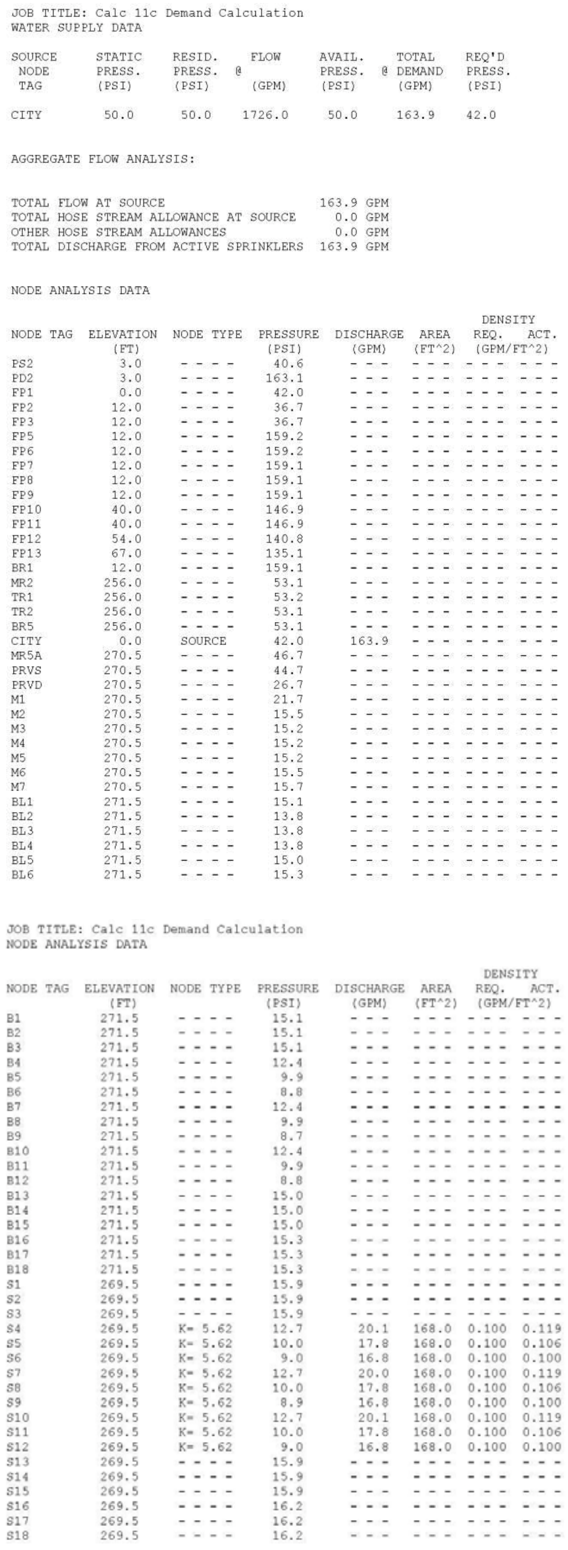
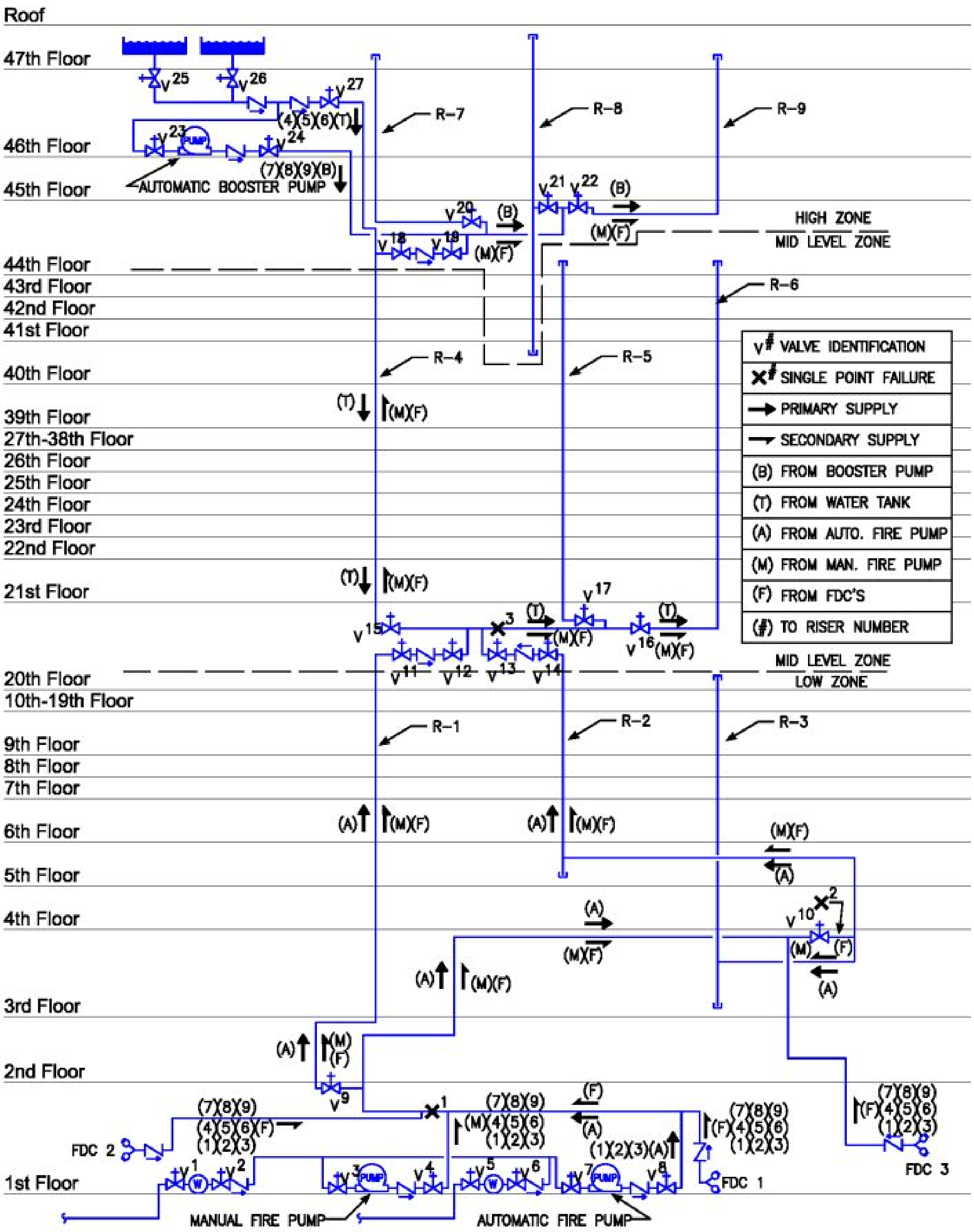
Figure B–49. Redundancies associated with the WTC complex fire department connections.



```
JOB TITLE: Calc 11c Demand Calculation
WATER SUPPLY DATA

SOURCE     STATIC    RESID.     FLOW      AVAIL.     TOTAL    REQ'D
 NODE      PRESS.    PRESS.  @            PRESS.  @ DEMAND    PRESS.
 TAG       (PSI)     (PSI)      (GPM)     (PSI)      (GPM)    (PSI)

CITY        50.0      50.0    1726.0      50.0      163.9     42.0


AGGREGATE FLOW ANALYSIS:


TOTAL FLOW AT SOURCE                     163.9 GPM
TOTAL HOSE STREAM ALLOWANCE AT SOURCE      0.0 GPM
OTHER HOSE STREAM ALLOWANCES               0.0 GPM
TOTAL DISCHARGE FROM ACTIVE SPRINKLERS   163.9 GPM


NODE ANALYSIS DATA

                                                          DENSITY
NODE TAG  ELEVATION  NODE TYPE  PRESSURE  DISCHARGE  AREA   REQ.   ACT.
             (FT)                (PSI)      (GPM)   (FT^2)  (GPM/FT^2)
PS2           3.0     - - - -     40.6      - - -   - - -  - - -  - - -
PD2           3.0     - - - -    163.1      - - -   - - -  - - -  - - -
FP1           0.0     - - - -     42.0      - - -   - - -  - - -  - - -
FP2          12.0     - - - -     36.7      - - -   - - -  - - -  - - -
FP3          12.0     - - - -     36.7      - - -   - - -  - - -  - - -
FP5          12.0     - - - -    159.2      - - -   - - -  - - -  - - -
FP6          12.0     - - - -    159.2      - - -   - - -  - - -  - - -
FP7          12.0     - - - -    159.1      - - -   - - -  - - -  - - -
FP8          12.0     - - - -    159.1      - - -   - - -  - - -  - - -
FP9          12.0     - - - -    159.1      - - -   - - -  - - -  - - -
FP10         40.0     - - - -    146.9      - - -   - - -  - - -  - - -
FP11         40.0     - - - -    146.9      - - -   - - -  - - -  - - -
FP12         54.0     - - - -    140.8      - - -   - - -  - - -  - - -
FP13         67.0     - - - -    135.1      - - -   - - -  - - -  - - -
BR1          12.0     - - - -    159.1      - - -   - - -  - - -  - - -
MR2         256.0     - - - -     53.1      - - -   - - -  - - -  - - -
TR1         256.0     - - - -     53.2      - - -   - - -  - - -  - - -
TR2         256.0     - - - -     53.1      - - -   - - -  - - -  - - -
BR5         256.0     - - - -     53.1      - - -   - - -  - - -  - - -
CITY          0.0     SOURCE      42.0      163.9   - - -  - - -  - - -
MR5A        270.5     - - - -     46.7      - - -   - - -  - - -  - - -
PRVS        270.5     - - - -     44.7      - - -   - - -  - - -  - - -
PRVD        270.5     - - - -     26.7      - - -   - - -  - - -  - - -
M1          270.5     - - - -     21.7      - - -   - - -  - - -  - - -
M2          270.5     - - - -     15.5      - - -   - - -  - - -  - - -
M3          270.5     - - - -     15.2      - - -   - - -  - - -  - - -
M4          270.5     - - - -     15.2      - - -   - - -  - - -  - - -
M5          270.5     - - - -     15.2      - - -   - - -  - - -  - - -
M6          270.5     - - - -     15.5      - - -   - - -  - - -  - - -
M7          270.5     - - - -     15.7      - - -   - - -  - - -  - - -
BL1         271.5     - - - -     15.1      - - -   - - -  - - -  - - -
BL2         271.5     - - - -     13.8      - - -   - - -  - - -  - - -
BL3         271.5     - - - -     13.8      - - -   - - -  - - -  - - -
BL4         271.5     - - - -     13.8      - - -   - - -  - - -  - - -
BL5         271.5     - - - -     15.0      - - -   - - -  - - -  - - -
BL6         271.5     - - - -     15.3      - - -   - - -  - - -  - - -


JOB TITLE: Calc 11c Demand Calculation
NODE ANALYSIS DATA

                                                          DENSITY
NODE TAG  ELEVATION  NODE TYPE  PRESSURE  DISCHARGE  AREA   REQ.   ACT.
             (FT)                (PSI)      (GPM)   (FT^2)  (GPM/FT^2)
B1          271.5     - - - -     15.1      - - -   - - -  - - -  - - -
B2          271.5     - - - -     15.1      - - -   - - -  - - -  - - -
B3          271.5     - - - -     15.1      - - -   - - -  - - -  - - -
B4          271.5     - - - -     12.4      - - -   - - -  - - -  - - -
B5          271.5     - - - -      9.9      - - -   - - -  - - -  - - -
B6          271.5     - - - -      8.8      - - -   - - -  - - -  - - -
B7          271.5     - - - -     12.4      - - -   - - -  - - -  - - -
B8          271.5     - - - -      9.9      - - -   - - -  - - -  - - -
B9          271.5     - - - -      8.7      - - -   - - -  - - -  - - -
B10         271.5     - - - -     12.4      - - -   - - -  - - -  - - -
B11         271.5     - - - -      9.9      - - -   - - -  - - -  - - -
B12         271.5     - - - -      8.8      - - -   - - -  - - -  - - -
B13         271.5     - - - -     15.0      - - -   - - -  - - -  - - -
B14         271.5     - - - -     15.0      - - -   - - -  - - -  - - -
B15         271.5     - - - -     15.0      - - -   - - -  - - -  - - -
B16         271.5     - - - -     15.3      - - -   - - -  - - -  - - -
B17         271.5     - - - -     15.3      - - -   - - -  - - -  - - -
B18         271.5     - - - -     15.3      - - -   - - -  - - -  - - -
S1          269.5     - - - -     15.9      - - -   - - -  - - -  - - -
S2          269.5     - - - -     15.9      - - -   - - -  - - -  - - -
S3          269.5     - - - -     15.9      - - -   - - -  - - -  - - -
S4          269.5     K= 5.62     12.7       20.1   168.0  0.100  0.119
S5          269.5     K= 5.62     10.0       17.8   168.0  0.100  0.106
S6          269.5     K= 5.62      9.0       16.8   168.0  0.100  0.100
S7          269.5     K= 5.62     12.7       20.0   168.0  0.100  0.119
S8          269.5     K= 5.62     10.0       17.8   168.0  0.100  0.106
S9          269.5     K= 5.62      8.9       16.8   168.0  0.100  0.100
S10         269.5     K= 5.62     12.7       20.1   168.0  0.100  0.119
S11         269.5     K= 5.62     10.0       17.8   168.0  0.100  0.106
S12         269.5     K= 5.62      9.0       16.8   168.0  0.100  0.100
S13         269.5     - - - -     15.9      - - -   - - -  - - -  - - -
S14         269.5     - - - -     15.9      - - -   - - -  - - -  - - -
S15         269.5     - - - -     15.9      - - -   - - -  - - -  - - -
S16         269.5     - - - -     16.2      - - -   - - -  - - -  - - -
S17         269.5     - - - -     16.2      - - -   - - -  - - -  - - -
S18         269.5     - - - -     16.2      - - -   - - -  - - -  - - -
```

Figure B–50. Calculation 11c (demand calculation), WTC 7.



Direction of Flow - Primary and Secondary Supplies to Zones

Figure B–51. Primary and secondary supply water flow diagram, WTC 7.

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NIST NCSTAR 1-4C

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Fire Alarm Systems

Robert J. Keough
Raymond A. Grill

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

NIST NCSTAR 1-4C

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Fire Alarm Systems

Robert J. Keough
Raymond A. Grill
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September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

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The policy of NIST is to use the International System of Units (metric units) in all publications. In this document, however, units are presented in metric units or the inch-pound system, whichever is prevalent in the discipline.

Disclaimer No. 3

Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is “voluntarily provided safety-related information” that is “not directly related to the building failure being investigated” and that “disclosure of that information would inhibit the voluntary provision of that type of information” (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

Use in Legal Proceedings

No part of any report resulting from a NIST investigation into a structural failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

National Institute of Standards and Technology National Construction Safety Team Act Report 1-4C
Natl. Inst. Stand. Technol. Natl. Constr. Sfty. Tm. Act Rpt. 1-4C, 148 pages (September 2005)
CODEN: NSPUE2

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ABSTRACT

This report was prepared to support the investigation of active fire protection systems as part of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation.

The purpose of this report is to document the design, installation, and modifications to the fire detection and alarm system for buildings 1, 2, and 7 of the WTC, including system performance during the September 11, 2001, attack.

Keywords: Fire alarm systems, fire protection, smoke detection, voice communication, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ADAAG	Americans with Disabilities Act Accessibility Guidelines for Building and Facilities
ANSI	American National Standards Institute
ASTM	ASTM International
ATC	ALD Terminal Cabinets
BBFAS	Base Building Fire Alarm System
BCNYC	Building Code of the City of New York
BPS	Building Performance Study
ESP	Elevator Starter Panel
EVAC	emergency voice alarm communication
FCS	Fire Command Station
FDNY	Fire Department of the City of New York
FEMA	Federal Emergency Management Agency
HVAC	heating, ventilating, and air conditioning
MER	Mechanical Equipment Room
NCC	Network Command Center
NFAC	National Fire Alarm Code
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NYC	New York City
OCC	Operation Control Center
PA	Public Address System
PANYNJ	Port Authority of New York and New Jersey
PSR	Pyrotronics Remote Transponder
RMT	Remote Monitoring Transponders
SEAoNY	Structural Engineers Association of New York
TSC	Terminal Strip Cabinet
USC	United States Code
WTC	World Trade Center

WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
cfm	cubic feet per minute
ft	foot
h	hour
in.	inch
L	liter
m	meter
μm	micrometer
min	minute
s	second
V	volt
W	watt

GLOSSARY

Active fire protection – A means to help prevent the loss of life and property from fire by extinguishing, suppressing or controlling a fire through functional systems. Sprinkler systems, fire alarm systems and smoke control systems are examples of active fire protection.

Area of refuge – A floor area to which egress is made through a horizontal exit or supplemental vertical exit.

Combustible – A material that will ignite and burn when subjected to fire or heat.

Damper – A device installed in HVAC ductwork used to prevent the spread of fire and/or smoke. Dampers are provided to maintain a fire resistance rating of the assembly being penetrated.

Detector – An initiation device that automatically detects a change in state, such as presence of smoke, high temperature or abnormal rate of temperature rise.

Fire alarm system – A system, automatic or manual, arranged to give a signal indicating a fire emergency and initiate the appropriate response.

Fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

Fireproofing – A method used to provide a fire resistance rating to a building component.

Firestopping – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

Initiation device – A system component that originates a change in state signal in the fire alarm system. An initiation device begins the life safety processes, such as evacuation, HVAC shut down, elevator recall, etc.

Manual fire alarm box – A manually operated initiation device that originates a change in state signal in the fire alarm system.

Means of egress – A continuous and unobstructed path of vertical and horizontal travel from any point in a building to a public way. The means of egress consists of: the exit access, the exit and the exit discharge.

Noncombustible – A material that does not ignite or burn when subjected to fire and heat.

Notification appliance – A fire alarm system component such as a bell, horn, speaker, or strobe that provides audible, tactile, or visible outputs, or any combination thereof.

Passive fire protection – A means to help prevent the loss of life and property from fire by increasing the time to ignition or time to failure of a material. Providing fire separations and divisions, applying sprayed fire-resistive material and enclosing structural members with noncombustible materials are examples of passive fire protection.

Smoke and heat venting – A process used to move products of combustion to the outdoor air.

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

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

The specific objectives were:

1. Determine why and how WTC 1 and WTC 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 current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze 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 WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze 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; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate 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; Project Leader: Dr. Richard G. Gann	Reconstruct 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; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

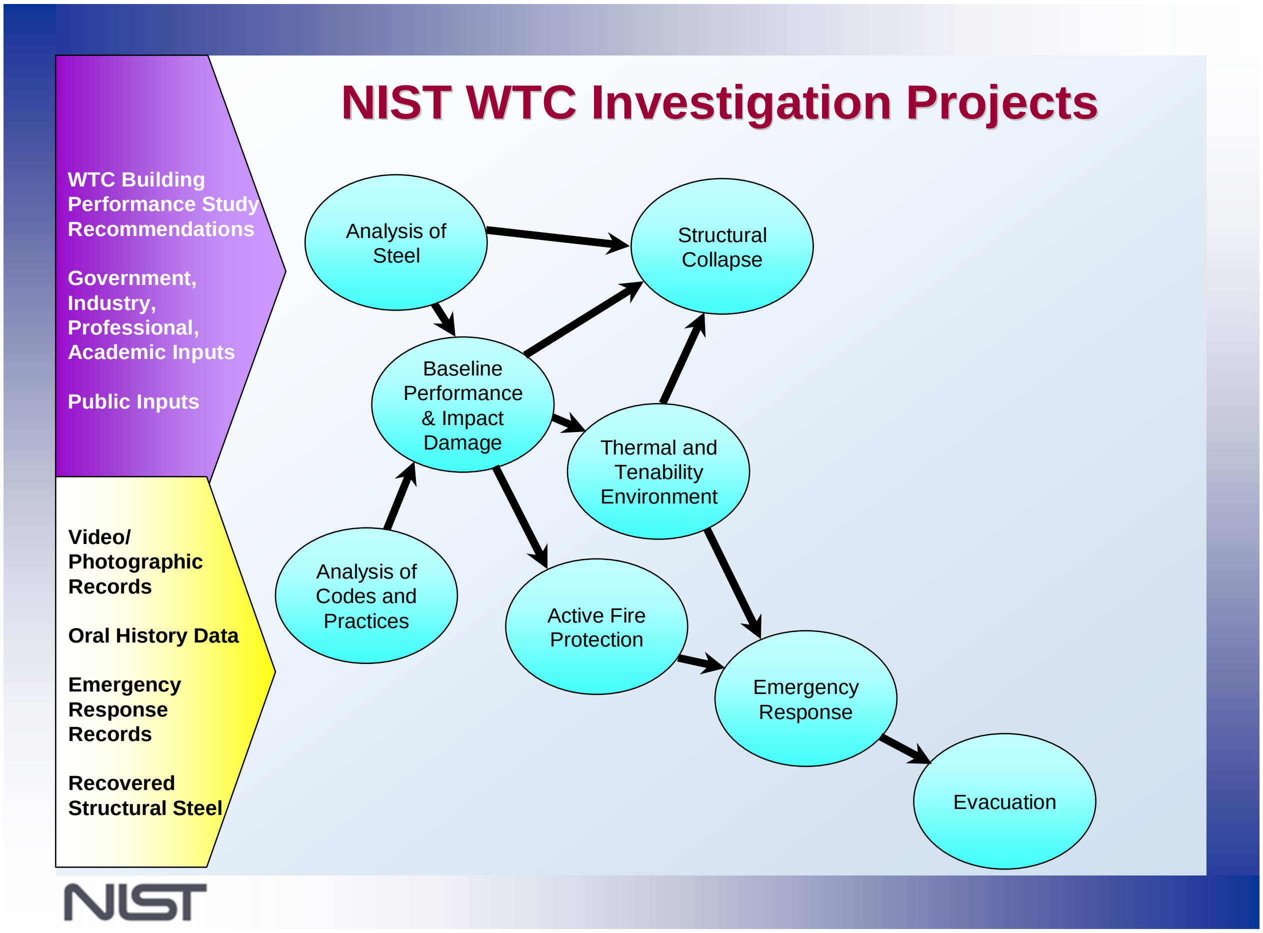

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

E.1 FIRE ALARM HISTORY AND APPLICATION

The application, performance, and use of fire alarms have changed over time through the development of technology, and the public's expectation for fire safe buildings. The goal of the early systems was to enhance property protection through early notification of first responders to initiate human intervention that would limit property damage. Although life saving acts were performed by first responders, the intent of the first fire alarm systems was to summon first responders to the fire, not to notify building occupants of an impending fire emergency.

It wasn't until major studies published in 1962 by Mc Guire and Ruscoe and the Federal Fire Council ("Needed—Protection for People") that it was recognized that the majority of fire protection devices in the market were devoted to property protection, not life safety enhancement. This realization has led to the development of a more holistic approach to fire protection that includes the fire alarm as one of numerous building systems involved in both occupant life safety and property protection.

The role played by a fire alarm system in the overall fire protection goals of a building is usually guided by codes and standards adopted for the project, or enforced within the jurisdiction of the project. As an interstate compact under the U.S. Constitution, the Port Authority was not subjected to any state or local building codes. The Building Code of the City of New York (BCNYC) provides the criteria for the type, location, and installation requirements for fire alarm protection within buildings in the City of New York. The code has adopted sections, but not the full content of the National Fire Alarm Code and National Electrical Code, as a Reference Standard (RS 17-3) for the installation of fire alarm systems. As in the case of model building codes, the BCNYC has referenced specific editions of the supporting codes and standards, such as the National Fire Alarm Code and National Electrical Code, which are not the most current editions published. This is due to the fact that standards are constantly undergoing revision to address new technologies and to incorporate issues identified during application of the standards. Also, a code or standard that is in effect when a system is designed is usually applied to the system during its existence, even if new codes or standards are developed or adopted by the authority having jurisdiction during the time between when the project was approved and when it is completed. As such, the most recent codes and standards are usually not applicable to a project due to the lag time between code or standard development and its adoption by an authority having jurisdiction over any project.

E.2 WORLD TRADE CENTER (WTC) 1, 2, AND 7 FIRE ALARM INTRODUCTION

The successful function and operation of a fire alarm system is dependent on its design, equipment, installation, maintenance, and on its use during an emergency. The majority of the documentation of the fire alarm systems in WTC 1 and WTC 2 were kept on the 81st floor of WTC 1, which served as the fire alarm contractor's office. This material was lost with the towers. Limited documentation maintained off-site, along with information gained from personnel involved with the systems, allowed for the re-creation of the system's design development, intended functions, and installation architecture. Actual documentation and personal experiences relevant to the systems function and use during the events of

September 11, 2001 are sporadic in detail, with very limited documentation on the actual use or functional interaction with the building occupants and other life safety systems.

The documentation and personal experiences relating to the WTC 7 system were limited, and only paint a partial picture of its equipment and architecture. Maintenance documentation was available, showing that the system was tested on a regular basis, but there was no documentation available on its design development, installation, or use. The information on the performance of the fire alarm system on September 11, 2001, is limited to a printout reporting of the systems alarm condition to an off-site monitoring service.

E.3 NORMAL OPERATIONS AND FIRE EMERGENCY RESPONSE

The Port Authority of New York and New Jersey (PANYNJ or Port Authority) had a Fire Safety Plan for WTC 1, 2, and 7 that provided direction for fire emergency response and was organized around a hierarchy of staff associated with its implementation. At the top of this hierarchy was the WTC Fire Safety Director. The Fire Safety Director oversaw fire emergency response until the arrival of The Fire Department of the City of New York (FDNY or Fire Department), and was responsible for gathering all necessary information for the Fire Department, which he/she relayed to the Chief upon his/her arrival. In WTC 1 and WTC 2, subordinate to the Fire Safety Director was the Assistant Fire Safety Coordinator, who was responsible for the availability and state of readiness of the Fire Brigade and the entire Emergency Response Team (members of the WTC Division of the Port Authority Police, who receive firefighting training and staff the WTC Fire Brigade). In WTC 7, the Fire Safety Director also performed the functions of the Assistant Fire Safety Coordinator as identified above. WTC 7 also had a Fire Brigade that the Fire Safety Director was responsible for organizing and training.

In addition to the WTC 1 and WTC 2 Assistant Fire Safety Coordinator, the towers had an Emergency Response Team consisting of Deputy Fire Safety Directors, Lobby Deputy Fire Safety Directors, Floor Wardens and Deputy Floor Wardens. Deputy Fire Safety Directors were responsible for performing the duties of the Assistant Fire Safety Coordinator in his/her absence and staffing the Fire Command Station for the purposes of executing the fire safety plan. At the end of the hierarchical chain for WTC 1, 2, and 7 were Floor Wardens and Deputy Floor Wardens, who were responsible for assessing conditions and assisting in evacuation of floor occupants on their respective floors upon direction from the Fire Brigade and/or Fire Command Station. Floor Wardens, Deputy Floor Wardens, and their alternates were appointed tenants or employees of the WTC complex (SafirRosetti 2002; Kastner 1990; PANYNJ 2001).

Fire drills were conducted at WTC 1, 2, and 7 every six months under the direction of the Floor Warden and Deputies of the Floor Warden. During the drills all employees, occupants, and visitors of the floor where the drill was conducted were physically required to leave their office areas and evacuate to a central hallway, near a stairwell. In addition, regular training exercises were conducted by the Port Authority and the Fire Department, the designated lead authority responsible for command of fire incidents at the WTC complex. The exercises oriented new staff to the building, its equipment and the appropriate emergency response procedures and served as a reminder to existing staff in the Port Authority and New York City Fire Department.

Fire inspections were performed annually in each tenant space to limit the risk of life and property loss from fire. A written report was prepared for all fire inspections and was maintained by the Fire Safety

Office. Any deficiencies or violations were noted in the report and forwarded to the appropriate person in the tenant space for correction.

Upon discovery of fire or smoke, the Fire Safety Plan called for occupants to activate the nearest building manual fire alarm station, typically at the intersecting corridor, and to notify the WTC police via telephone. The Police Desk dispatched the Fire Brigade and verified transmission of the alarm to the New York City Fire Department. The Fire Safety Director could also initiate evacuation from the area or the entire building. In this situation, the fire alarm emergency voice communication system was activated on the floors to be evacuated. It is important to note that the transmission of the alarms to the building occupants in WTC 1 and WTC 2 was not automatic and required the Fire Safety Director's initiation. Tenant Fire Safety Procedures exercised during regular fire drills require that building occupants proceed to the corridor areas to wait for verbal instructions provided over the fire alarm emergency voice communication speakers.

E.4 ORIGINAL BUILDING FIRE ALARM SYSTEM

The WTC was designed in accordance with the New York City Building and Fire Prevention Codes of 1968, in effect at the time of the building's construction. The Port Authority of New York and New Jersey's objective was to adhere to or exceed local code requirements whenever practical.

In addition to legislated building codes, the Port Authority relied on nationally recognized fire safety standards published by the American National Standards Institute (ANSI) and the National Fire Protection Association (NFPA), as well as internal protocols established with fire officials in the city. Two noteworthy protocols included the "Protocol For Periodic Joint Port Authority/Fire Department of New York Inspections of Port Authority New York City Facilities" of 1988 and the "WTC/FDNY Joint Protocol for Inspectional Activity at the World Trade Center Complex" of 1986. The Port Authority maintained a working relationship with the New York City Fire Department through these protocols that allowed the Fire Department access for inspections and evaluation of life safety and fire protection systems at the complex. The Fire Department was provided with the authority to issue advisory reports resulting from their inspections, which the Port Au

Fire alarm systems have the capability and are usually configured to initiate an alarm signal automatically upon alarm initiation. Means are available to notify building occupants at risk automatically by an alarm signal upon activation of the fire alarm system.

- There is a disparity in performance requirements for the different types of circuits common to a fire alarm system. As an example, a Class A Style 7 Signaling Line Circuit will continue to perform if the circuit experiences a short. A Class A Style Z Notification Appliance Circuit will not perform if it experiences a short. A Signaling Line Circuit may be required to turn on loudspeakers connected to a Notification Appliance Circuit. If an event were to cause a short on both circuits, then the Signaling Line Circuit would be able to turn on Notification Appliance Circuits serving the loudspeakers, but the Notification Appliance Circuits providing the voice message or alarm tone to the speakers would not perform. Since the primary intent is to broadcast from the loudspeakers through the Notification Appliance Circuits, it would be appropriate for the Notification Appliance Circuits to have the same performance requirements as the Signaling Line Circuits.

- The disparity in circuit performance is also relevant to the floor warden and standpipe fireline telephones. The fault tolerance performance standards for telephone communication circuits are not as well defined as compared to other types of fire alarm circuits. This limits the survivability characteristics of the telephone communication circuits in comparison to other types of fire alarm circuits. Although manufacturers commonly provide some survivability characteristics, there is not a standard requiring minimum circuit performance. As with the Notification Appliance Circuits, a Signaling Line Circuit with robust survivability from functional faults may be controlling the operation of a telephone circuit, which has minimal survivability capabilities. If a fire alarm system objective is to provide enhanced survivability characteristics through a Signaling Line Circuit that will control a required function such as a telephone, then it would be appropriate for the survivability performance characteristics of the circuits for the required function to match the performance of the circuit supporting the function.

- Although there is evidence that the floor warden telephones were used, the after action interviews of the firefighters conducted by the National Institute of Standards and Technology (NIST) did not find that there was any attempt to use the standpipe fireline telephone system. This is not uncommon since the firefighters are trained to use their radios as the preferred means of communication. The resources used to install a firefighter telephone system would appear to be better served by installing radio repeaters to support their radio communication instead of installing dedicated telephones.

- Although the fire alarm systems in WTC 1 and WTC 2 used multiple communication path risers, the systems experienced performance degradation, especially in WTC 1 where all fire alarm notification and communication functions appear to have been lost above the floors of impact. The use of multiple risers does improve physical survivability in tall buildings, but other measures may be necessary to address the extensive damage associated with a possible explosion. Additional fire alarm system survivability can be gained through the location of the fire alarm equipment and a riser in a central building core area, and by protecting the area with structural hardening and fire-resistive construction. Similar enhancements can be achieved through the provision of additional fire alarm risers remotely located away from the central core, supported by structural members, and provided with fire-resistive protection.

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Chapter 1
INTRODUCTION

1.1 PURPOSE

The purpose of this report is to document the design, installation, and modifications to the fire detection and alarm system for buildings 1, 2, and 7 of the World Trade Center (WTC), including system performance during the September 11, 2001, attack.

1.2 HISTORY OF FIRE ALARM SYSTEMS

The application, performance, and use of fire alarms have changed over time through the development of technology, and the public's expectation for fire safe buildings. The history of fire alarms began in 1847, when the first municipal fire alarm system was installed in New York City. This first system consisted of a dedicated telegraph system connecting City Hall to outlying fire stations. The central monitoring and emergency force notification concept was improved upon in 1852, when Boston installed 40 fire alarm signaling boxes throughout the city that provided a localized signal directly to first responders. This technology was further enhanced through the installation of fire alarm telegraph stations within buildings willing to pay for the service. The goal of all of these systems was to enhance property protection through early notification and to initiate human intervention that would limit property damage. Although life saving acts were performed by first responders, the intent of the first fire alarm systems during this time was to summon first responders to the fire, not to notify building occupants of an impending fire emergency.

Technology development continued with the introduction of automatic heat detectors that were remotely monitored. These devices were introduced in New York City as a function of a fire alarm system in the 1870s. This was the beginning of automatic fire department notification by a fire alarm system without the need for human action. Again, the intent was to provide early fire department notification for property protection, not building occupant notification. Fire detection technology improvements continued with the introduction of smoke detection in the 1930s, which had limited success until the 1960s, when lower costs and simpler technology made the devices more attractive to the market place. But, again, the primary use of both heat and smoke detectors was to enhance property protection.

It wasn't until major studies published in 1962 by Mc Guire and Ruscoe and the Federal Fire Council ("Needed—Protection for People") that it was recognized that the majority of fire protection devices in the market were devoted to property protection, not life safety enhancement for people. This realization has led to the development of a more holistic approach to fire protection that includes the fire alarm as one of numerous building systems involved in occupant life safety and property protection.

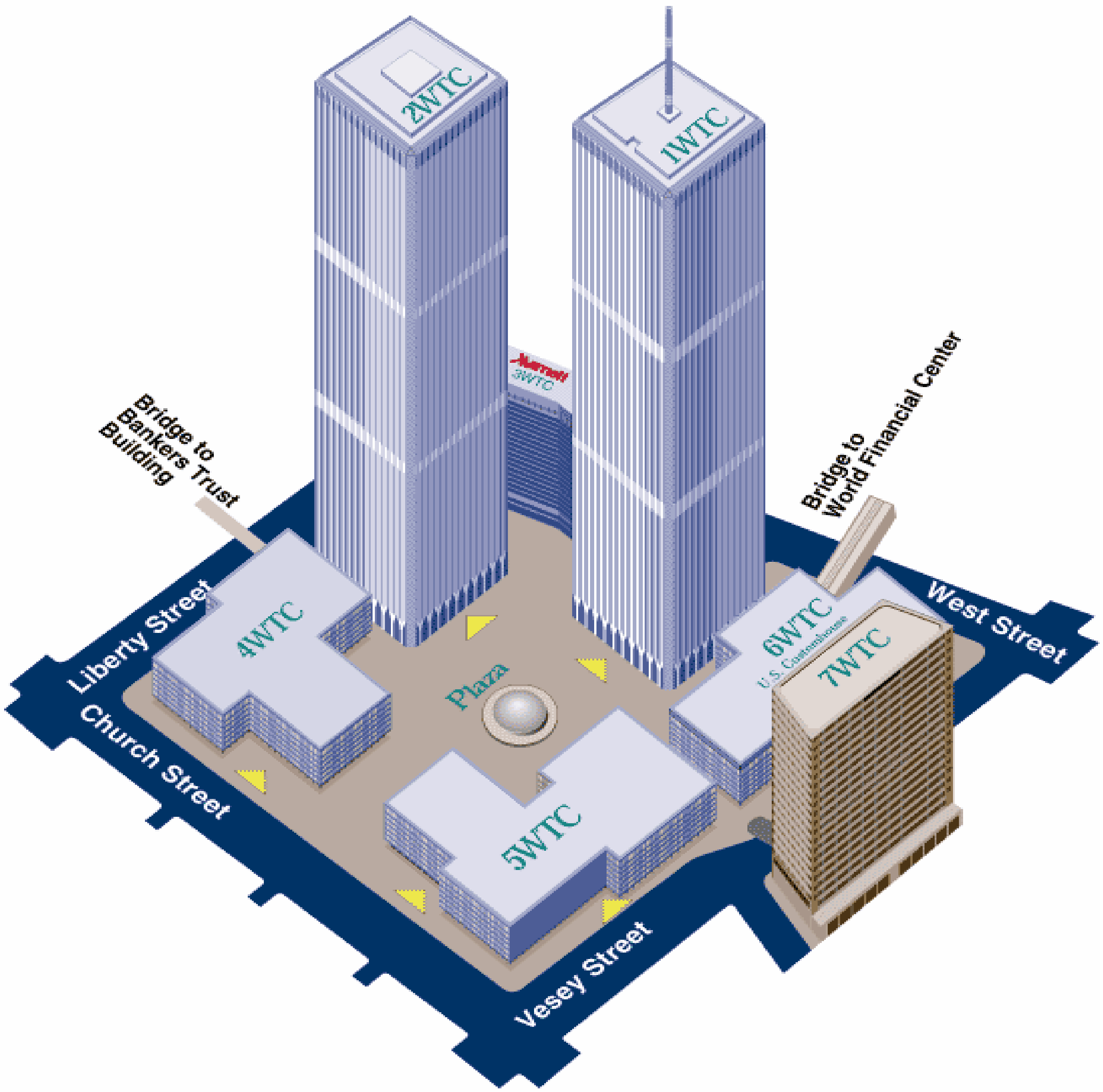
The role played by a fire alarm system in the overall fire protection goals of a building is usually guided by codes and standards adopted for the project, or enforced within the jurisdiction of the project. The codes and standards adopted represent the minimum performance requirements for the fire alarm system, along with all other components, structures, and systems that make up a "building." The first fire alarm signaling standard, “General Rules for the Installation of Wiring, and Apparatus for Automatic Fire Alarms, Hatch Closers, Sprinkler Alarms, and Other Automatic Alarm Systems and Their Auxiliaries” was published in 1899 by the National Fire Protection Association (NFPA). This standard was the first of numerous editions that preceded the “National Fire Alarm Code” (NFPA 72), which is the baseline standard universally used in the United States today for fire alarms. The document provides the performance requirements for fire alarm equipment and devices, but does not provide direction on where a system or its devices are required. In addition to this performance standard for the fire alarm equipment and devices, a separate code provides direction for the installation of the fire alarm’s cable (wire) and supporting hardware. The universal baseline code used in the United States for power cabling and hardwire is the “National Electrical Code” (NFPA 70), which includes fire alarm requirements. The National Electrical Code does not provide direction on what devices or equipment to install, only how to install the supporting cable and hardware. The what, when, and where fire alarm system requirements for a building are defined by the building code for the jurisdiction having authority over the protected structure. The Building Code of the City of New York (BCNYC) provides the criteria for the type, location, and installation requirements for fire alarm protection within buildings in the City of New York. The code has adopted sections, but not the full content of the National Fire Alarm Code and National Electrical Code, as a Reference Standard (RS-3) for the installation of fire alarm systems. As with all model building codes, the BCNYC has referenced editions of the supporting codes and standards, such as the National Fire Alarm Code and National Electrical Code, which are not the latest editions. Also, a code or standard that is in effect when a system is designed is applied to the system during its existence, even if new codes or standards are developed or adopted by the authority having jurisdiction during the time between when the project was approved and when it is completed. As such, the most recent codes and standards unless they contain retroactive provisions are usually not applicable to a project due to the lag time between code or standard development and its adoption by an authority having jurisdiction over any project.

As an interstate compact under the U.S. Constitution, the Port Authority was not subjected to any state or local building codes. Still, the Port Authority of New York and New Jersey’s (PANYNJ’s or Port Authority’s) objective was to adhere to or exceed local code requirements whenever practical.

1.3 WTC 1, 2, AND 7 INTRODUCTION

Figure 1–1 shows the buildings in the WTC complex. The availability and volume of documented history outlining the development of the alarm systems for WTC 1 and WTC 2 was substantially greater than what was available for WTC 7. The information available for WTC 7 was limited to system specifications, basic installation criteria, design drawings, and maintenance records. As such, the documentation and analysis of the WTC 7 fire alarm system is based on the limited information available.

The history of the WTC 1 and WTC 2 fire alarm system is well documented considering the fact that the central repository of the system’s documentation was lost on September 11, 2001. The fire alarm system protecting the WTC towers was a direct result of February 26, 1993, when a bomb exploded in the B-2 underground parking level of the WTC virtually destroying all the WTC 1 and WTC 2 fire alarm signaling and communication entering the Operations Control Center (OCC). That event effectively made the fire alarm system at the time nonfunctional. Although electricians were able to restore, the operability of the fire alarm, public address, and manual station systems within two weeks, the Port Authority questioned the WTC’s existing fire alarm system’s capability to provide reliable life safety support functions. In particular, the existing system, which was developed and supplied exclusively for the WTC by the American Multiple System Company, was no longer manufactured, and the software was not supported. In addition, the 1993 bombing proved the system infrastructure to be vulnerable to a single point of failure. Based upon the inability to obtain spare parts and system support and the vulnerability of the system infrastructure, on March 17, 1993, the Port Authority signed a purchase order for $1,930,000, authorizing the purchase of a new, state-of-the-art addressable fire alarm system for the WTC complex (including buildings 4 and 5, which were also protected by the fire alarm system protecting buildings 1 and 2) (PANYNJ 1993). New fire alarm drawings were developed for WTC 1, 2, 4, and 5 and were issued for bid on March 25, 1993. On April 5, 1993, the fire alarm installation project was awarded for construction. On March 26, 1997, PANYNJ issued another purchase order for $3,500,000 to complete the fire alarm retrofit project.



Source: Drucker 2001.

Figure 1–1. WTC complex.

The replacement fire alarm system was manufactured by Cerberus Pyrotronics Services, and was a MXL-V fire alarm system with emergency voice/alarm communication capabilities. The system supported a decentralized infrastructure that consisted of six independent fire alarm systems protecting WTC 1, WTC 2, WTC 4, WTC 5, Concourse Level, and the Sub-Grade Levels. The four buildings had a master monitoring and control Network Command Center (NCC) located at each building's Fire Command Station (FCS) which were located in the entrance lobby of each building. Building 4 was also provided with redundant remote NCC that monitored Building 5, and Building 5 was provide with a redundant remote that monitored Building 4. The Concourse and Sub-Grade master NCCs' were installed in the WTC 2 FCS, and remote NCCs' for the Concourse and Sub-Grade were installed in the WTC 1 FCS along with a remote NCC for WTC 2. Furthermore, a redundant remote NCC for monitoring and control of all six systems was installed in the OCC located on the B1 Level below WTC 2 (Drucker 2004).

Due to the scope of the fire alarm project, and since the bombing required the Sub-Grade Levels to undergo a major restoration, the fire alarm system design for the WTC site was separated into four sub-projects:

1. WTC 1 and WTC 2
2. WTC 4 and WTC 5
3. Concourse Level
4. Sub-Grade Level

The installation of the WTC 1 and WTC 2 fire detection and alarm systems was further separated into three phases to address the constructability of the new systems, while enhancing fire protection capabilities in the quickest manner possible and to ensure fire protection continuity during the switchover to the new fire alarm system. The phases were planned as follows:

Phase 1 – The scope of this phase required the installation of the backbone for the systems (see Fig. 1–2). The backbone consisted of the building's master fire alarm panel (MXL-V), remote transponder panels (MXL-VR), and amplifier cabinets. Terminal Strip Cabinets (TSC) were installed on each floor to provide cable termination for existing or new fire alarm devices that were wired back to the transponder panels during Phase III. Interface Cabinets (IC) were installed, which contained interface modules to provide monitoring and control functions between the existing systems (CR-7) and new system (MXL-V) during the transition. Older documentation (Marchese 1993) indicates the phase was originally scheduled to be completed in September 1993, while the Buchsbaum/Mizrahi 1994 article indicates both Phase I and II were to be completed by the beginning of 1995. In 1997, a memo was issued to the WTC 2 tenants indicating that Phase I was completed (Sileo 1997).

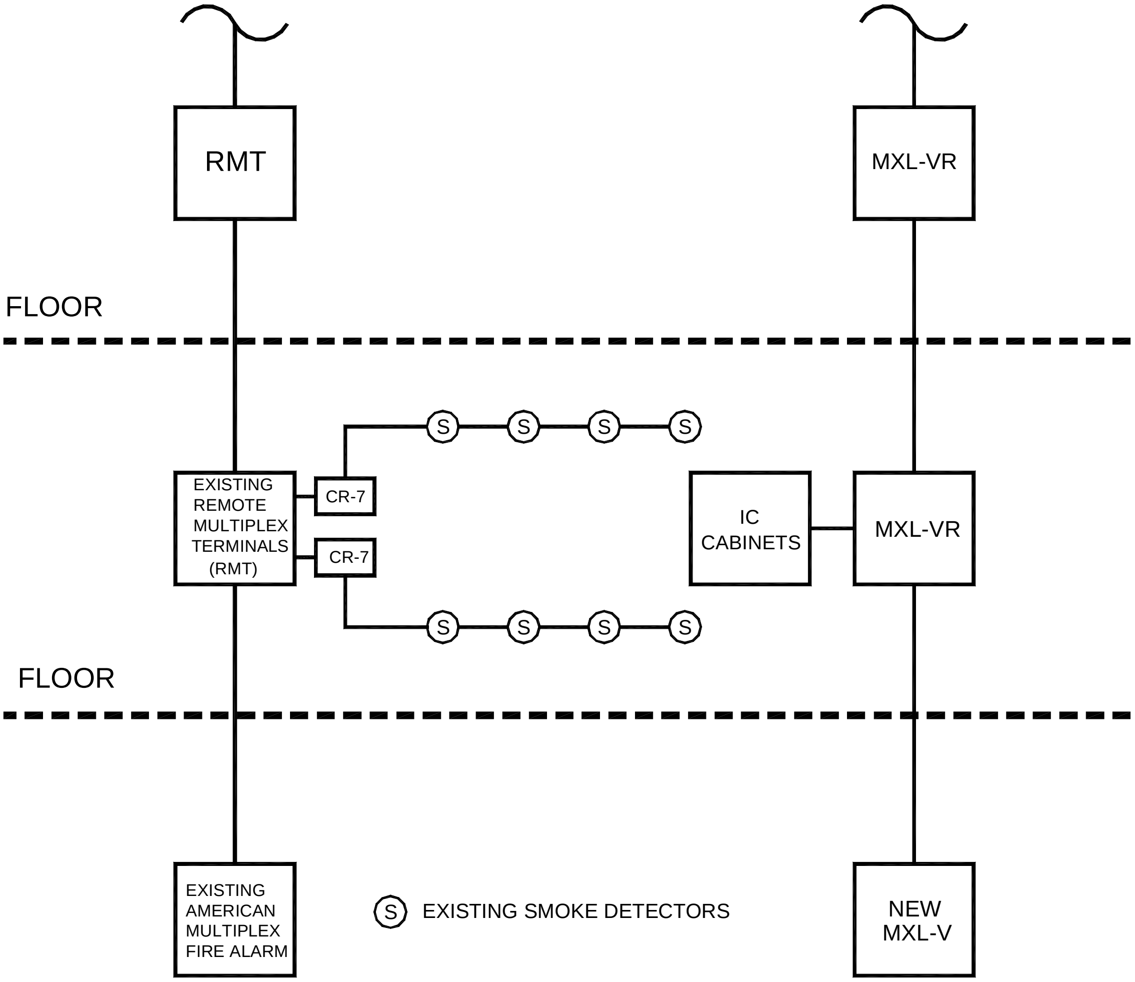


Figure 1–2. Phase I backbone.

Phase II – Transition of the monitoring and control of existing fire alarm devices to the new system was accomplished as Phase II (see Fig. 1–3). During this phase both the existing American Multiplex system and the MXL-V system were operating concurrently. Also, the new core area speakers, warden phones, and pull stations were connected to the new fire alarm system. Older documentation (Marchese 1993) indicates the phase was originally scheduled to be completed in October 1993, while the Buchbaum 1994 article indicates both Phase I and II were to be completed by the beginning of 1995. In 1997, a memo was issued to the WTC 2 tenants indicating that Phase II was completed (Sileo 1997).

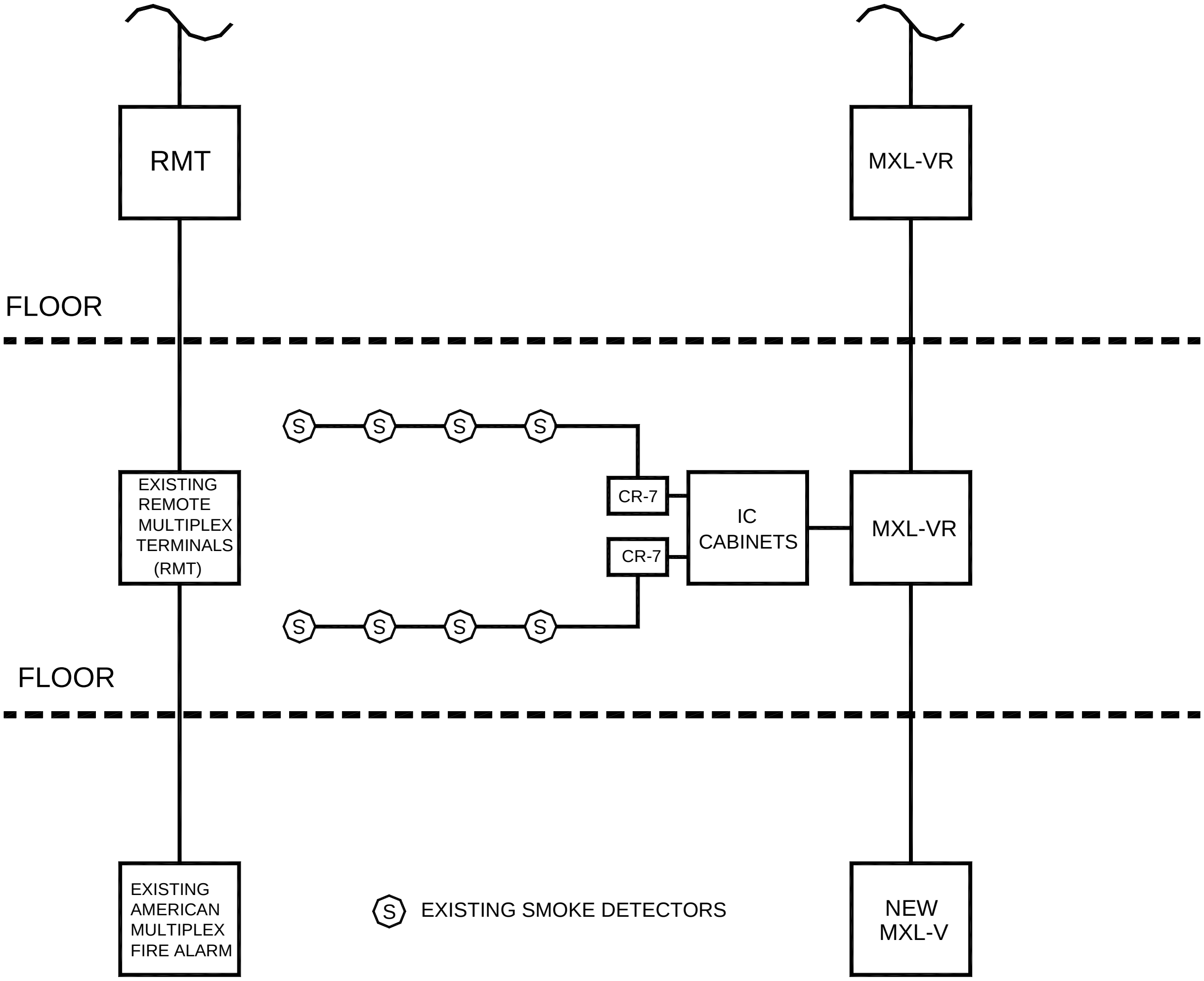


Figure 1–3. Phase II transition.

Phase III – This phase required replacing all existing fire detection devices, and expanding the new speaker and strobe capabilities into all tenant and mechanical spaces. All areas protected by the new fire alarm system were designed to be in compliance with the New York Building Code – Class “E” system requirements, and other applicable code criteria. The existing American Multiplex system was to be disconnected and removed. This had not occurred by September 11, 2001.

Although the original schedule for completion was not found, the Buchbaum 1994 article indicates this phase was planned to be completed by the end of 1996. In 1997, a memo was issued to the WTC 2 tenants indicating that the Phase III portion of the fire alarm system that included the installation of manual pull stations and warden telephones was completed (Sileo 1997). However, there are conflicting reports as to the actual status of the fire alarm project. The most recent report on the status of completion for the fire alarm retrofit indicated the following (PACO 2002):

1. WTC 1 – 85 percent complete.
2. WTC 2 – 80 percent complete.
3. WTC 4 and 5 – 60 percent complete.
4. Concourse Level – 100 percent.
5. Sub-Grade Levels – 0 percent complete.
6. Sub-Grade Levels Backbone Modification – 0 percent complete.
7. Convert existing fire alarm protection in Mechanical Rooms to new system – 40 percent complete.
8. Global Fiber Optic Loop interconnecting all six fire alarm systems – 0 percent complete.

It was estimated that 25 percent of the original American Multiplex system was still in use at the time of the attack (PACO 2002). Documentation was not found providing a description of the extent and what type (existing or new) of fire alarm protection was provided in each building on September 11, 2001.

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Chapter 2
NORMAL OPERATIONS AND FIRE EMERGENCY RESPONSE

The Port Authority of New York and New Jersey (PANYNJ or Port Authority) had a Fire Safety Plan for World Trade Center (WTC) 1, 2, and 7 that provided direction for fire emergency response and was organized around a hierarchy of staff associated with its implementation. At the top of this hierarchy was the WTC Fire Safety Director. The Fire Safety Director oversaw fire emergency response until the arrival of the Fire Department of the City of New York (FDNY or Fire Department), and was responsible for gathering all necessary information for the FDNY, which he/she relayed to the Chief upon his/her arrival. In WTC 1 and WTC 2, subordinate to the Fire Safety Director was the Assistant Fire Safety Coordinator, who was responsible for the availability and state of readiness of the Fire Brigade and the entire Emergency Response Team (members of the WTC Division of the Port Authority Police, who receive firefighting training and staff the WTC Fire Brigade). In WTC 7 the Fire Safety Director also performed the functions of the Assistant Fire Safety Coordinator as identified above. WTC 7 also had a Fire Brigade that the Fire Safety Director was responsible for organizing and training.

In addition to the WTC 1 and WTC 2 Assistant Fire Safety Coordinator, the towers had an Emergency Response Team consisting of Deputy Fire Safety Directors, Lobby Deputy Fire Safety Directors, Floor Wardens and Deputy Floor Wardens. Deputy Fire Safety Directors were responsible for performing the duties of the Assistant Fire Safety Coordinator in his/her absence and staffing the Fire Command Station (FCS) for the purpose of executing the fire safety plan. At the end of the hierarchical chain for WTC 1, 2, and 7 were Floor Wardens and Deputy Floor Wardens, who were responsible for assessing conditions and assisting in evacuation of floor occupants on their respective floors upon direction from the Fire Brigade and/or FCS. Floor Wardens, Deputy Floor Wardens, and their alternates were appointed tenants or employees of the WTC complex (SafirRosetti 2002; Kastner 1990; PANYNJ 2001; PANYNJ).

2.1 FIRE COMMAND STATION

WTC 1, 2, and 7 FCS were located in the lobbies of each building. WTC 1 and WTC 2 had redundant command centers. A back-up command center for WTC 1 was located at the Operations Control Center (OCC) on the B1 sub-grade level of WTC 2. The back up command center for WTC 2 was located in the WTC 1 FCS and the OCC. The FCSs facilitated two-way communication between mechanical rooms, elevator control rooms, and each floor through telephone, two-way fire alarm box, fire standpipe telephone, portable radios, public address systems, elevator intercom, and cellular telephones issued to Floor Wardens. Additional information and equipment valuable to the Emergency Response Team was also maintained at the FCSs. This information and equipment included copies of all appropriate building information, a minimum of one set of master keys for the buildings, a list of floor wardens and their contact information, and a list of mobility-restricted individuals and other tenants requiring special assistance in the event of evacuation (SafirRosetti 2002).

2.2 WTC 1 AND WTC 2 OPERATIONS COMMAND CENTER

The OCC for the WTC (located in level B-1 of WTC 2) was where WTC Operations and Management Staff evaluated the operation of the buildings' systems including elevators, intercoms, and communications systems. During a fire incident, Operations Management staff assisted with evacuation upon request. The staff of the mechanical section of Operations Management operated fire pumps and manually activated smoke control upon request. They also secured sprinkler water shutoff valves upon request of the Fire Safety Director or FDNY Chief Commanding Officer. The staff of the electrical section of Operations Management reset smoke detector or fire alarm panels upon the request of the Fire Safety Director or FDNY Chief Commanding Officer when the fire incident had been secured. The staff of the electrical section also responded to electrical incidents and remotely secured related equipment upon request.

The backup command center at the OCC provided redundancy to FDNY at any of the FCSs in WTC 1, 2, 4, and 5 to operate systems in any of the four buildings.

2.3 FIRE PREVENTION AND FIRE PREPAREDNESS PROCEDURES

2.3.1 Fire Drills

Fire drills were conducted at WTC 1, 2, and 7 every six months under the direction of the Floor Warden and Deputies of the Floor Warden. During the drills all employees, occupants, and visitors of the floor where the drill was conducted were physically required to leave their office areas and evacuate to a central hallway, near a stairwell. Building tenants and persons designated as Floor Wardens and Deputy Floor Wardens were informed of the location, date, and time of the fire drill. Floor Wardens and Deputy Floor Wardens were responsible for informing all employees on their floor of the date and time of the drill.

2.3.2 Training Exercises

In addition, regular training exercises were conducted by the Port Authority and the Fire Department (the designated lead authority responsible for command of fire incidents at the WTC complex). The exercises oriented new staff and served as a reminder to existing staff in the Port Authority and Fire Department with the building, its equipment, and the appropriate emergency response procedures. In 2001, twelve of these training exercises were conducted before September 11th. Although the incidents of September 11, 2001, were beyond the expected scope of emergency response personnel, the emergency response plan was implemented, and many of the emergency response staff involved possessed a high level of familiarity with the building and its associated emergency procedures.

2.3.3 Fire Prevention Inspections

Fire inspections were performed annually in each tenant space to limit the risk of life and property loss from fire. It was the intent that as a result of the inspections, the likelihood of a fire occurring was minimized, or that if a fire occurred, the spread of the fire and its duration would be limited. Tenants were advised to limit combustibles and avoid locating combustible materials in aisles, under desks, or piled on top of office furniture. Smoking was not permitted in the buildings. Storage of materials was not permitted within 18 in. of the ceiling and sprinkler heads.

A written report was prepared for all fire inspections and was maintained by the Fire Safety Office. Any deficiencies or violations were noted in the report and forwarded to the appropriate person in the tenant space for correction.

In addition to annual tenant space inspections, WTC staff conducted daily operational inspections. The purpose of these inspections was to ensure that all necessary exits were maintained and available for egress, all exit hardware was functional, and there were no obstructions to means of egress within the WTC.

2.4 ALARM NOTIFICATION

Staff notification of a fire or smoke condition occurred when a smoke detector or sprinkler activation transmitted an alarm to the FCS in the affected building. Staff notification also occurred through activation of a manual pull station by a building occupant or a phone call reporting a fire or smoke condition to the WTC Police Desk and/or FCS.

Occupant notification in WTC 1 and WTC 2 was initiated manually from the FCS by the Fire Safety Director or his designees.

Occupant notification in WTC 7 was automatically provided in the event of fire alarm system activation.

2.5 FIRE SAFETY PLAN

Upon discovery of fire or smoke, the Fire Safety Plan called for occupants to activate the nearest building manual fire alarm station, typically at the intersecting corridor, and to notify the WTC police via telephone. The Police Desk would dispatch the Fire Brigade and transmit the alarm to the Fire Department. The WTC Fire Safety Director was responsible for transmission of the fire alarm and notification of the Fire Brigade, Floor Warden(s), and building occupants. If necessary, the Fire Safety Director utilized the Security Staff to restrict building occupant access to the area(s) affected by the incident. Staff at the Visitors' Desks were also notified to stop issuing visitors' passes to the area(s). The managers of the Windows on the World restaurant and Top of the World Observation Deck were notified of any facility emergency by the OCC Supervisor. The purpose of this notification was to reduce any panic or anxiety that may be experienced by tenants, visitors, and other guests upon observing the response of emergency personnel to the building/complex. Notification of an incident to building occupants was performed through the Property Management staff, which coordinated with the Fire Safety Director on issues directly affecting building tenants. During the emergency incident it was the responsibility of the Property Management Staff to supply information to the building tenants as appropriate.

The Fire Safety Director could also initiate evacuation from the area or the entire building. In this situation, the fire alarm emergency voice communication system was activated on the floors to be evacuated. Per Tenant Fire Safety Procedures exercised during regular fire drills, building occupants proceed to the corridor areas to wait for verbal instructions provided over the fire alarm emergency voice communication speakers. Occupants were instructed to evacuate the floor(s) using stairways to the designated “safe” area, which was at least three levels below the fire floor. Occupants were not to use the elevators. Occupants with special needs, requiring assistance in evacuating, were to be aided by the Floor Warden(s).

The WTC Fire Brigade members would respond to the floor directly below the fire floor and proceed to the fire floor utilizing stairways. Upon the initiation of evacuation procedures, Fire Brigade members conducted searches of the floor and utilized firefighting appliances as necessary to control the fire as much as possible until the arrival of the Fire Department, whereupon the Fire Brigade would transfer firefighting operations to the Fire Department. While in control of firefighting operations, however, the Fire Brigade was responsible for keeping the FCS and WTC Police Desk informed of all operational details.

Floor Wardens were to notify the FCS of any non-ambulatory or mobility restricted individuals requiring special assistance during evacuation, utilizing the fire alarm Floor Warden Phone system. Tenants requiring special assistance in evacuating the WTC would be assisted by members of the Fire Brigade upon notification of fire or smoke in the buildings. Fire Brigade members were dispatched via staffed freight elevators to the floor directly below the affected floor. Based on available information, the Fire Brigade would take the freight elevator to the fire floor, or if conditions were severe and the use of the freight elevators would expose these tenants to danger, tenants requiring special assistance were hand carried down the stairwells by members of the Fire Brigade to areas of refuge.

Occupants of the building located on the floor of fire incidence and above were evacuated to locations at least three or more floors below the fire floor. It was the responsibility of Floor Wardens via the fire alarm Floor Warden Phone system to inform the FCS (staffed by Deputy Fire Safety Directors) of the evacuation actions taken and location of evacuees.

If stairways serving the fire floor or floors above the fire floor were not usable due to fire, smoke, or overcrowding situations, the use of elevators could be considered for evacuation as long as the elevators used did not serve the fire floor, and the elevators did not connect to other shafts opening onto the fire floor. Only elevators staffed by fire fighters or other trained building personnel could be utilized for evacuation.

2.6 FIRE DEPARTMENT RESPONSE

The primary objective of the Fire Department was to perform rescue operations of persons in the building. This was achieved through ventilation of the building, entry into the building, and searches for persons trapped in the building. Another important objective of the Fire Department was to control and extinguish the fire. The Chief of the Fire Department was the highest-ranking uniformed firefighter and was responsible for all operations when on the scene.

2.6.1 Alarms

Alarms were received by FDNY by several means. “Nine-one-one” telephone calls were made to report fire. Activation of the fire alarm system within the buildings transmitted an alarm to the Fire Department. Fire alarms were also received from street pull boxes.

Upon alarm notification, Fire Department units were immediately dispatched to the scene. The average response time of the Fire Department in 2001 was less than 5 min.

2.6.2 Communication

Fire Department communications were achieved through VHF radios and hand-held radios. The VHF radios were used for dispatching units as well as communicating between apparatus (trucks, engines, etc.). Hand held radios were used on site during tactical operations. Repeaters were installed in the WTC complex after the 1993 bombing to amplify radio signals and help alleviate these difficulties. Communications between the Lobby Command Post and Fire Department units operating on upper floors were achieved through the fire alarm’s Standpipe Telephone System hard wire phones as well as hand held radios. The fire alarm hard wire phones consisted of Floor Warden phones, which were in-house fire alarm phones that connected the FCS in the lobby to each floor, and Standpipe Telephone phones, which connected the FCS to the fire pump room and each Standpipe Phone outlet.

FDNY has established firefighting procedures for high-rise office buildings. The main objectives are to locate, control, and extinguish the fire. The strategy in achieving these objectives includes determining the specific fire floor, search of the fire floor and the floor directly above, and evacuation of any persons found during the search. The building’s elevators, ventilation system, communications systems, and fire pumps are controlled and utilized. The ultimate goal is to control and extinguish the fire.

2.6.3 Support from Neighboring Fire Departments

FDNY maintained mutual agreements for two-way support with fire departments of neighboring jurisdictions, including Nassau and Westchester Counties, Jersey City, and the cities of Mt. Vernon and Yonkers. Historically, members of FDNY have responded to alarms in other municipalities and vice versa.

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Chapter 3
ORIGINAL FIRE ALARM SYSTEM PRIOR TO THE 1993 BOMBING AND MODIFICATIONS SUBSEQUENT TO 1993

The pre-1993 system outlined for the World Trade Center (WTC) encompassed the following facilities:

- WTC 1
- WTC 2
- WTC 4
- WTC 5
- Concourse Level
- Sub-Grade Level

The system integrated detectors and alarm devices from the various buildings, to be tied into a control panel for that building or level. All control panels simultaneously annunciated alarms and troubles at the Operations Control Center (OCC).

The system consisted of American Multiplex Remote Monitoring Transponders (RMT), on every third floor, connected to the Digital Computer and Console in the OCC on the B-1 Sub-Grade Level. The Transponder monitored Pyrotronics CR-7 Equipment connected to type DI-2, DI-3, DI-4A, and DI-6 smoke detectors (non-addressable type), Pyrotronics System 3 panels, tenant proprietary systems, waterflow switches, tamper switches, and control contacts (PANYNJ 1986).

Pryrotronics XL3 smoke detector systems, with addressable type detectors, were installed in the mechanical equipment rooms of both WTC 1 and WTC 2, and connected via a CXL Communication Device to a console in the OCC.

Manual Pull Stations were wired to an existing Executone system which alarmed directly to the Fire Department.

The Public Address Communication System with manually activated selection of floor was also located at the OCC. Alarms from these systems were called in to the Fire Department, manually, by the Port Authority Police on duty 24 h a day at the Police Desk.

3.1 FIRE ALARM SYSTEM

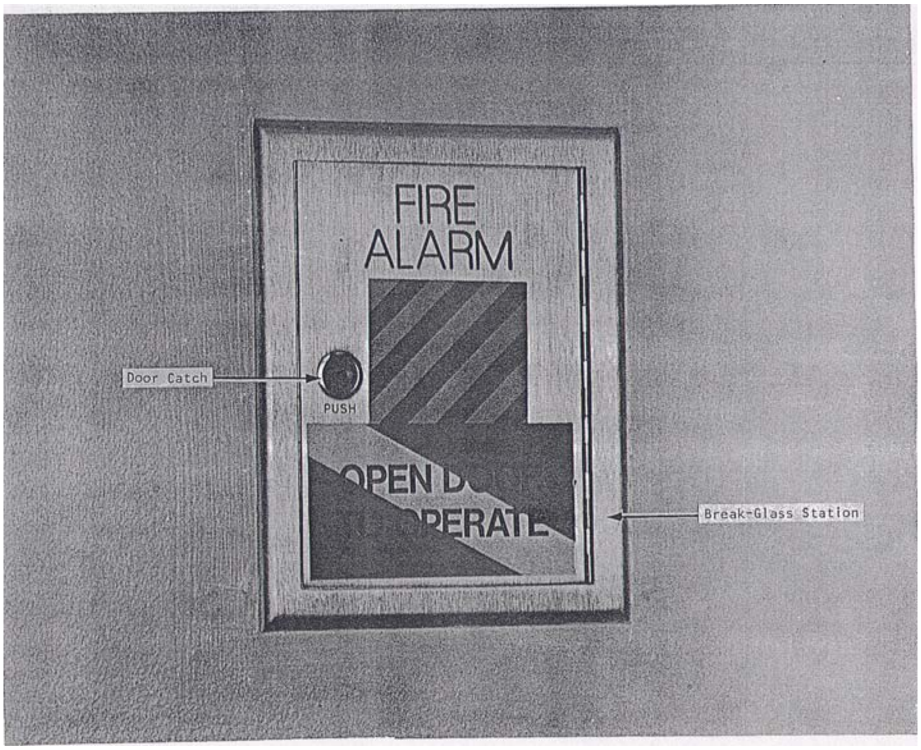
The Fire Alarm System in the WTC combined fire alarm signaling with an intercom, enabling fire safety personnel to speak to the person turning in the alarm. Alarms could be initiated at break glass stations in public and common areas throughout the WTC. Control and intercom equipment for the system were located in the Police Security Room, on Level B1.

3.1.1 Description

Figures 3–1, 3–2, and 3–3 illustrate the break glass stations used in the pre-1993 fire alarm system. The break glass stations combined a break glass alarm station and a two-way intercom in one unit. The alarm-setting mechanism was exposed by opening the spring-loaded door catch (see Figs. 3–1 and 3–2).

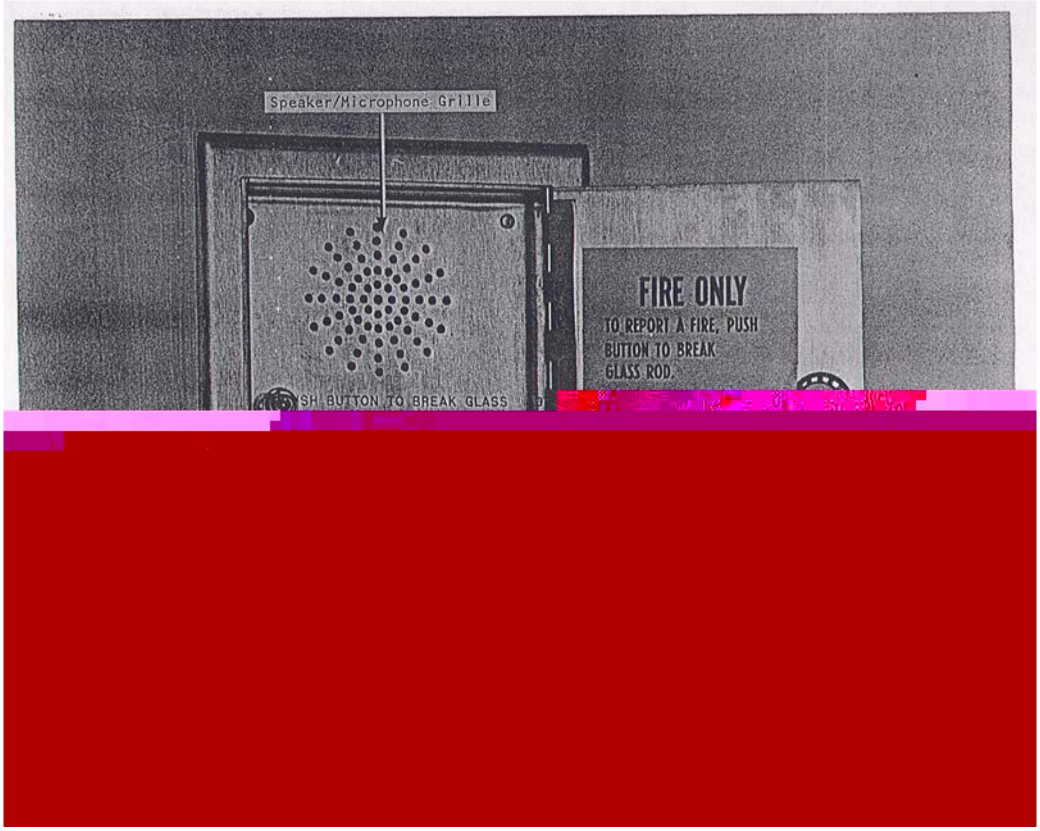
The glass rod was broken by pushing the spring-loaded pushbutton. A protective shield helped to stop flying glass (see Figs. 3–2 and 3–3). The switch actuating plunger activate the alarm. The mechanical relationship between the glass rod and the pushbutton is shown in Section B-B of Fig. 3–3.

The speaker/microphone, behind the grille, permitted conversation over the fire intercom system to the Police Security Room on Level B1. The break glass stations were model C3002, manufactured by Executone, Inc., Long Island City, New York 11101.



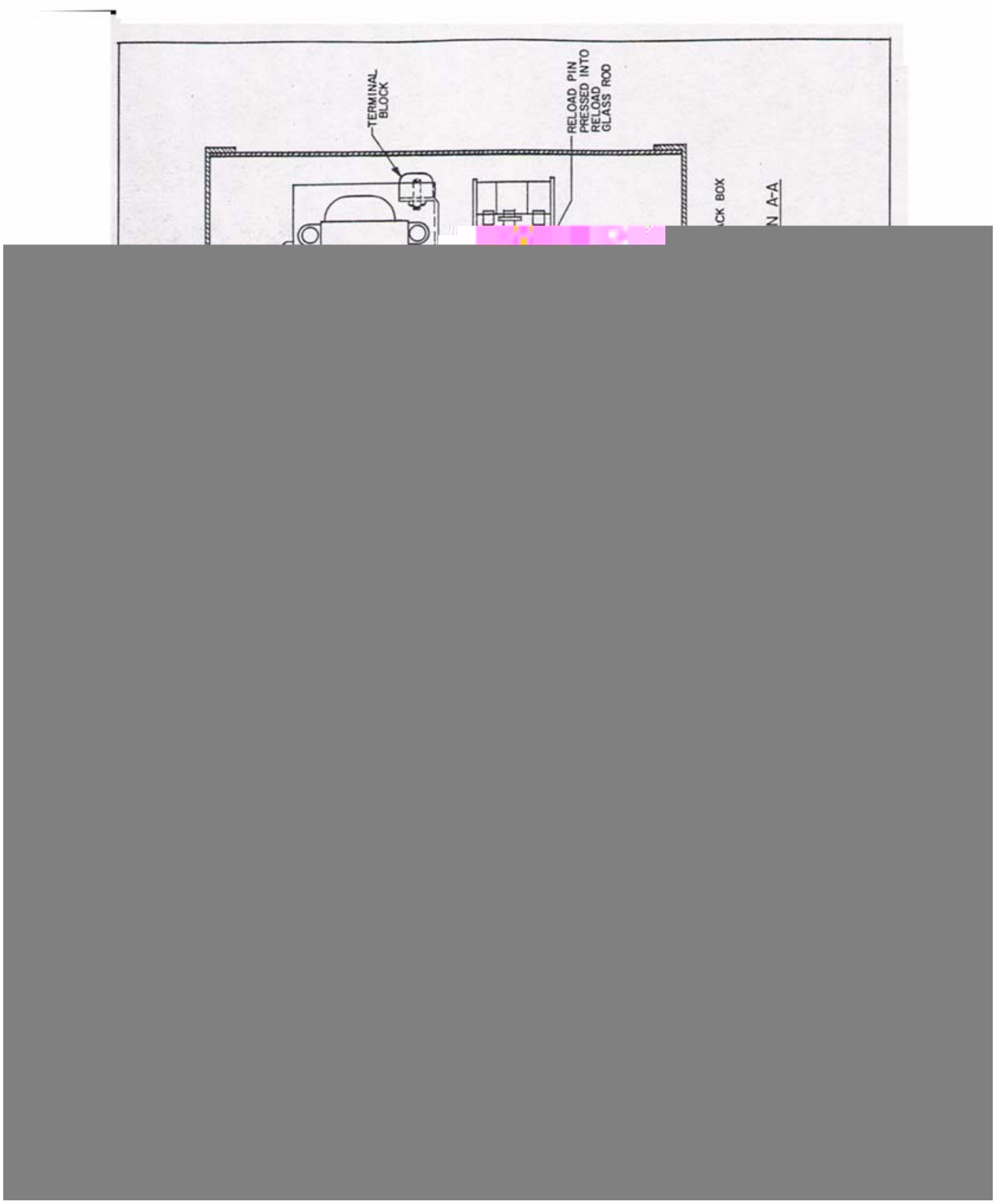
Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–1. Typical break-glass station.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

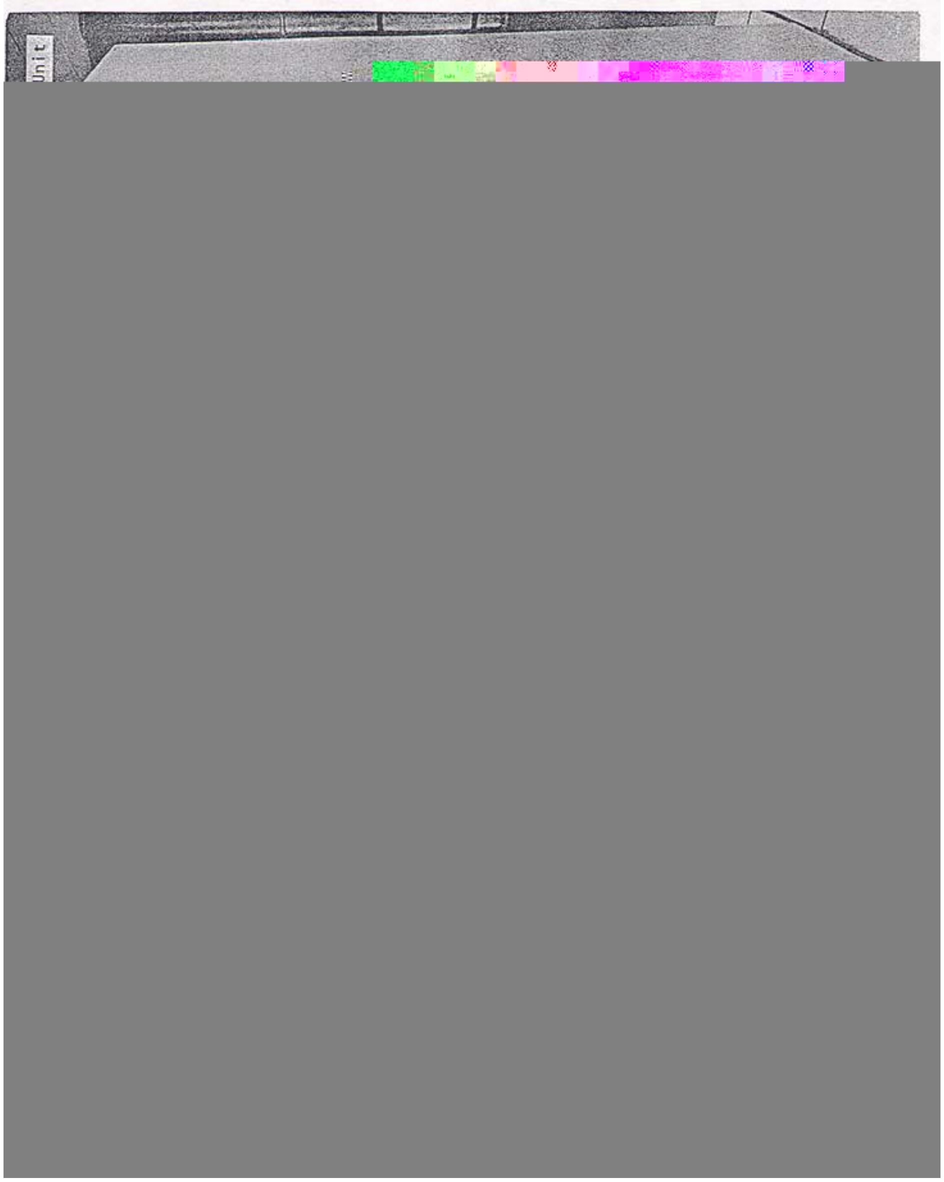
Figure 3–2. Interior of break-glass station.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–3. Break-glass station.

The Fire Alarm Console (see Fig. 3–4) contained the equipment that processed fire alarms called in from break glass stations, retransmitted alarms to the City Fire Alarm Signal Boxes, and controlled the intercom for each break glass station (PANYNJ 1986).



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–4. Fire alarm console.

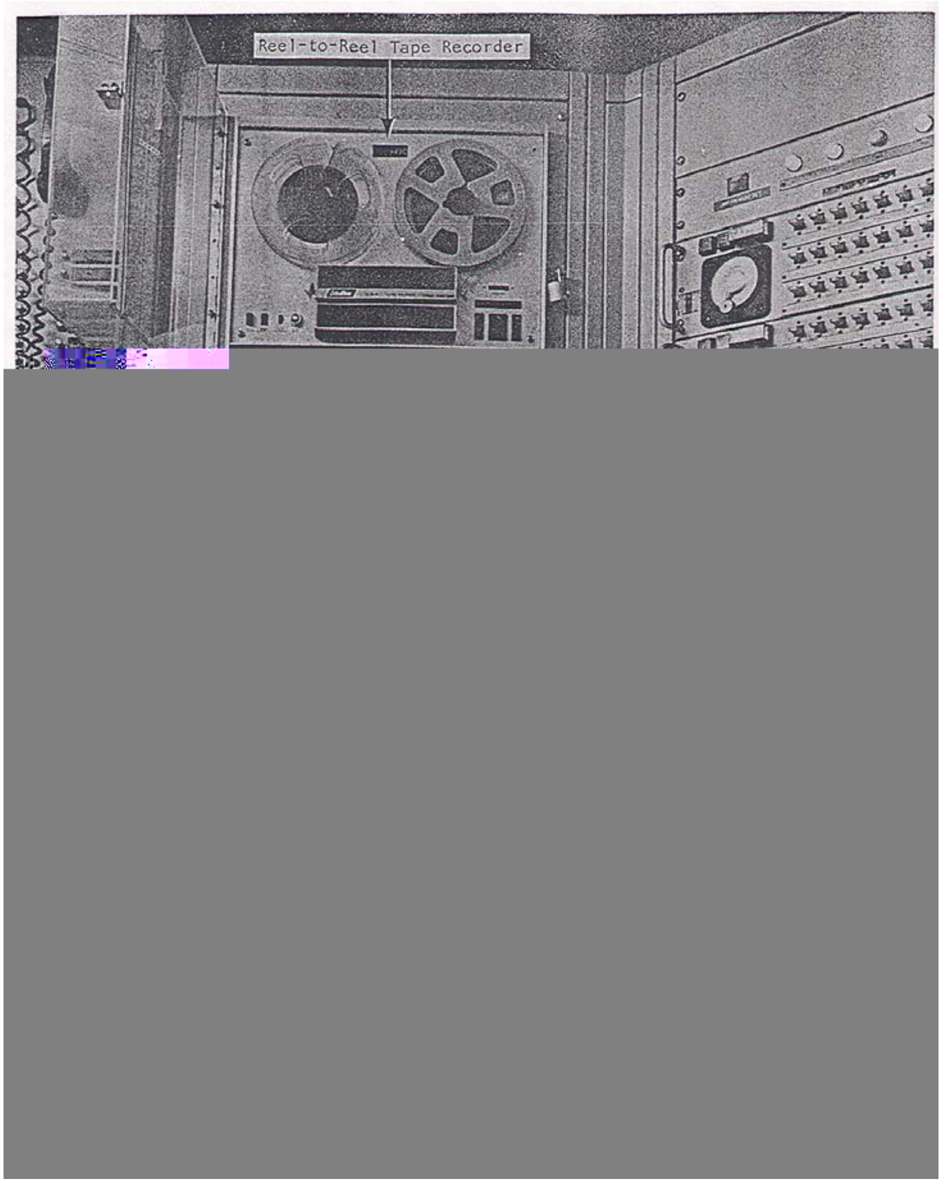
Each section of the Fire Alarm Console contained many Fire Alarm and Intercom Panels (see Figs. 3–4 and 3–5). Each fire alarm and intercom panel contained: illuminated intercom channel selector switches, a fire call button, a city fire alarm cancel button, a station reset button, a zone test button, an adjustable city alarm delay timer for calling in city fire alarms, a fixed timer designed to delay broadcast of an alerting signal to the fire zone until the console operator had 20 s to answer the call, and a buzzer indicating that someone activated a break glass station.

Each panel represented a separate fire zone and actuated a separate New York City Fire Alarm Signal Box by means of a remote electrical trip. Each intercom channel selector switch served an individual break glass station and illuminated when that station initiated a fire alarm. The switch position corresponded to the intercom channel (A or B) to be used.

The buzzer sounded when an alarm was called in from a break glass station or an intercom channel selector switch was actuated. The Fire Call button actuated the City Fire Alarm Signal Box for that zone independent of calls from break glass stations. The City Fire Alarm Cancel button defeated the initiation of a City fire alarm from a break glass station, provided that the adjustable City alarm delay timer had not run out.

The Station Reset button stopped the internal 20-s timer from actuating an alerting signal directed to the fire zone; no alerting signal was connected to that timer. The appropriate intercom channel selector switch also had to be activated. The Zone Test button tested the supervisory circuits of the panel. The Fire Alarm and Intercom Panels, model M423-36, were manufactured by Executone, Inc.

The Reel-to-Reel Tape Recorder (see Fig. 3–5) transcribed conversations made over the fire intercom system. It was capable of recording, at 3 ¾ in./s or 7 ½ in./s, intercom channels A and B simultaneously. The recorder was manufactured by Sony for Executone and was Sony Model 666-D, Executone Model M432.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–5. Fire alarm console (Zones 1, 2, 3, 8, 10).

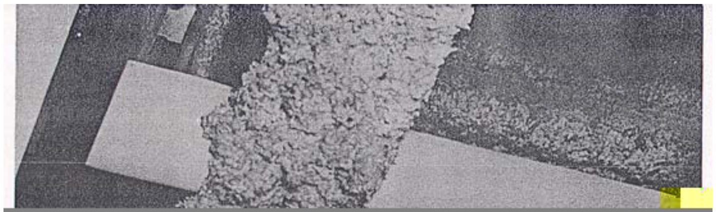
3.2 SMOKE DETECTION AND ALARM SYSTEMS

The pre-1993 Smoke Detection and Alarm Systems in the WTC are dealt with in this section (PANYNJ 1986). Three types of systems are described; Interior Return Air, Elevator Lobby, and the ventilation ducts in the Mechanical Equipment Rooms.

3.2.1 Interior Return Air Smoke Alarm System

The function of the Interior Return Air Smoke Alarm System was to alert Police Security Room personnel to the presence of smoke or other combustion products in the return air ducts of individual floors. The ionizations type detectors were in the hung ceiling of each tenanted floor, close to the intake of the return air ducts. A typical installation is shown in Fig. 3–6.

The detectors were connected to a computer-multiplex system which scans each smoke detector and reports alarm conditions to the Police Security Room on Level B1. The automatic computer and the vertical panel computer performed separate alarm functions. The automatic computer operated the alarm printout teletype, and the vertical panel computer operated the "horn."



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–6. Typical interior return air smoke detector (ceiling tile removed).

3.2.2 Elevator Lobby Smoke Alarm System

There was at least one smoke detector at the ceiling of each elevator lobby, directly above the elevator call button (see Fig. 3–7). These detectors had two functions: (1) like the interior return air smoke detectors, they transmitted a smoke detection signal to the Police Security Room; and (2) they caused the elevators to return to their main lobby or to an upper floor.

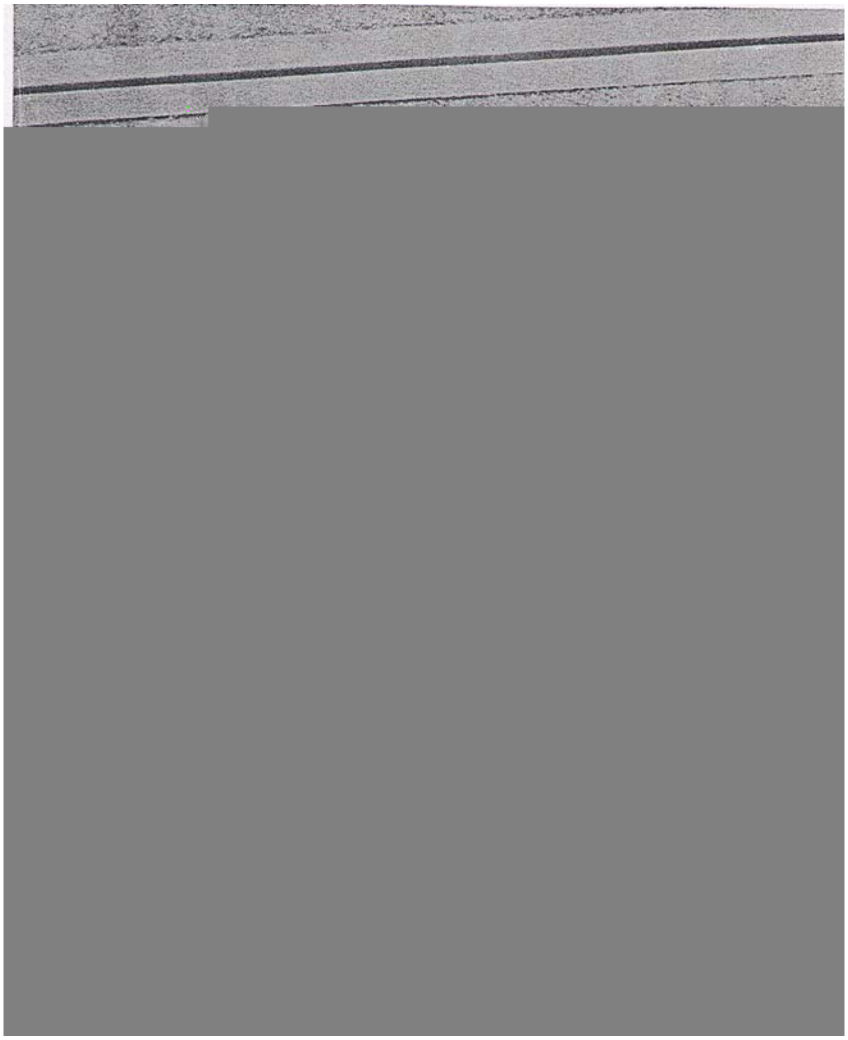

[redacted]

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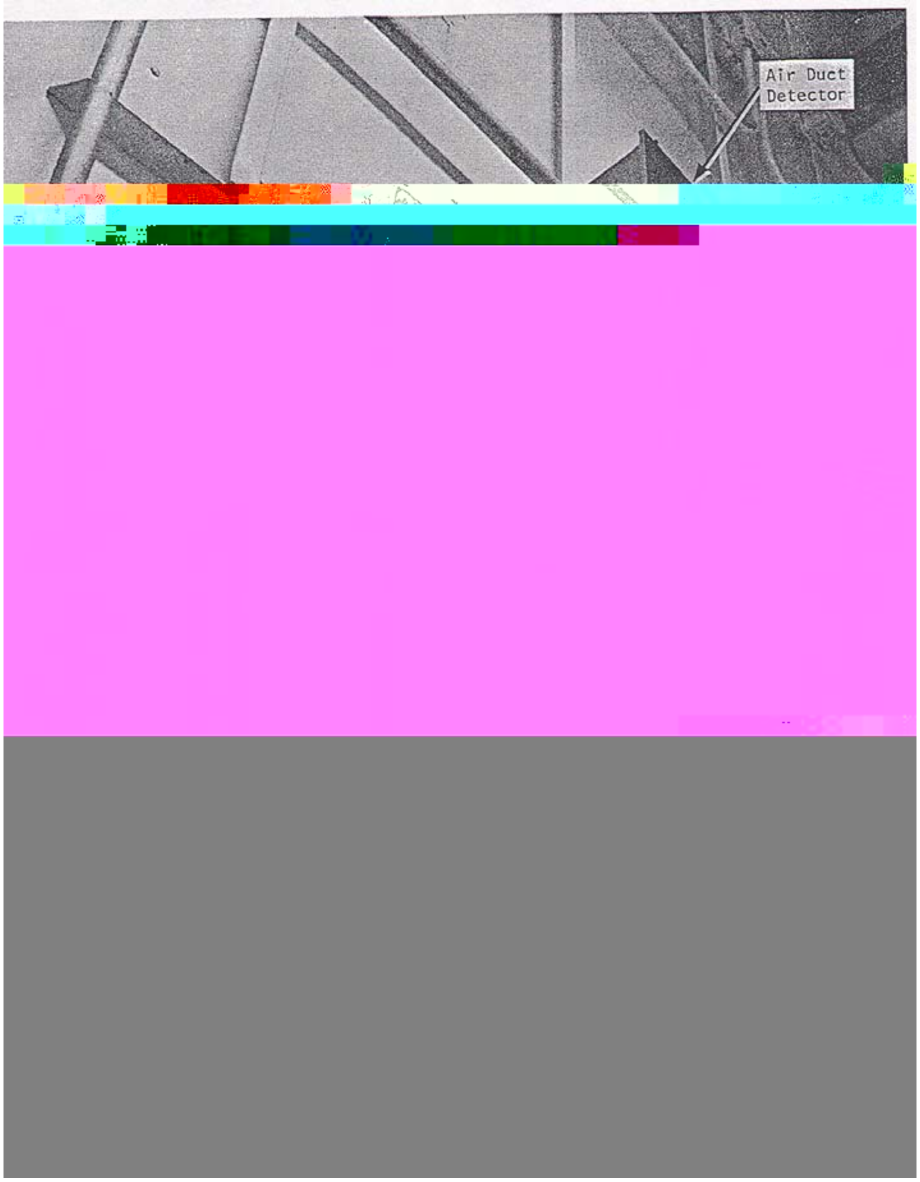
Figure 3–7. Elevator lobby smoke detector.

3.2.3 Ventilation Smoke Alarm System

The Ventilation Smoke Alarm System monitored the supply and return air ducts in the Mechanical Equipment Rooms (MERs) in the WTC. The function of the system was to shut down the affected ventilation fans and alert appropriate personnel when smoke or other combustion products were detected in the supply or return air ducts. The MER exhaust ducts were monitored and controlled in a similar manner.

The ventilation smoke alarm system was comprised of air duct detectors, pendent-mounted detectors, control panels, and bells. The air duct detectors were mounted on the supply and return air ducts of the heating, ventilating, and cooling (HVAC) units in the MERs (see Figs. 3–8 and 3–9). The pendent-mounted smoke detectors monitored the air entering the MER exhaust fan inlets. Figure 3–10 shows a typical installation of one of these detectors.

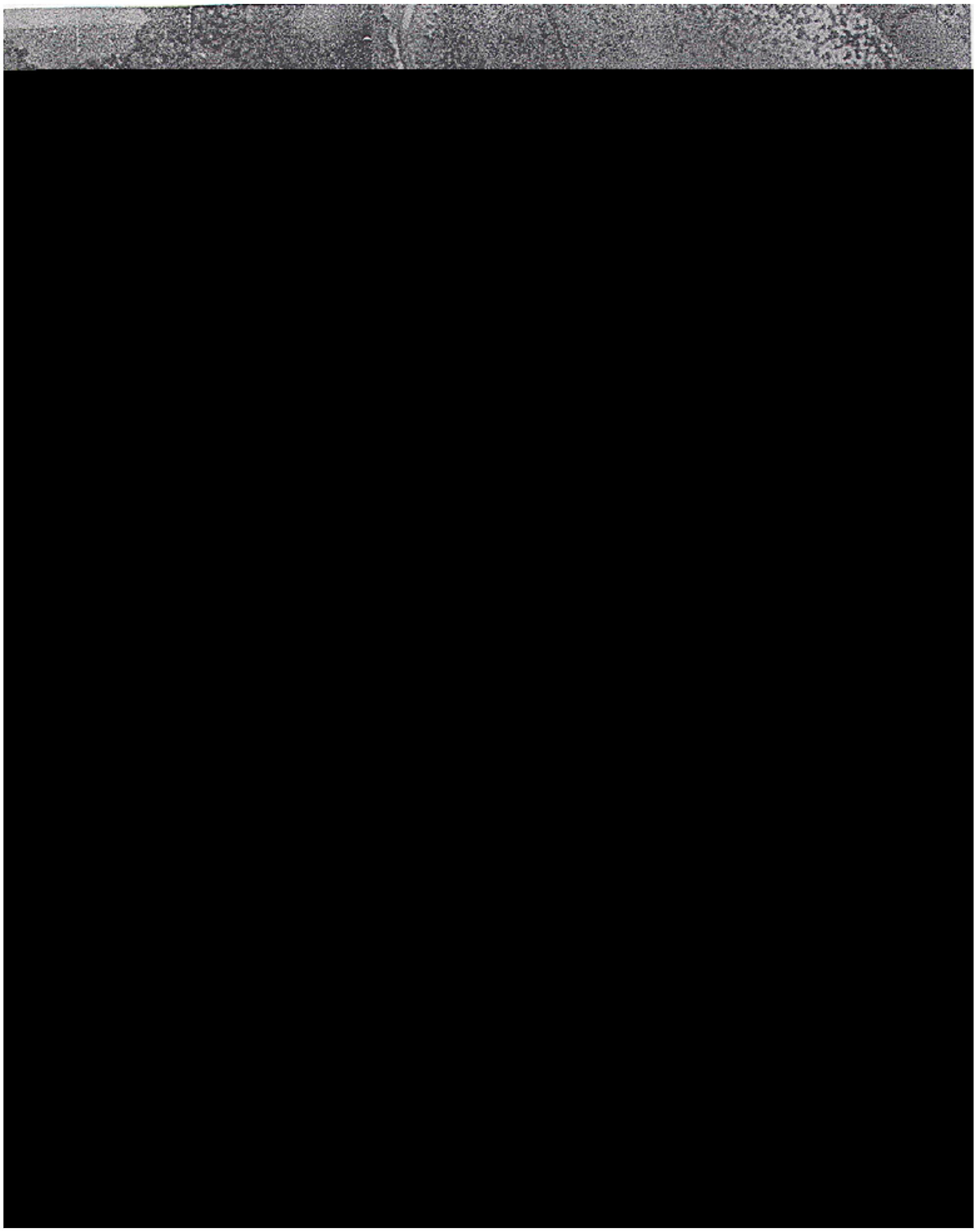


Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–8. Typical supply air duct detector installation.

Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–9. Typical return air duct and duct detector.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–10. Typical pendant mounted smoke detector.

The air duct smoke detectors were ionization-type devices that sensed products of combustion that may have been circulating in the air ducts. When such gases or smoke were detected, ventilation fans were automatically shut down to prevent recirculation of the smoke and/or gases. In addition, an alarm bells rang in the affected MER, and an alarm message was printed on the printer in the Police Security Room. A maintenance electrician and mechanic were then dispatched to the affected MER to investigate the cause of the alarm and take the necessary corrective action.

3.2.4 Tenant Smoke Alarm Systems

Many tenants had their own Smoke Alarm Systems. The designs of these systems were varied, and their descriptions are beyond the scope of available documentation.

3.3 PUBLIC ADDRESS SYSTEM

The All-Purpose Public Address System (PA) (PANYNJ 1986) was provided with two channels of sound transmission: Channel “A” and Channel “B.” For voice paging between zones both channels were available. Communications from the skylobbies could be executed only through Channel “A.” The circuitry of the PA system allowed for both simultaneous and independent announcements to selected speaker zones or areas.

Voice announcements were made via the microphones either at the Control Center Console at the Police Desk on Level B1 (Elevation 294 ft) or at the Elevator Starter Panels (ESPs) in the Main Lobbies or Skylobbies. There was one ESP in the Main Lobby of each tower and one ESP on the 44th and 78th floor skylobby of each tower. From these locations announcements could be made to any zone or area of the WTC during an emergency, including a fire situation.

3.3.1 Speaker System

Speakers used in this system were positioned so that all areas of the WTC complex received voice transmissions from the various microphone locations. The speakers were in stairways, corridors, and ventilation ducts of the core area of the WTC. Speakers in the corridors, stairways, and ducts were positioned so that voice transmissions could be adequately relayed to all occupants in that particular floor or stairway area.

There were basically two types of speakers in the WTC: the horn loudspeaker (see Fig. 3–11) and the recessed ceiling speaker (see Fig. 3–12) (PANYNJ 1986).

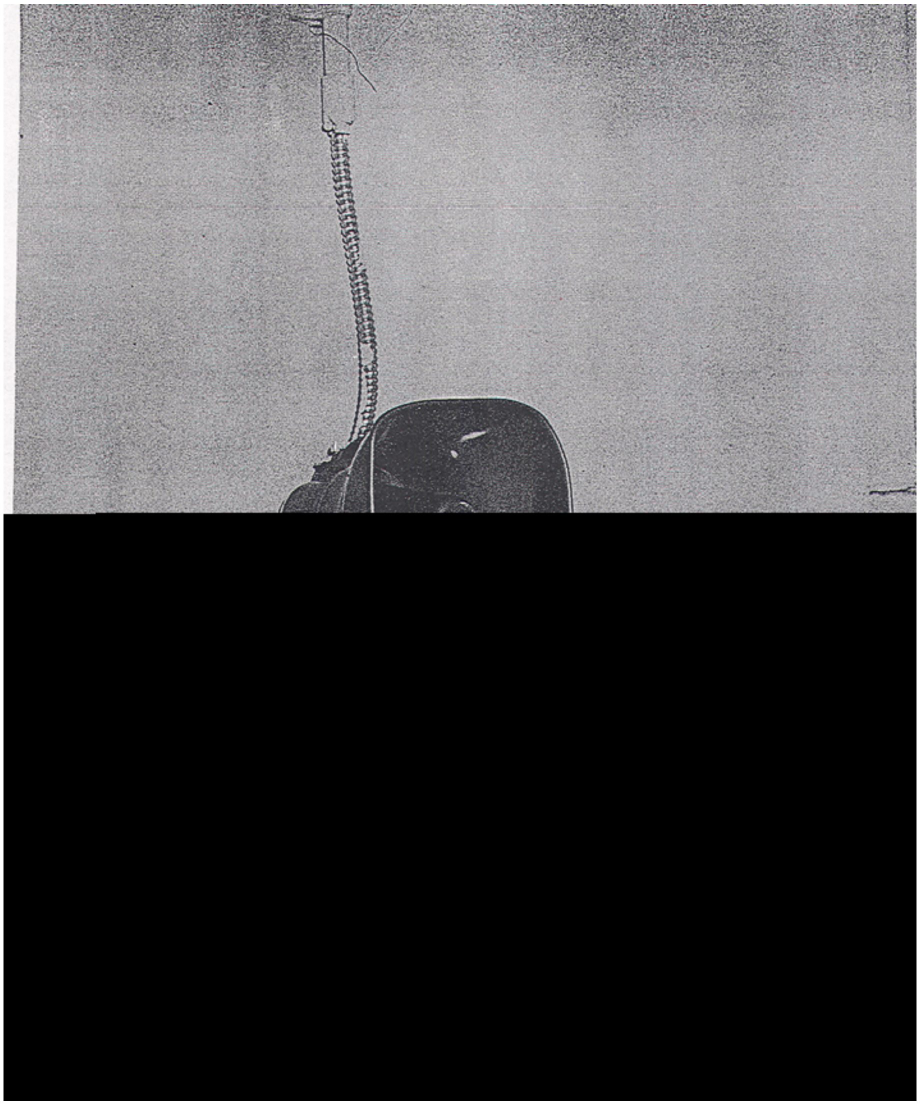


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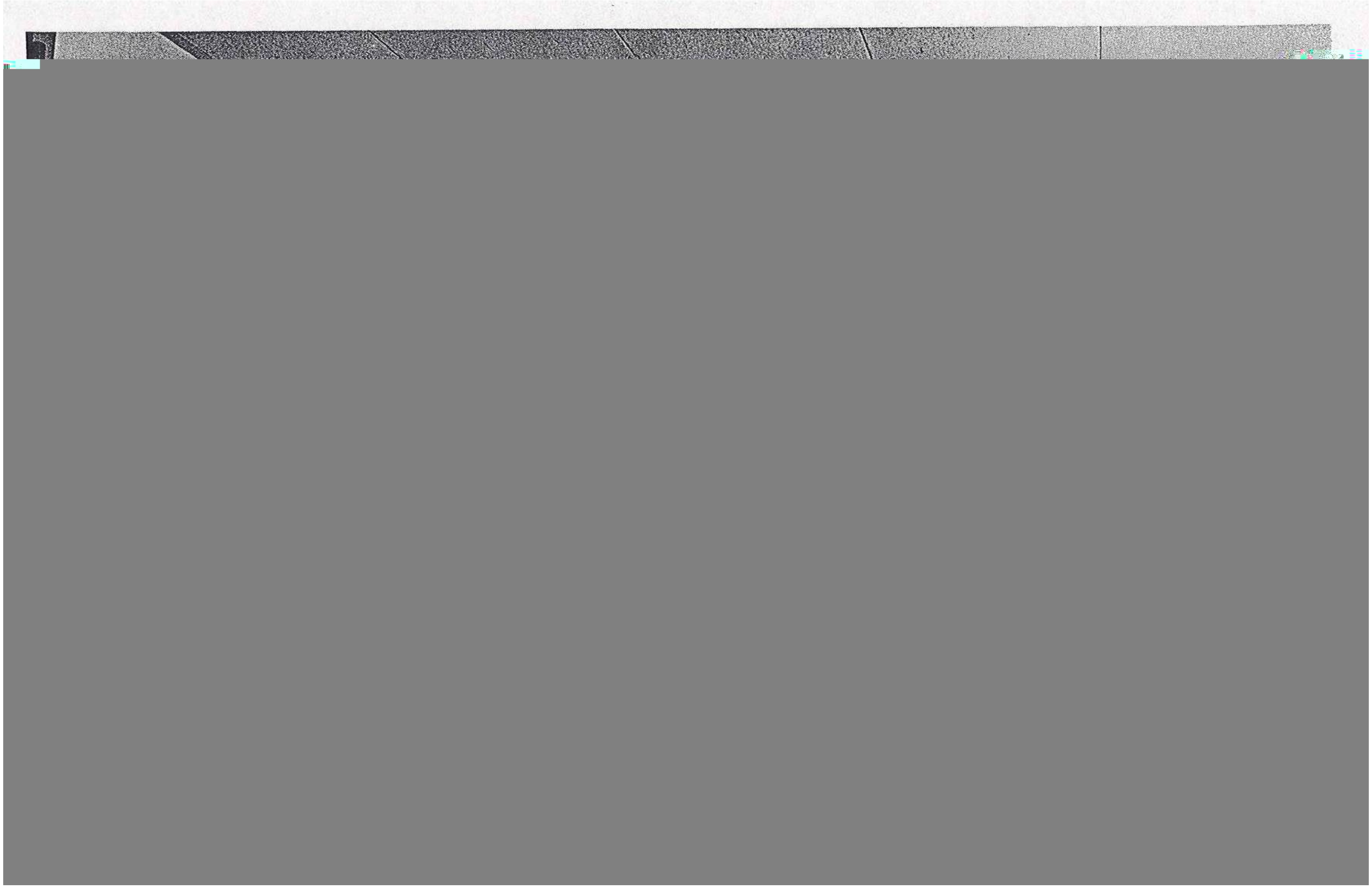
Figure 3–11. Horn type speaker in a stairway enclosure.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–12. Recessed speaker in corridor.

3.4 PUBLIC ADDRESS CONSOLE

The Public Address Console was the right-hand portion of the Control Center Console that included the Fire Alarm Console (see Fig. 3–13) (PANYNJ 1986). The Control Center Console was in the Police Security Room on Level B1. The Public Address Console was the heart of the All-Purpose PA System and contained most of its controls and monitors (see Fig. 3–14).

Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–13. Control center console police desk Level B1.

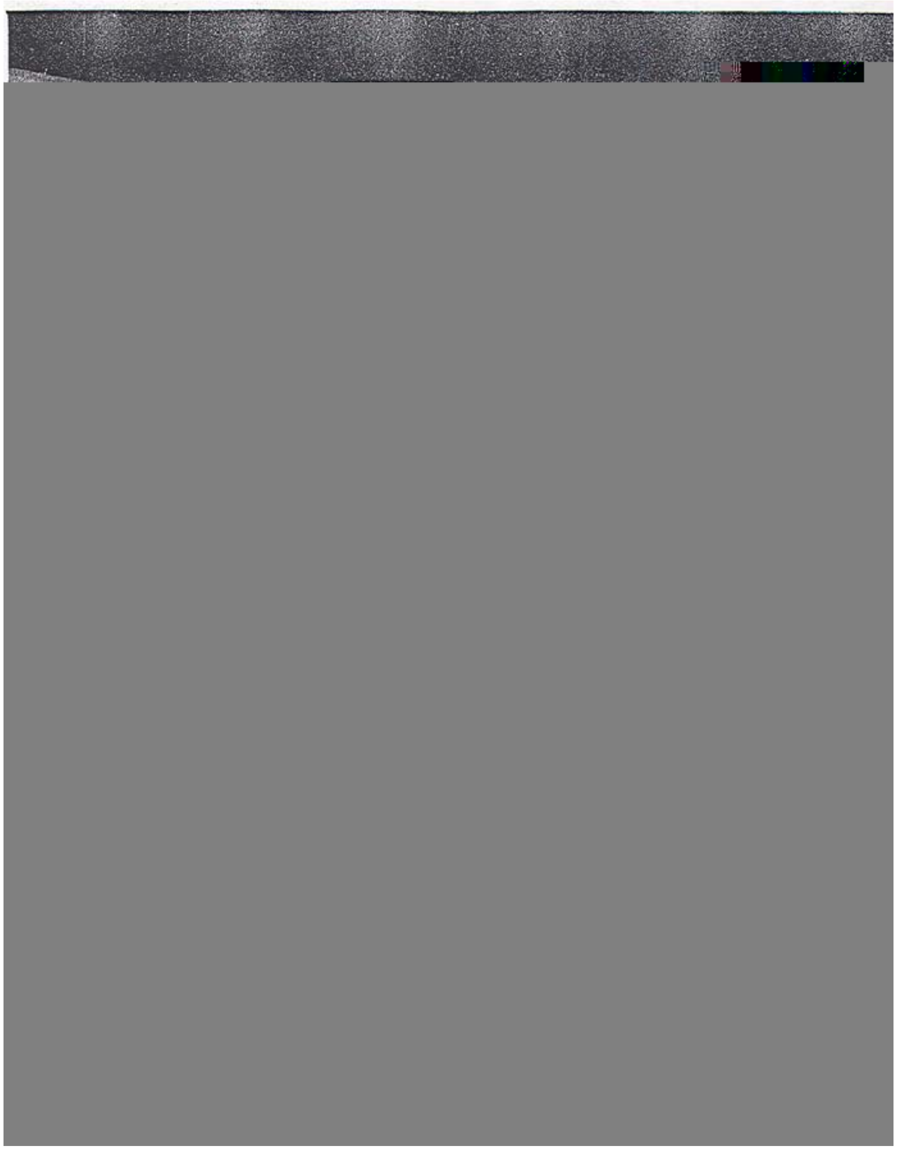


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Figure 3–14. Public address console.

3.5 SPRINKLER WATERFLOW ALARM SYSTEM

The Sprinkler Waterflow Alarm System in the Subgrades of the WTC is the subject of this subsection (PANYNJ 1986). It contains descriptions of the major components of the system and their functions.

The function of the Sprinkler Waterflow Alarm System was to alert personnel in the Police Security Room on Level B1 that sprinkler water was flowing. The system included supervisory alarms that monitored water level conditions in the fire reserve tanks and the condition of the pumps associated with the Sprinkler System.

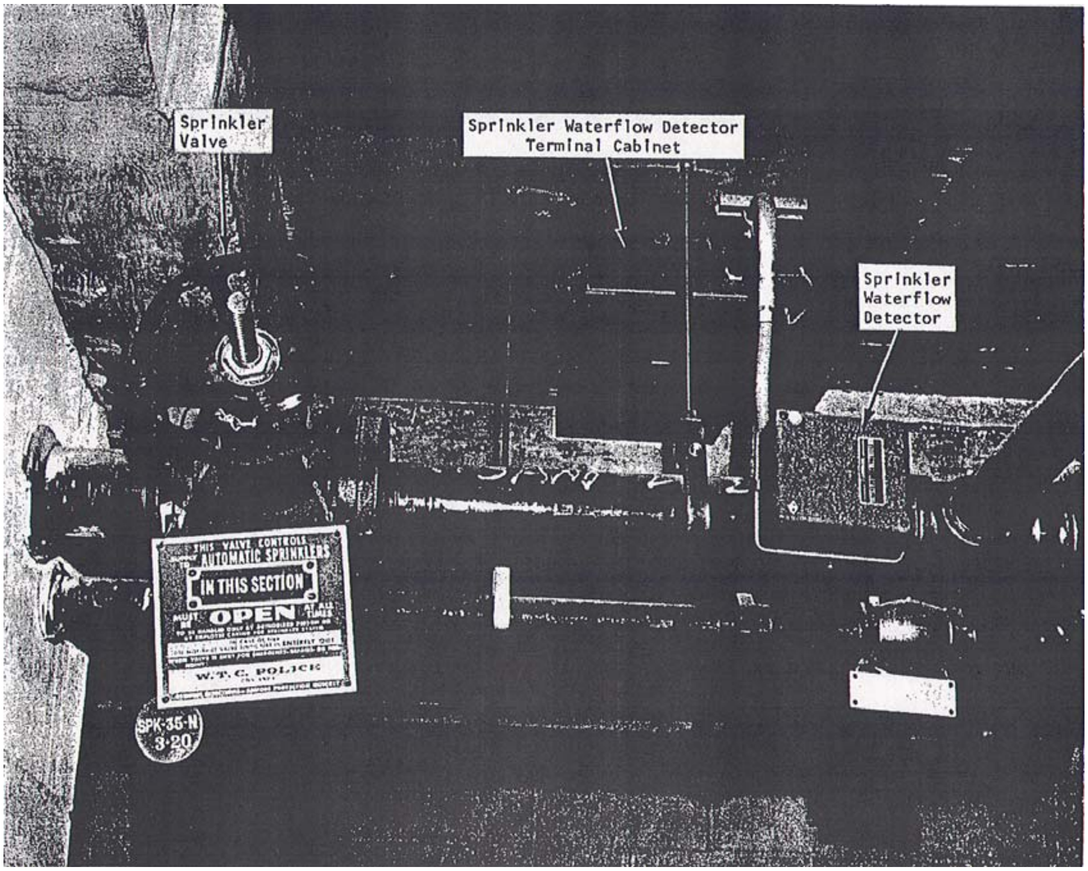
3.5.1 Component Descriptions

Sprinkler Waterflow Detectors

A sprinkler waterflow detector is an electromechanical device that initiates an electrical alarm when there is a flow of water through a sprinkler pipe. A typical installation is shown in Fig. 3–15. The sprinkler waterflow detector terminal cabinet shown in this figure connected the waterflow detector to the sprinkler alarm annunciator in the old HVAC computer room on Level B4 (see Fig. 3–16).

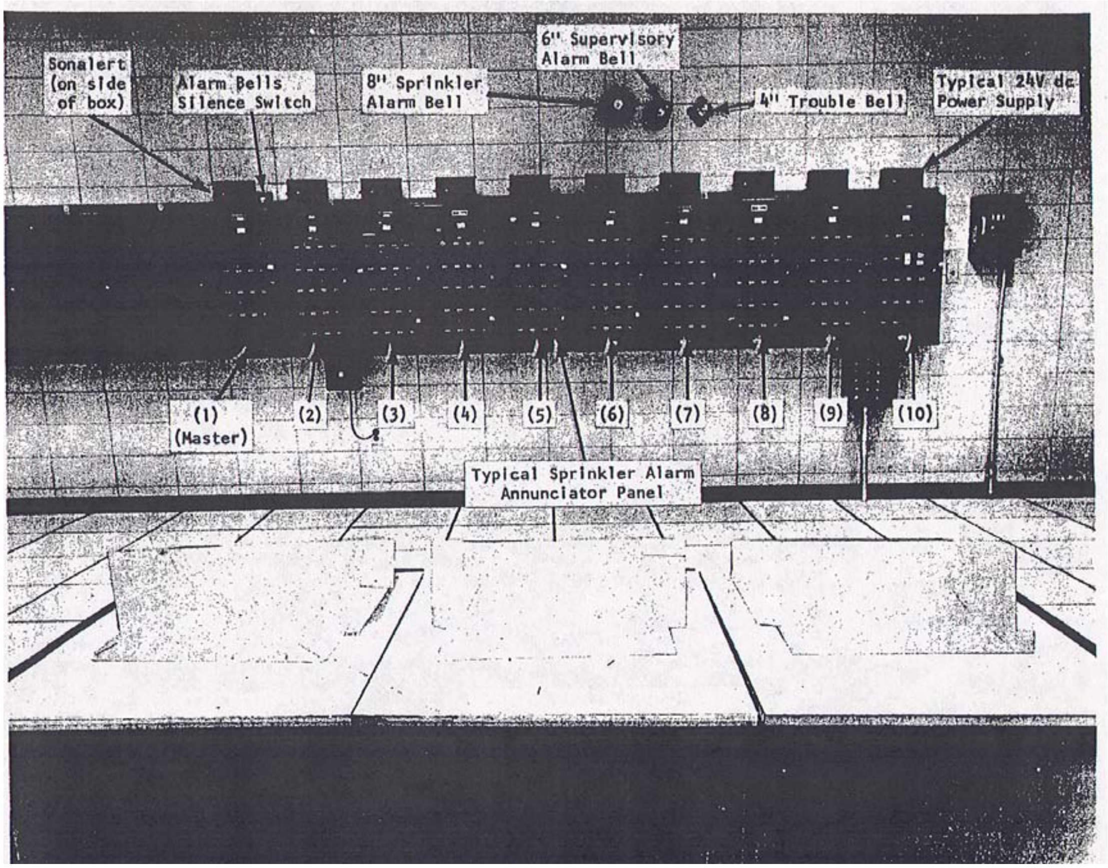
The sprinkler waterflow detector was equipped with a vane that protruded into the sprinkler pipe. The pressure of the water flowing through the pipe moved the vane, which in turn caused a microswitch to close. This closing transmitted an alarm to the sprinkler alarm annunciator panel in the old HVAC computer room, and a flag dropped down, indicating the zone in which the water was flowing.

The sprinkler alarm annunciator panel that sent a signal to the multiplex computer in the Police Security Room on Level B1, where the alarm was printed out on a teletype unit. A mechanical maintenance person was then dispatched to the old HVAC computer room to determine which flag on the annunciator panel had dropped down. Then he or she reported the location of the flow to the Police Security Room. Police and operations personnel then investigated the reason for the alarm.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–15. Sprinkler waterflow detector installation.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–16. Sprinkler alarm annunciator in HVAC computer room.

Sprinkler Alarm Annunciator Panel

The sprinkler alarm annunciator panel was in the old HVAC computer room on Level B4. The panel contained sprinkler waterflow and supervisory alarms. The supervisory alarms indicated when and if the conditions of certain equipment in the sprinkler system were abnormal. The conditions monitored were: the level of water in the fire reserve tanks; and the operating status of the fire standpipe pumps, the sprinkler fire pumps, the combination sprinkler/fire standpipe pumps, and the sprinkler jockey pump.

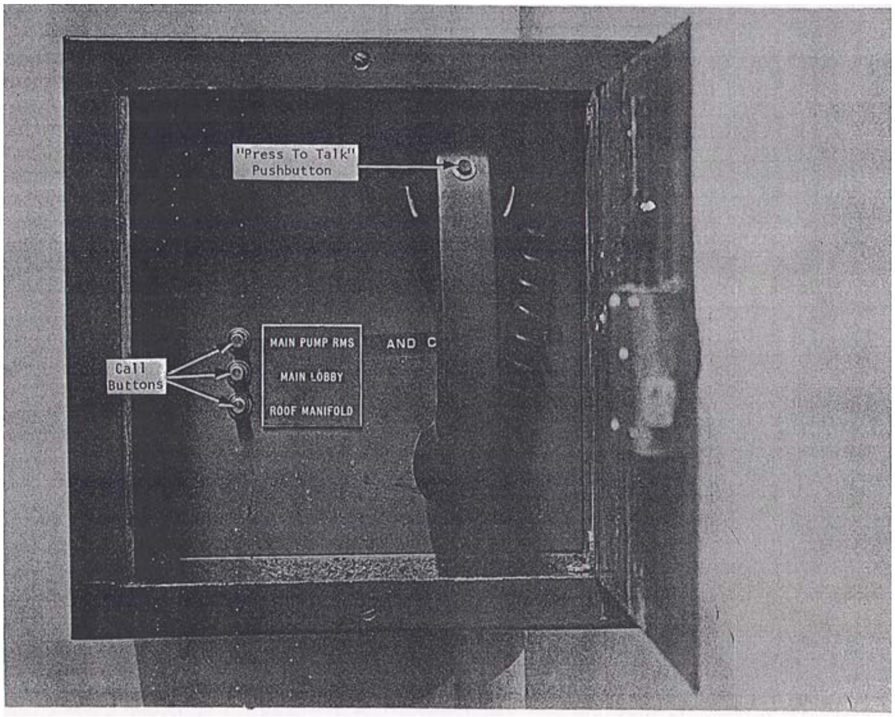
3.6 STANDPIPE FIRELINE COMMUNICATION SYSTEM

The Standpipe Fireline Communication System in the WTC is dealt with in this subsection (PANYNJ 1986). Included are verbal descriptions of the system, photos of the equipment utilized, and block diagrams of the entire system.

The Standpipe Fireline Communication System in the WTC was provided for firefighter use during operation of the standpipe system. This system included two-way telephone communications.

The Standpipe Fireline Communication System was a selective-ringing, common-talking system that was comprised of a Master, Submasters, and Outlying Stations, with a power supply, and an amplifier. The

Master and Submaster Stations were in the pump rooms, MERs, main lobbies, skylobbies, and near roof manifolds of the Standpipe Fireline System. The Outlying Stations were generally near standpipe hose racks (see Figs. 3–17 and 3–18).



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

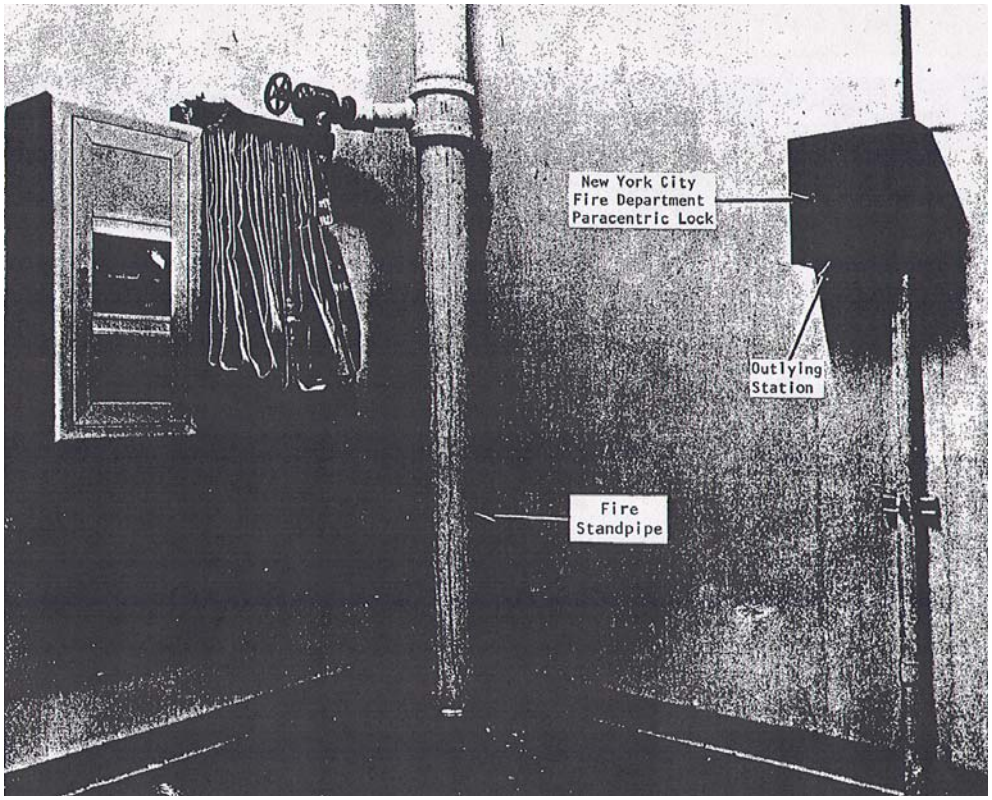
Figure 3–17. Outlying station interior view.

In WTC 1 and WTC 2, the Outlying Stations were in the B staircase, on the odd-numbered floors 1 through 109, and Elevations 294 ft, 264 ft, and 242 ft (see Fig. 3–18). In the WTC 4 and 5, Outlying Stations were in the staircases, on the Concourse (Elevation 310 ft), Elevation 285 ft 6 in., Elevation 266 ft, and Elevation 246 ft.

Outlying Stations

Each Outlying Station was either surface-mounted or flush-mounted, depending upon its location. The station consisted of a red telephone handset with a press-to-talk pushbutton and three call buttons (see Fig. 3–17). By means of the three call buttons a firefighter could signal certain designated Master and Submaster Stations. The Outlying Stations were not capable of receiving signals other than voice (PANYNJ 1986).

All Outlying Stations were equipped with a Fire Department of the City of New York (FDNY or Fire Department) paracentric lock which was to be locked at all times, except when the phone was in use (see Fig. 3–18). The lock could be opened only by personnel of the World Trade Fire Safety Coordinator’s Office, World Trade electrical maintenance personnel, and the Fire Department (PANYNJ 1986).



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–18. Outlying station of Standpipe Fireline Communication System.

The pre-1993 Fire Alarm System in the WTC included the various Smoke Detection and Alarm Systems and the All-Purpose Public Address System used to make announcements during fire drills or an actual fire emergency (PANYNJ 1986).

3.7 COMPARISON OF THE PRE-1993 AND POST-1993 FIRE ALARM SYSTEMS

This section provides a comparison of the fire alarm systems in place in the WTC complex before the 1993 bombing with those installed after the bombing and in place on September 11, 2001 (PANYNJ 1986; Drucker 2001; Drucker 2004; SafirRosetti 2002).

3.7.1 General

The American Multiplex Digital Computer and Console was a fire alarm and communication system engineered and built specifically for the WTC. Although it was state-of-art at time of construction, fire protection technology had changed significantly in the decades since the original installation. Performance based codes and standards had consolidated the fire detection, monitoring, control, and communication systems that were originally separate packages into one system sharing common functions and capabilities. The Port Authority did upgrade the MER fire alarm protection with the installation of a microprocessor controlled, addressable Pyrotronics XL3 system in each MER, which was monitored by a CXL Command Center monitor in the OCC. The XL3 fire alarm system was the predecessor to the Siemens Pyrotronics MXL-V system installed post-1993.

3.7.2 Fire Command Station Pre-1993

The original OCC on the B-1 Sub-Grade Level provided a single, central fire alarm monitoring and control station for both the WTC 1 and WTC 2 towers. The fire alarm system consisted of multiple components, from differing manufacturers, configured into a single-seat monitoring station for:

- Detection, monitoring, and control of fire alarm devices.
- Alarm and voice broadcast by floor.
- Floor intercom communication.
- Fire Department notification.

The original American Multiplex system was engineered and produced exclusively for the WTC towers. The manual interface for monitoring and control of the fire alarm system consisted of visual indicators, switches, audible notification appliances, alpha-numeric printouts, phones, and microphones.

The CXL Command Center monitor provided the status of the alarm and malfunction conditions for the XL3 fire alarm panels located in the mechanical equipment rooms.

3.7.3 Fire Command Station Post-1993

Each tower, WTC 1 and WTC 2, had its own Fire Command Station, which contained the building's fire alarm system. Also, there were redundant fire alarm system monitoring and controls for each building's system in the OCC. As another layer of redundancy, since the WTC 2 Fire Command Station was located above the OCC, a second remote fire alarm system for WTC 2 was located in the WTC 1 Fire Command Station.

The post-1993 fire alarm system in the Fire Command Stations and OCC were manufactured, tested, and produced as a single, integrated fire alarm system providing multiple, inter-relating functions. The system was modular in design and could be modified or expanded as needed to provide:

- Detection, monitoring, and control of fire alarm devices.
- Alarm and voice broadcast by floor.
- Floor intercom communication.
- Fire Department notification.

The system consisted of off-the-shelf technology that was produced by the manufacturer for large fire alarm projects. The manual interface for monitoring and controlling the system consisted of a Network Command Center monitor and computer keyboard, which provided alpha-numeric detail of the fire alarm status and condition. Additional visual indicators, switches, phones, and microphone were available for interfacing with the differing fire alarm functions.

The major differences between the pre-1993 fire alarm system monitoring and control capabilities found at the main operator's monitoring station and the post-1993 fire alarm system were the level of information provided about the status of the system and the ergonomic interface improvements offered by the newer system. Since the newer system was a microprocessor based, addressable fire alarm system, it was able to provide an alpha-numeric accounting of its status in both an alarm and abnormal functioning condition. This was critical since any large system serving a facility with multiple tenants is going to experience constant changes in configuration. These dynamic changes to the system require controls by policy, procedure, and system. The system could provide immediate feedback on where changes to the system were made through internal condition monitoring capabilities that provided an alpha-numeric indication at the fire alarm monitoring stations. The system condition reports provide the general or specific location of the induced faults that occurred during any system modification. These indications allowed the system operator to remotely monitor if and when the system's status had returned to normal, or if further actions were needed to return the system to normal.

The newer fire alarm system also offered a single-seat interface for all of its monitoring functions. The Network Command Center monitor and keyboard offered the operator the ability to interrogate the status of any alarm or fault condition and provided a historic log of past alarms or changes to the overall status of the system. The control of the warden and Standpipe Fireline communications systems was accomplished at the panels within the Fire Command Station, along with the control of the emergency voice alarm communication (EVAC) capability. The newer system provided more information and better monitoring and control through fewer visual indicators, switches, phones, and microphones.

3.7.4 Base Building Fire Alarm System Pre-1993

In addition to the main Digital Computer and Console in the Operations Control Center located in B-1 Sub-Grade Level Operations Control Center, the pre-1993 fire alarm system consisted of American Multiplex RMT located on every third floor. The RMT monitored Pyrotronics CR-7 Equipment, which was connected to the non-addressable smoke detectors, tenant proprietary systems, and waterflow switches through the remote sprinkler alarm annunciator located on the B4 level.

In addition, Pryrotronics XL3 smoke detector systems, with addressable type heads, were installed in the mechanical equipment rooms of both WTC 1 and WTC 2, and connected via a CXL Communication Device to a console in the OCC.

3.7.5 Base Building Fire Alarm System Post-1993

The post-1993 Base Building Fire Alarm System consisted of a head-end MXL-V fire alarm panel connected to five MXL-VR remote panels, and the remote MXL-VR panels monitored and controlled up to eight PSR panels. The PSR panels monitored and controlled fire alarm circuits for typically three floors.

The major differences between the old and new systems were the consolidation of all fire alarm monitoring and controls into a single system and the survivability characteristics that were selected and engineered into the newer system. The pre-1993 fire alarm system consisted of components made by different manufacturers consolidated into a single system out of necessity because all the functions and capabilities required from the system was not available from a single manufacturer at the time. Although documentation was not available to verify operator and maintenance personnel experiences with the system, historically, separate systems and components that are consolidated into a uniquely configured system can provide continual challenges for maintenance and modifications.

The improved survivability characteristic of the newer system resided in both the equipment and the architecture of the system circuits. The distribution of the system's intelligence among the five remote panels allowed each remote panel to act independently to follow its programmed sequence of operations during a fire emergency. As an example, if the remote MXL-VR panel's communication was severed from the head-end or other remote panels, it would switch to a communication degrade mode and initiate audible and visual alarms throughout its protection area upon activation of an alarm device. This capability was also true for the PSR panels, which would switch to a degrade mode and initiate a visual and audible alarm signal within its protection area if it lost communication with its remote MXL-VR when receiving an alarm indication from a monitored device. In addition to the degrade operation mode, the PSR panels contained a back-up tone generator in case they lost the main audio signal circuit that was controlled by the Head-end MXL-V panel. This allowed the PSR panels, which contained the audio amplifiers and speaker circuits, to broadcast a general alarm signal when it received an alarm indication from any connected panel or its own monitored devices. The signal would not contain a voice message since all messages originated from the head-end MXL-V panel, but could provide a general alarm signal for occupant notification.

Additional survivability was obtained from the newer system with the installation of Class A circuits when available, which provided redundant paths for the transmission of signals and information for the detection, monitoring, control, and EVAC communication. Class A circuits were not available for the Warden and Standpipe Fireline systems. The redundant paths allowed the system to switch to an alternate communication path if the cable or equipment was damaged. The extent of damage that could be sustained while maintaining communication over the redundant paths was dependent on the type of circuit. The Class A, Style 7 Signaling Line Circuit, used for detection, monitoring, and control, was able to sustain communication while experiencing a wire-to-wire fault while the Class A, Style Z Notification Appliance Circuit that provided the EVAC signal from the head-end panel was not able to sustain communication with a wire-to-wire short. Although there was a disparity in circuit performance, the circuits used provided the best survivability characteristics available for the cable used.

3.7.6 Detection, Monitoring, and Control Devices Pre-1993

Documentation shows that the original fire alarm system provided general detection, monitoring, and control capabilities for the following:

- Return air smoke detectors located on each floor.
- Elevator lobby detectors that initiated elevator recall.
- Monitoring of the sprinkler water flow and tamper switches.
- Monitoring of tenant fire alarm system.

- Monitoring of the air handling unit's smoke detectors in the mechanical equipment rooms. The activated smoke detector would shut down the associated air handling unit.
- Manual break glass station would automatically activate an alarm on the floor of occurrence if the system operator did not respond within 20 s.

The detection, monitoring, and control were performed by devices and equipment from different manufacturers.

3.7.7 Detection Monitoring, and Control Devices Post-1993

The replacement fire alarm system provided detection, monitoring, and control capabilities for the following:

- Return air smoke detectors located on each floor which would shut down its associated air handling unit upon alarm.
- Smoke detector protection for the electrical, telephone, and fire alarm closets.
- Elevator lobby detectors that initiated elevator recall.
- Monitoring of the tenant fire alarm panels.
- Monitoring of the sprinkler water flow and tamper switches.
- Monitoring of the air handling unit's smoke detectors in the mechanical equipment rooms. The activated smoke detector would shut down the associated air handling unit. The activation of a second detector within each air handling unit would activate the unit's sprinkler deluge system.
- Manual stations located at every stairway entrance.

The main differences between the old and newer systems were the additional information and control capability provided by the newer system and the inability of the newer system to provide automatic occupant notification upon receipt of an alarm signal.

The newer system's detection, monitoring, and control capabilities were programmable and addressable. The activation of any addressable device would provide the system operator with a detailed message for identification. The device could also be programmed to control any associated addressable device that had control functions. These capabilities provided for the automatic activation and control of life safety function without human intervention.

The automatic control capability was not incorporated into the automatic notification of the occupants upon device activation. The system had the capability to provide automatic notification based upon programmed parameters, but this capability was not implemented.

3.7.8 Notification Appliance Devices Pre-1993

Documentation shows that the original fire alarm system provided occupant notification through the following:

- Speakers in the corridors.
- Speakers in the stairways.
- Speakers in the core area of the ventilation ducts.

The PA was provided with two channels of sound transmission. Voice announcements were made via the microphones either at the Control Center Console at the Police Desk on Level B1 or at the ESPs in the Main Lobbies or Skylobbies. There was one ESP in the Main Lobby of each tower and one ESP on the 44th and 78th floor skylobbies of each tower. From these locations announcements could be made to any floor of the WTC.

3.7.9 Notification Appliance Devices Post-1993

The newer fire alarm system provided occupant notification through:

- Speakers in all floor areas spaced to insure intelligibility and audibility.
- Strobes in all common areas that were area spaced and rated to ensure adequate illumination for notification of the hearing impaired.

The major differences between the pre-and post-1993 occupant notification capabilities were the engineered spacing of the newer system to ensure performance, the inclusion of visual strobes on the new system for the hearing impaired, and the ability of the newer system to broadcast voice commands from selected telephones.

The design of the newer system required that minimum audibility and intelligibility performance requirements were met in the spacing and locations of the speakers. This effort was performed to ensure that the alarm and voice announcements could be heard and understood throughout the building.

The newer system also provided visual strobe alarms that were spaced and located in the common use areas. The location and spacing of the strobes was engineered to provide the illumination required to notify persons with hearing impairments.

The newer fire alarm system also had the ability to allow the head-end system operator the ability to patch selected telephones into the EVAC system for remote voice broadcasts.

3.7.10 Warden and Standpipe Fireline Communication System Pre-1993

Documentation shows that the original fire alarm system provided occupant and firefighter two-way communication through an Executone intercom system for the occupants, and a Standpipe Fireline

Communication System for firefighter use. The devices for the separate communication systems were as follows:

- Occupant communication was provided with break glass stations located on every floor.
- Firefighter communication was provided with phone stations located near standpipe hose racks on each floor, in the fire pump rooms, the MERs, the main lobbies, the skylobbies, and near the roof standpipe manifolds.

The Executive intercom system was monitored and controlled at the OCC. The system was also monitored by a reel-to-reel tape recorder that kept a history of all communications over the intercom system.

The Standpipe Fireline Communication System was a selective-ringing, common-talking system that comprised Master, Submaster, and Outlying Stations; a power supply; and an amplifier. The Master and Submaster Stations were in the pump rooms, the MERs, the main lobbies, the skylobbies, and near the roof manifolds of the standpipe system. The Outlying Stations were generally near standpipe hose racks.

3.7.11 Warden and Standpipe Fireline Communications System Post-1993

The newer fire alarm system provided warden and firefighter communications through:

- Floor Warden telephone stations located on each floor.
- Standpipie fireline communication stations located near standpipe hose racks on each floor, in the fire pump rooms, the MERs, and near the roof standpipe manifolds.

The major differences between the pre-and post-1993 arrangements were the use of a single communication system for both the warden and the firefighter communication in the new system and the ability of the newer system to broadcast voice messages over the speakers.

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Chapter 4

FIRE ALARM SYSTEM PERFORMANCE REQUIREMENTS

As an interstate compact under the U.S. Constitution, the Port Authority was not subjected to any state or local building codes. The World Trade Center (WTC) was designed in accordance with the New York City Building and Fire Prevention Codes of 1968 in effect at the time of the building's construction. The Port Authority of New York and New Jersey's (PANYNJ or Port Authority) objective was to adhere to or exceed local code requirements.

In addition to the New York City building codes, the Port Authority relied on nationally recognized fire safety standards published by the American National Standards Institute and the National Fire Protection Association, as well as internal protocols established with fire officials in the city. Two noteworthy protocols included the "Protocol for Periodic Joint Port Authority/ Fire Department of New York Inspections of Port Authority New York City Facilities" of 1988 and the "WTC/ FDNY Joint Protocol for Inspectional Activity at the World Trade Center Complex" of 1986. The Port Authority maintained a positive working relationship with The Fire Department of the City of New York (FDNY or Fire Department) through these protocols that allowed the Fire Department access for inspections and evaluation of life safety and fire protection systems at the complex. The Fire Department was provided with the authority to issue advisory reports resulting from their inspections, which the Port Authority could consider on a voluntary basis (NIST NCSTAR 1-1H[1]).

This spirit of cooperation was reciprocated with the New York City Department of Buildings and formally acknowledged in a Memorandum of Understanding between the two parties after the explosion at the towers on November 3, 1993. The most current edition of the New York City Building Code was identified as the design basis for any construction after November 1993.

The applicable building codes document the requirements to achieve the minimum acceptable level of safety for occupants. The building codes in effect are the primary source for determining what safety features will be installed in a building. Many building codes include referenced standards that address how various aspects of the building and systems are to be installed and constructed in order to provide the intended levels of safety. Another regulatory element that comes into play is product safety standards. Building codes and installation standards require the use of products that have been investigated to verify that they perform as intended without causing a safety hazard. Product safety standards and listing agencies, such as Underwriters Laboratories, Inc., provide vehicles for evaluating the performance of products from a safety perspective. Verification and testing of products for public safety ensures that the level of safety established by the building codes for the building design, and implemented per recognized installation standards during the building's construction, will be accomplished through the products' performance.

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[1] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

4.1 GENERAL FIRE ALARM REQUIREMENTS

The fundamental purpose of a fire alarm system is to detect fires, notify occupants, and summon emergency responders. The applicable building and fire codes establish basic requirements for the types of devices and functions required for a specific facility based on its use. The actual layout and interaction with other building systems are established by the designers as part of the fire protection plan for a facility. The goals and objectives of the fire alarm system are usually defined by a Fire Protection Engineer as they relate to the fire protection needs of the facility.

4.2 FIRE COMMAND STATION FIRE ALARM SYSTEM FUNCTIONS

The fire alarm system within the WTC offered multiple functions to enhance the overall life safety features within the buildings. The primary monitoring and control of the fire alarm system was performed at the Fire Command Station (FCS) within each building. The life safety functions performed by the FCSs were (PANYNJ 1999a; NIST NCSTAR 1-1H):

- An audible alarm signal upon an alarm condition or system malfunction.
- Manual control of the emergency voice and alarm communication capability. Voice or alarm notification could be selected by individual floor, group of floors, or throughout the building.
- A means to silence the audible alarm signals when the loud speakers were in use and for activating the audible alarm system automatically when use of the loud speakers was terminated.
- Manual acknowledgment of the alarm or system fault condition through an alpha/numeric display and keyboard.
- A two-way telephone system for the firefighters with the capability to make announcements over the emergency voice and alarm communication system.
- A two-way telephone system for the floor warden stations, mechanical control center, and air-handling control rooms.
- A means to manually transmit a fire alarm signal to the Fire Department.
- Means for testing the display, alarms, and connection to the Fire Department.

4.3 FIRE ALARM SYSTEM FUNCTIONS

The detection and notification functions were performed throughout the building by the fire alarm system. The life safety functions performed by the fire alarm system were (PANYNJ 1999a; NIST NCSTAR 1-1H):

- Emergency voice and alarm speakers for audible notification and communication in all areas within the building.

- Strobes to provide visual alarm indications for the hearing impaired.
- Two-way firefighter telephone communication system.
- Two-way floor warden telephone communication system.
- Two-way maintenance telephone communication located at the remote fire alarm panel locations.
- Automatic smoke detection that would provide an alarm signal at the FCS upon activation.
- Monitor the fire sprinkler system for water flow or disabled performance conditions that would alarm at the FCS upon activation.
- Manual stations for occupant activation that would alarm at the FCS upon activation.
- Monitoring of independent fire alarm systems installed by individual tenants that would annunciate their alarm condition at the FCS.
- Automatically notify the Fire Department upon fire alarm activation.

4.4 FIRE ALARM SYSTEM INSTALLATION CRITERIA

The overall performance of the fire alarm system is dependent on the installation of the equipment and devices meeting prescribed standards. Installation standards originate from the manufacturer, design criteria, and local requirements. A synopsis of the major equipment installation standards as they relate to their performance included (PANYNJ 1999a; NIST NCSTAR 1-1H):

- Speakers located to ensure their operation would be heard clearly above ambient noise level.
- The voice loudspeaker system was required to ensure 50 percent of the system would remain operable throughout the building in the event 50 percent became inoperable.
- Visual alarm devices were required in common use spaces.
- Automatic smoke detectors were required in the mechanical rooms, electrical switch gear rooms, electric and telephone closets.
- Automatic smoke detectors installed at the return air ducts serving each floor were required to shut down its corresponding air handling unit upon the detector’s activation.
- Automatic smoke detectors at each elevator landing for recalling elevators upon detector activation.
- At least one manual fire alarm station was required to be installed in each story in the path of escape. No point on a floor could be more than two hundred feet from the nearest station.
- Floor warden telephone stations were required to be located between required stairways.

- Firefighter telephones were required near the main standpipe in the stairway on each floor, and within the sprinkler water tank and fire pump rooms.
- FCS was required to be located in the lobby of the building.
- The fire alarm wire criteria required a minimum size and type that would not support flame.
- Riser cable and its branches were not required to be installed in conduits or raceways if not exposed to public view.
- A terminal connection box for the wiring served a maximum of five floors above and five floors below the terminal box.

Chapter 5

FIRE ALARM SYSTEM DESIGN, EQUIPMENT, INSTALLATION, AND PERFORMANCE CRITERIA

The magnitude, size, and scope of the World Trade Center (WTC) fire alarm retrofit project rivaled any effort performed by the fire protection industry. It was estimated that over 10,000 initiating devices (smoke detectors, manual pull stations, waterflow indicators, etc.), with 30,000 notification appliances (speakers and strobes), supported by over 700,000 ft of conduit and 5 million ft of wire was installed in the WTC as part of the fire alarm system retrofit project (Mizrahi). Project development documentation found and analyzed was focused on the system's architecture and performance. No documentation was found that indicated cost was a factor in obtaining the WTC's fire protection goals.

Before the original fire alarm system operation was fully restored after the 1993 bombing, The Port Authority of New York and New Jersey (PANYNJ or Port Authority) Engineering Department began to explore the WTC's fire detection and alarm system's goals, and how to incorporate these requirements into a replacement system. Based upon its findings, the Port Authority Engineering Department initiated a fire alarm retrofit project, which was developed from the following objectives (PANYNJ 1998):

1. Identify the type and extent of fire detection, communication, notification, and monitoring capabilities required.
2. Select the fire alarm technology to support the size of the WTC complex (approximately 12,000,000 ft^2), with the capability to interface with the existing fire alarm systems. All the equipment was required to be New York City (NYC) BSA/MEA approved, and was required to be readily available for initial purchase and spare parts.
3. Determine the size, type, and number of equipment, devices, and hardware needed for the fire alarm infrastructure. Identify location and space for the infrastructure.
4. Determine how to interface the new system with the existing fire alarm systems and their components.
5. Develop standards, guidelines, and specifications for the design of the retrofit fire alarm system.
6. Develop standards, guidelines, and specifications for the installation of the fire alarm system.
7. Institute maintenance procedures to ensure the availability and performance of the fire alarm system.

Although documentation of the decision-making processes or directives defining the WTC fire alarm protection goals were not located, the overall design development, installation, and maintenance of the system indicates that it was the intention of the Port Authority to meet or exceed all local code and American with Disabilities Act requirements as interpreted by the Chief Engineer of the WTC. If the Port

Authority believed that it was in the best interest of the WTC and its tenants to vary from the code requirements due to operations and/or other features of the fire alarm system, the Port Authority would obtain agreement or approval from the Fire Department and/or Department of Buildings as per the Memorandum of Understanding signed between the Port Authority and the Department of Buildings (Semah 1996).

5.1 SYSTEM DESIGN AND INSTALLATION CRITERIA FOR WTC 1 AND WTC 2

The magnitude and size of the fire alarm system was reflective of the protected building's size and large number of people that occupied the building on any given day. To control a project of this size, specific design criteria were developed based upon the system's performance objectives and fire protection goals. The design criteria designated type, models, location, and performance of the fire alarm control and monitoring equipment, supporting hardware, and fire alarm devices. Procedures were also developed to monitor and track the project's progress. The phased project approach and its criteria allowed the transfer of the original system's fundamental monitoring, controls, and communication capabilities to be transferred to the replacement system during the first phase of the project, and allowed new or revised fire alarm devices to be put into service as soon as they were functional during succeeding phases.

The coordination of multiple projects involving the installation of the system and changes during tenant fit outs required close coordination between the Port Authority, equipment supplier, architects, engineers, and contractors. The equipment supplier, Siemens, provided the fire alarm equipment, system engineering, technical support, and overall project management liaison. Project coordination meetings were held on a weekly basis with the Port Authority Engineering, Risk Management, Operations, and Contractor Representatives to coordinate all project activities. Additionally, daily conference calls were made with the Port Authority Maintenance Supervisor to review the effect of all ongoing projects on the overall operational status of the system. Tracking ongoing projects was documented through (Drucker 2001):

1. System inspection records and Fire Department logs.
2. System maintenance records.
3. Updates to core capital record for changes.
4. Design compliance review functions.
5. System reacceptance testing records.

5.1.1 System Arrangement

The baseline for defining the fire alarm system's performance was derived from the objective to meet Local Law 76 as it related to existing high-rise office buildings over 100 ft tall. The Fire Alarm and Communication System for a Class "E" building was required to contain the following components to monitor and annunciate the status of its devices and initiate an appropriate response (PANYNJ 1999a; NIST NCSTAR 1-1H):

1. Fire Command Station (FCS) located in the lobby of the building on the entrance floor.
2. Manual Fire Alarm Stations provided in each story along the path of escape with additional stations installed so that the maximum travel distance between stations would not exceed 200 ft.
3. Speakers located on all floors, stairways, and elevators[2] that can be operated in the FCS.
4. Visual Alarm Devices (strobes) are to be provided in spaces used by people having physical disabilities. The Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG) was used as the criteria for determining what areas require visual alarm devices.
5. Floor Warden Stations on each floor that provided two-way communication with the Fire Command Station.
6. Standpipe Fire Line Telephone System with communication stations provided at FCS, each floor near the standpipe riser, gravity tank rooms, and fire pump rooms.
7. Associated monitoring and controls:
   a. Smoke and heat detection
   b. Sprinkler monitoring
   c. Status of air handling systems

5.1.2 Design Criteria

The fire alarm system was considered a single part of a comprehensive approach for the WTC's fire protection needs. As such, quality controls were maintained through quality assurance analysis, standards, and criteria for the design and installation of the replacement fire alarm replacement system. This was an ongoing effort that introduced changes as studies or experiences identified areas requiring improvement or new technology offered enhanced system performance (Drucker 1994; WTC Engineering Dept 1994; Syska & Hennessy 1996; Drucker 1996; Semah 1996; Menno 1998; Drucker 1998; Semah 1998; Barbella 1999; Boyle 1999; Bonacci 1999; Drucker 1999; Drucker 1999).

5.1.3 Speaker Audibility and Intelligibility

The Port Authority performed an in-depth analysis on speaker intelligibility and audibility for the WTC (see Fig. 5–1). The intent of the analysis was to develop a speaker location guideline that would ensure an acceptable level of intelligibility (message clarity) and audibility (loud enough to be heard).

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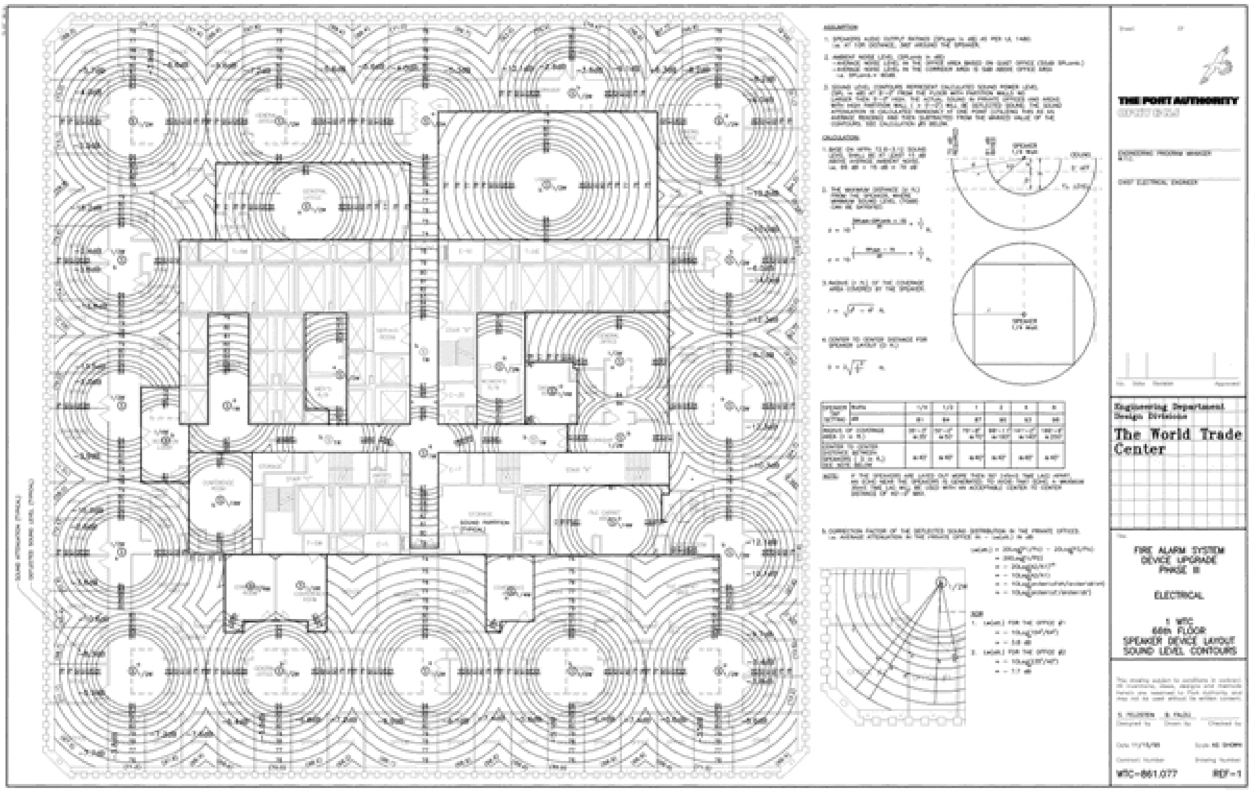
[2] Elevator speaker communication controlled by a separate elevator system.



Source: PANYNJ. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–1. Speaker intelligibility and audibility performance drawing.

5.1.4 Design Guidelines

The "MANDATED Fire Alarm Guidelines" (WTC 1999) was the basis for the installation of new equipment and changes during new tenant fit out. The guideline provides a comprehensive approach that includes:

1. An introduction providing a general description of the WTC.
2. Terms, definitions, and general information required for the design and installation.
3. Fire alarm system backbone system architecture that describes the core system interface equipment and hardware.
4. Intent, location, and requirements of the distributed fire alarm interface cabinets. The guideline included typical cabinet configurations and connections.
5. Fire detection and interface device design criteria for device locations, installation, and connections.
6. Audio and visual notification appliance design criteria for device locations, installation, and connections. The notification appliance information was required to include its audio power in watts and luminous intensity in candela requirements for the speakers and strobes.

7. Fire alarm riser/one line diagram criteria requiring a diagrammatic format for each interface cabinet, circuit, raceway, detection device type, and notification appliance type.

8. Circuit performance criteria with forms for documenting test procedures, results, and verification.

9. Contractor tie-in and pretest checklist to document that the design and installation procedures have been followed.

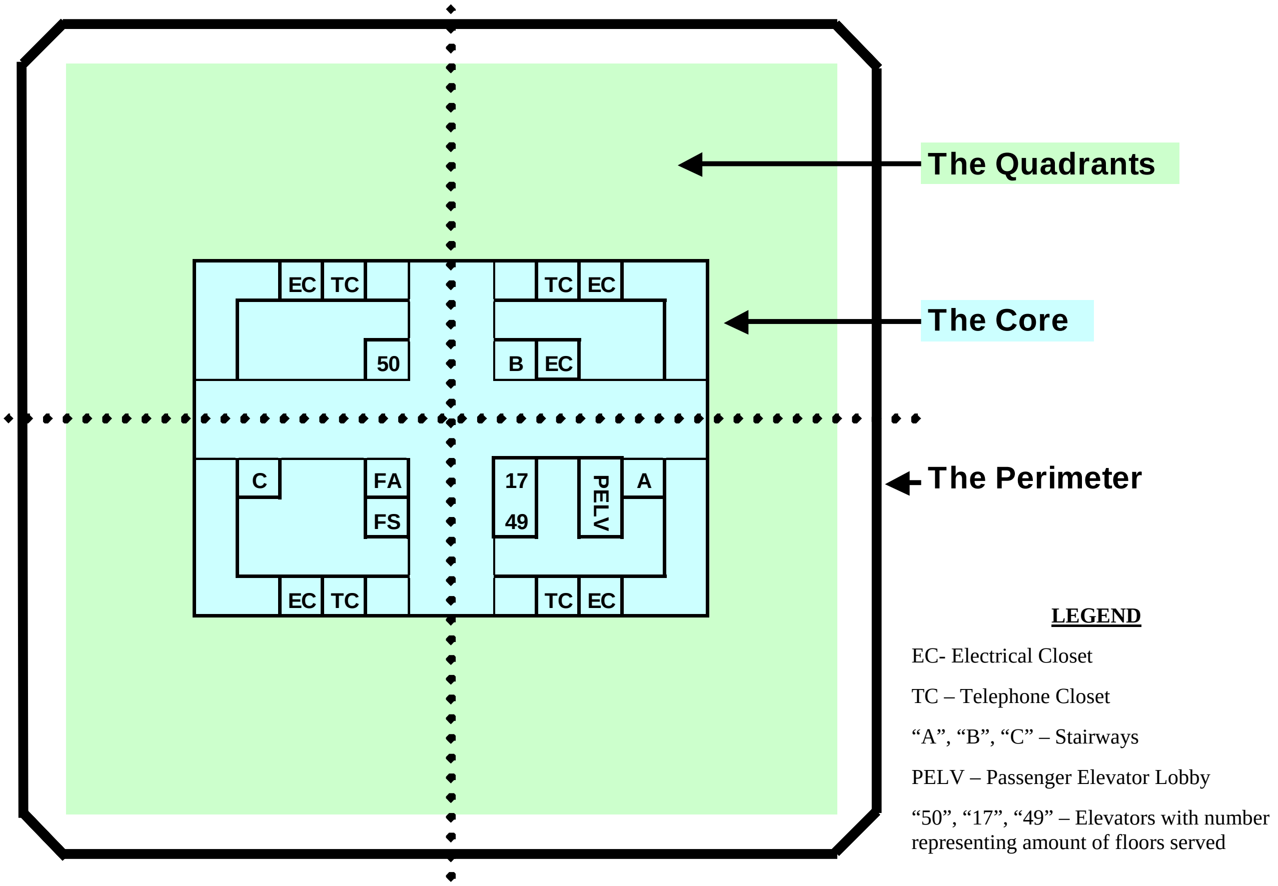
10. Acceptance testing forms to document and assure the performance of the fire alarm monitoring, detection, and notification devices.

11. Project summary that reviews the deliverables required for the fire alarm installation through design, installation, acceptance, as-built documentation, and final project close out.

The standardized design concept was reinforced in the “Tenant Construction Review Manual” that provided the technical criteria for all architectural and engineering consultants in connection with construction work undertaken by the WTC tenants (Engineering Dept 1997).

5.1.5 Design Approach

A standardized approach for the design and installation of the tower fire alarm equipment and devices was developed by subdividing a typical floor plate into a core and quadrants (see Fig. 5–2). The intent was to set quality control standards with typical requirements and locations for common equipment, devices, and circuits within an assigned area.

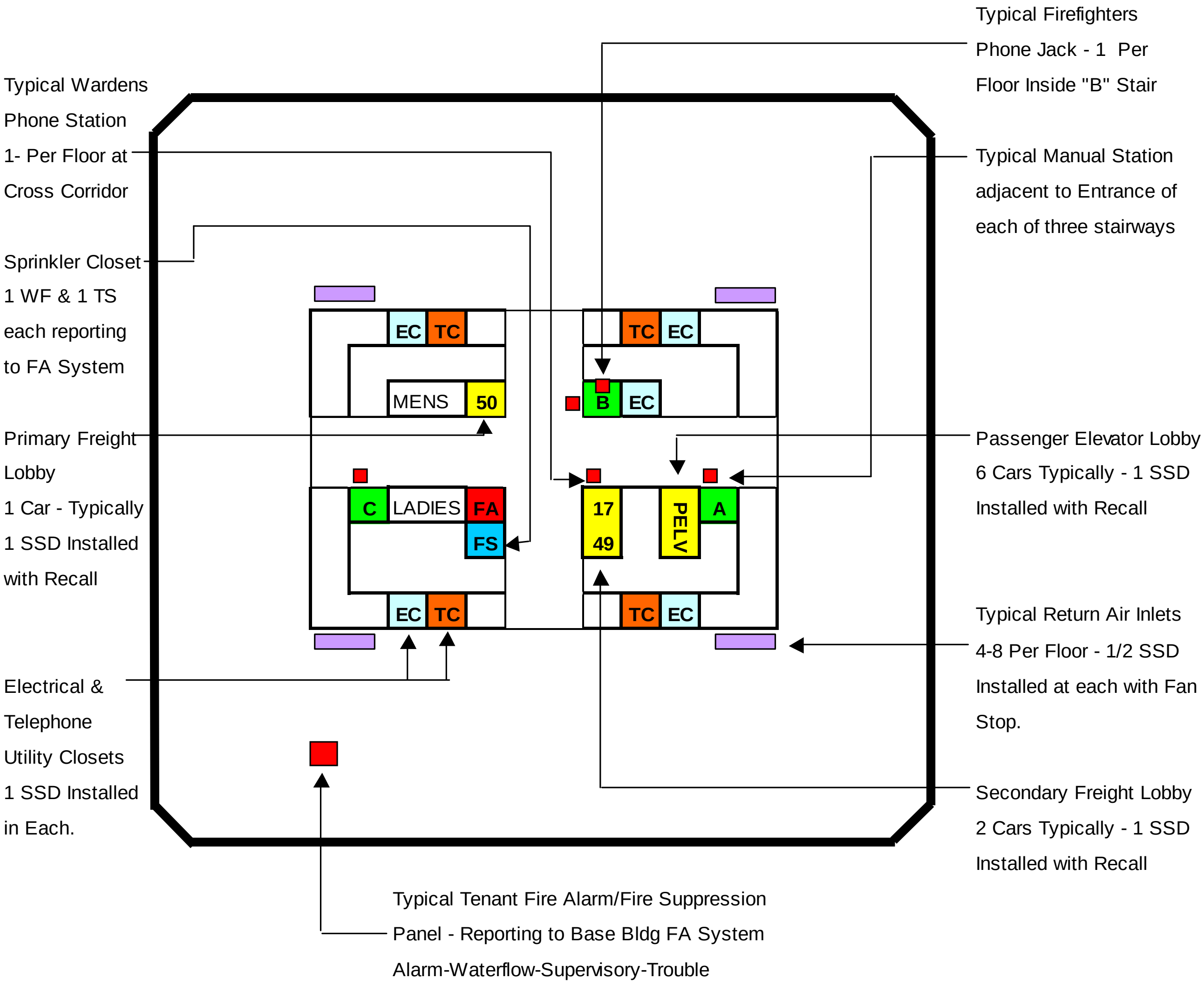


Source: Drucker 2001.

Figure 5–2. Core and quadrants.

5.1.6 Typical Fire Alarm Equipment and Device Locations

Specific areas within the typical floor template were designated for the fire alarm control equipment, initiating devices, and communication equipment (see Fig. 5–3).

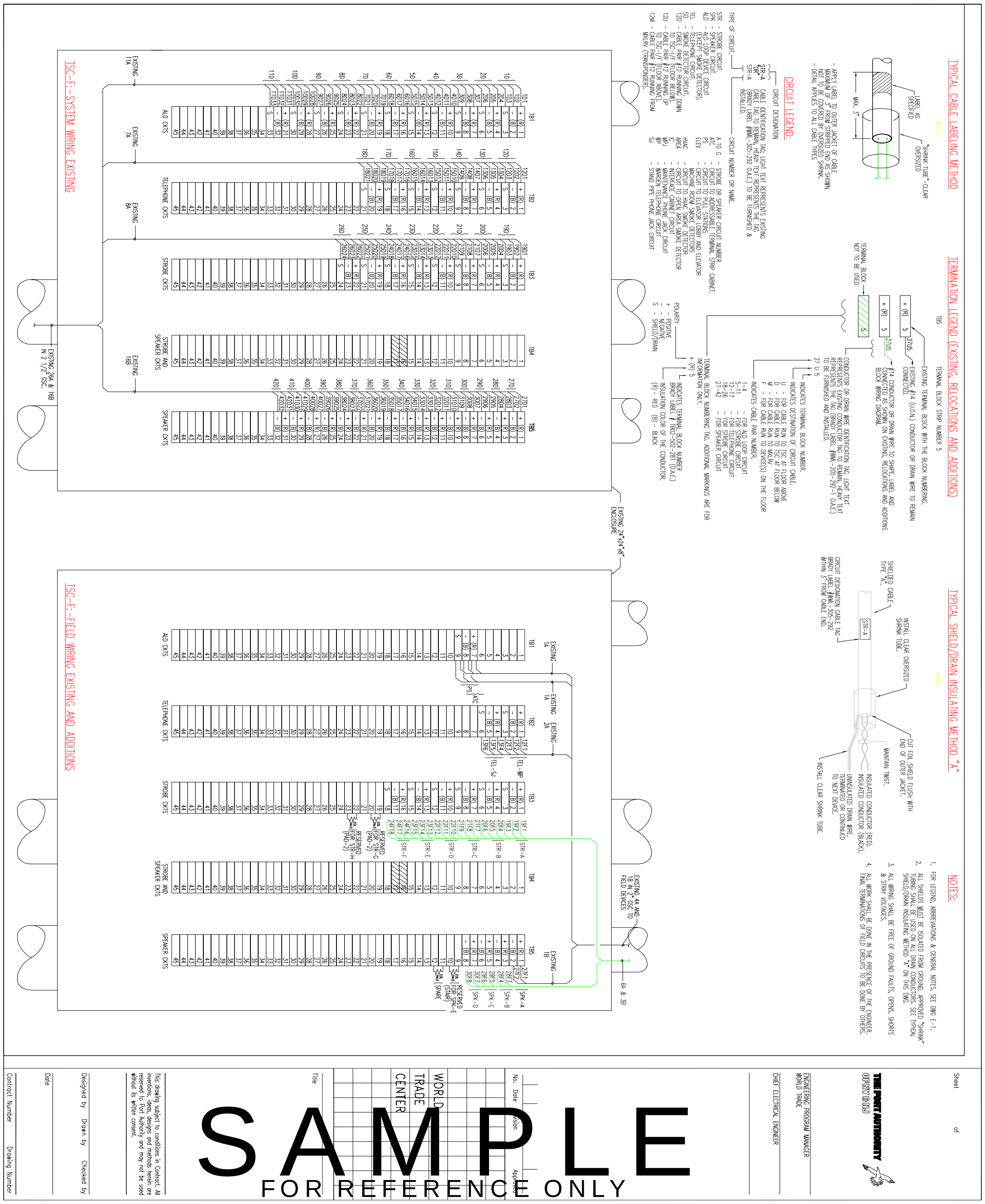


Source: Drucker 2001.

Figure 5–3. Standard locations for fire alarm equipment and devices.

5.1.7 Typical Fire Alarm Cabinet Connections

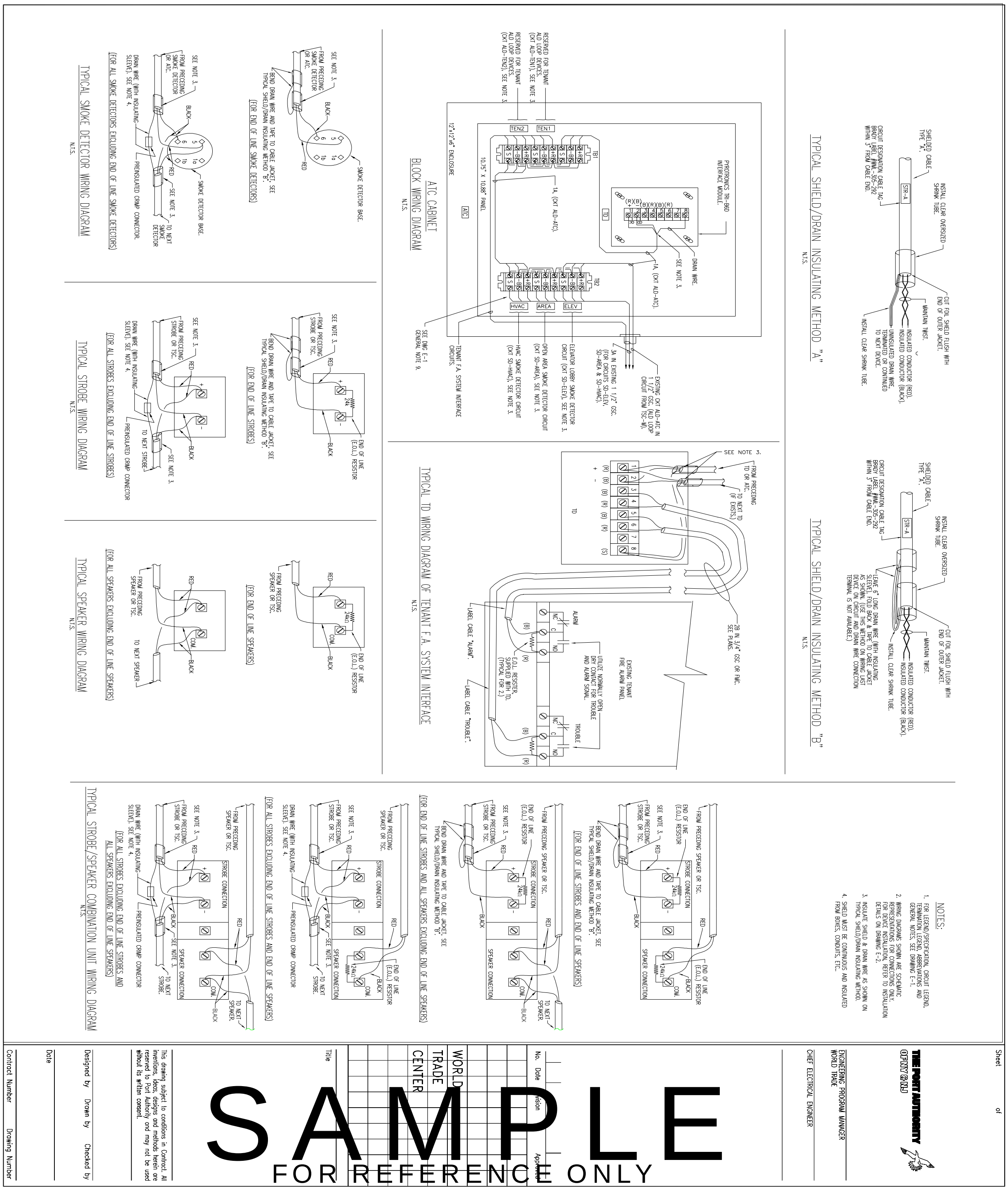
The Core Fire Alarm Closets and Core Fire Sprinkler Closets were designated locations for fire alarm interface panels and cabinets, which supported and distributed the system's monitoring, control, and communication circuits. The Terminal Strip Cabinet (TSC) was located in the fire alarm closet when a remote fire alarm panel was present, and located in the fire sprinkler closets on floors without remote fire alarm panels (see Figs. 5–4 and 5–5). The TSC supported the telephone, speaker, and strobe notification appliance circuits. The typical drawings for the TSC included the cable connection details to maintain quality control.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–4. Standard configuration for Terminal Strip Cabinet

The ALD Terminal Cabinets (ATC) were located in the core fire sprinkler closets. ALD is the fire alarm manufacturer's abbreviation for "Analog Loop Driver," which are the circuits for the fire alarm monitoring and control devices. The typical drawing included device and circuit connection details.

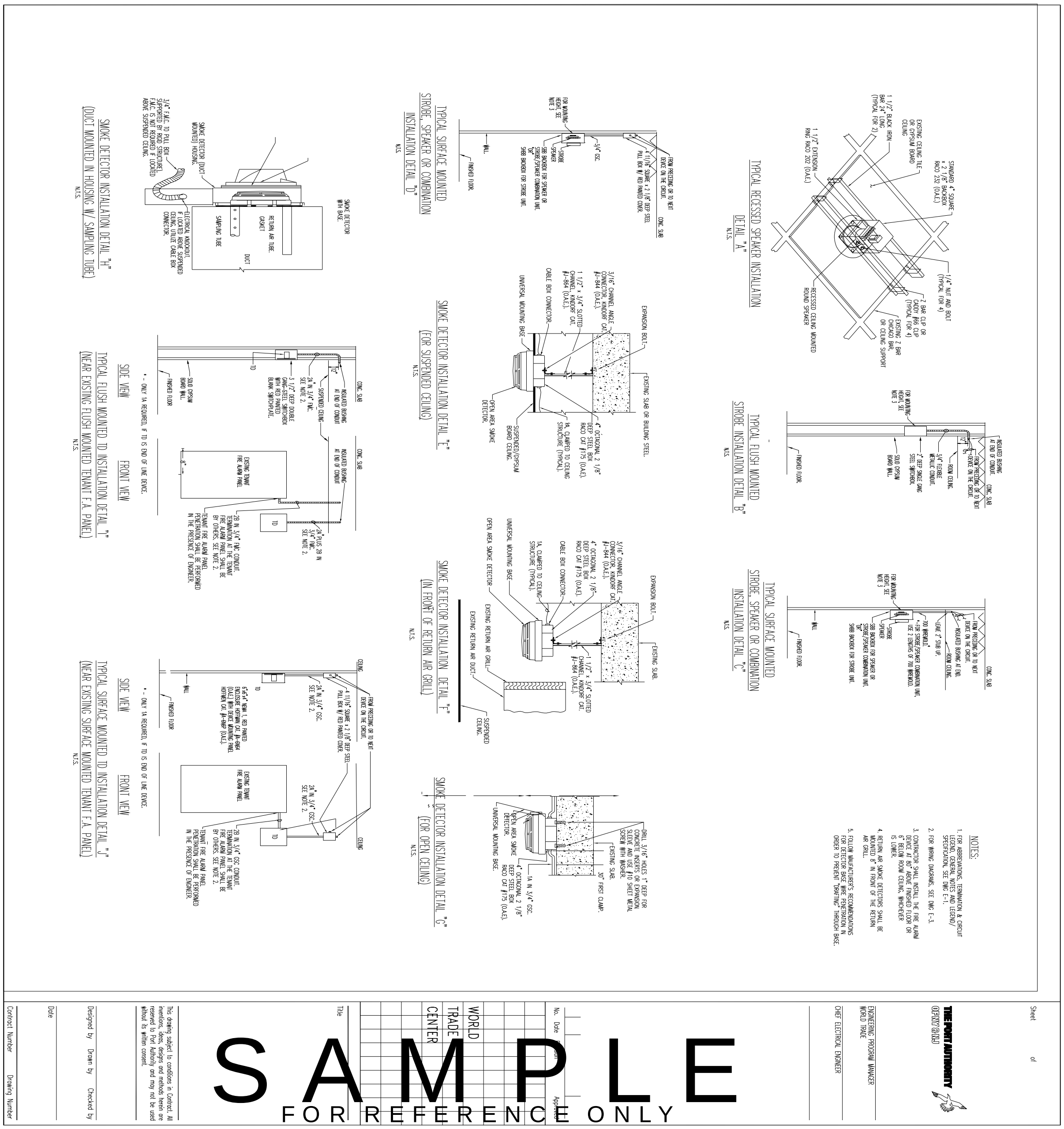


Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–5. Standard configuration for Terminal Strip Cabinet.

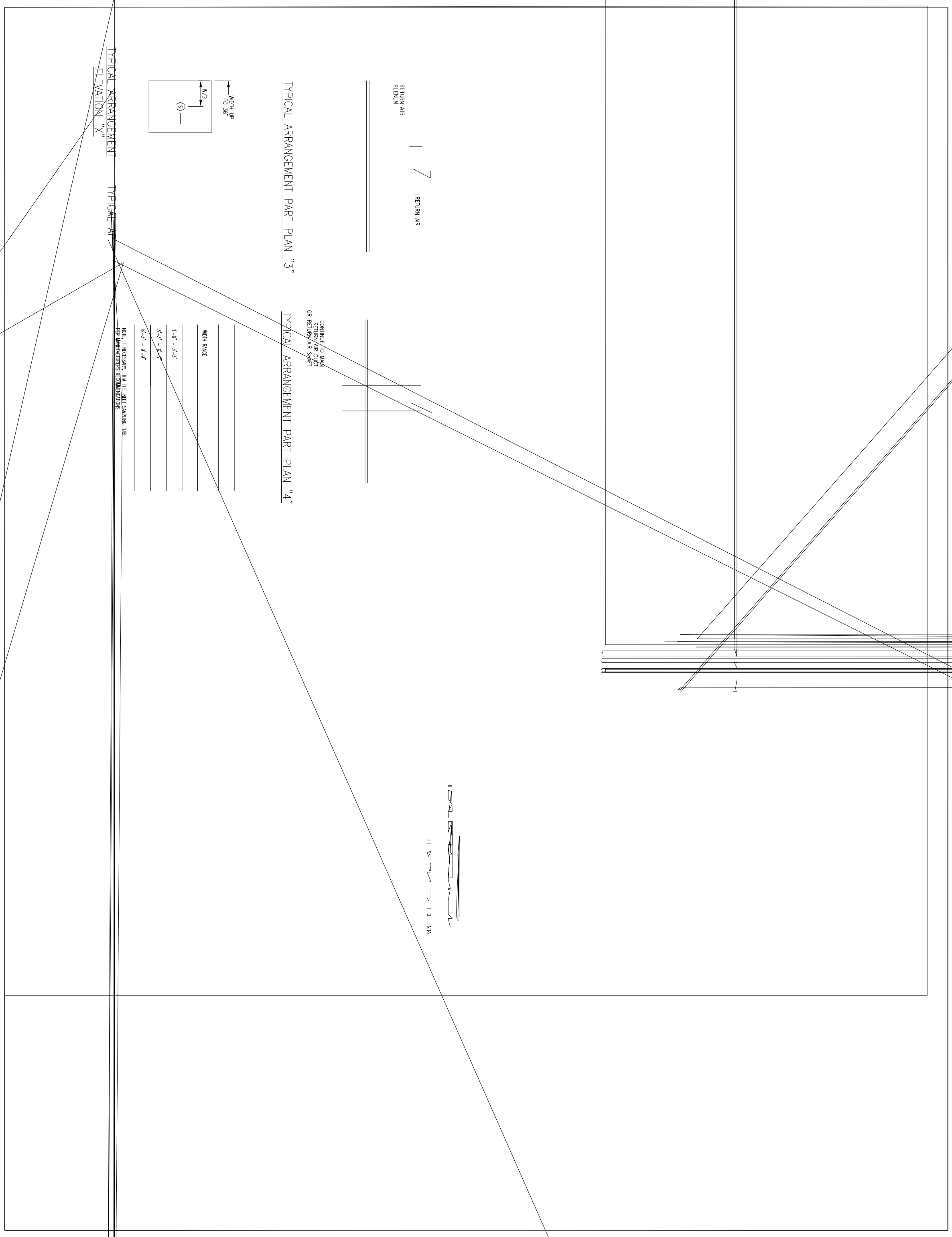
5.1.8 Typical Fire Alarm Installation Detail

Typical drawings were developed to provide guidance on the installation criteria for the devices to meet tolerances required by code and the manufacturer (see Figs. 5–6 and 5–7).



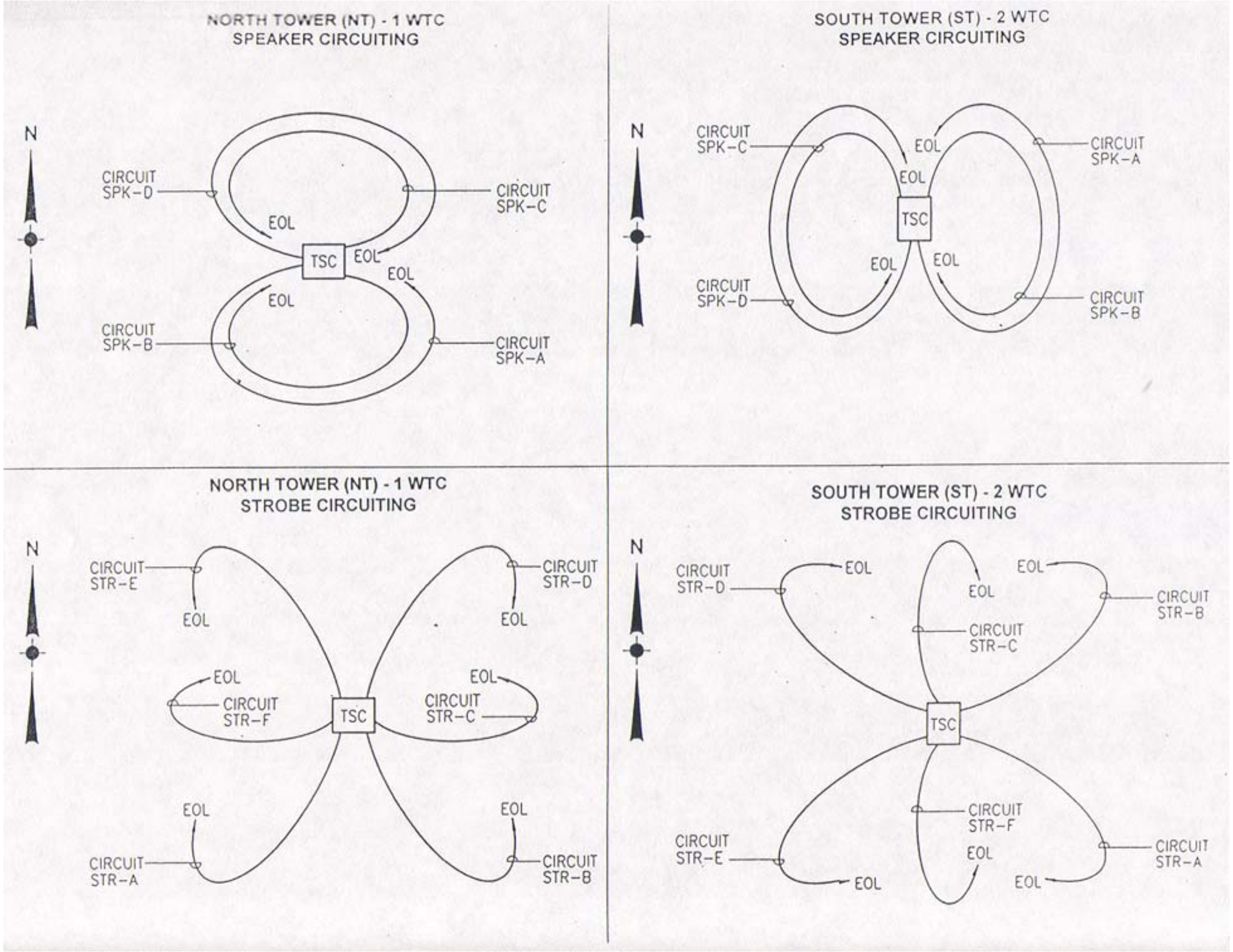
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–6. Standard location for fire alarm devices.


TYPICAL ARRANGEMENT ELEVATION "X"
TYPICAL AR
WIDTH UP TO 36"
W/2
S
TYPICAL ARRANGEMENT PART PLAN "3"
RETURN AIR PLENUM
RETURN AIR
TYPICAL ARRANGEMENT PART PLAN "4"
CONTINUE TO MAIN RETURN AIR DUCT OR RETURN AIR SHAFT
WIDTH RANGE
1'-8" - 3'-5"
3'-5" - 6'-5"
6'-5" - 9'-9"
NOTE: IF NECESSARY, TRIM THE INLET SAMPLING TUBE PER MANUFACTURERS RECOMMENDATIONS.

5.1.9 Typical Fire Alarm Circuit Routing Criteria

A schematic diagram was included in the design criteria, providing a standard for the layout of the fire detection and notification circuits (see Fig. 5–8). The circuit configurations were developed to meet code requirements and to improve overall survivability of the system's functions within the protected area. The intent of the circuit configurations was to limit the effects from a single circuit loss to performance degradation of its function within the protected area, without causing a catastrophic failure.

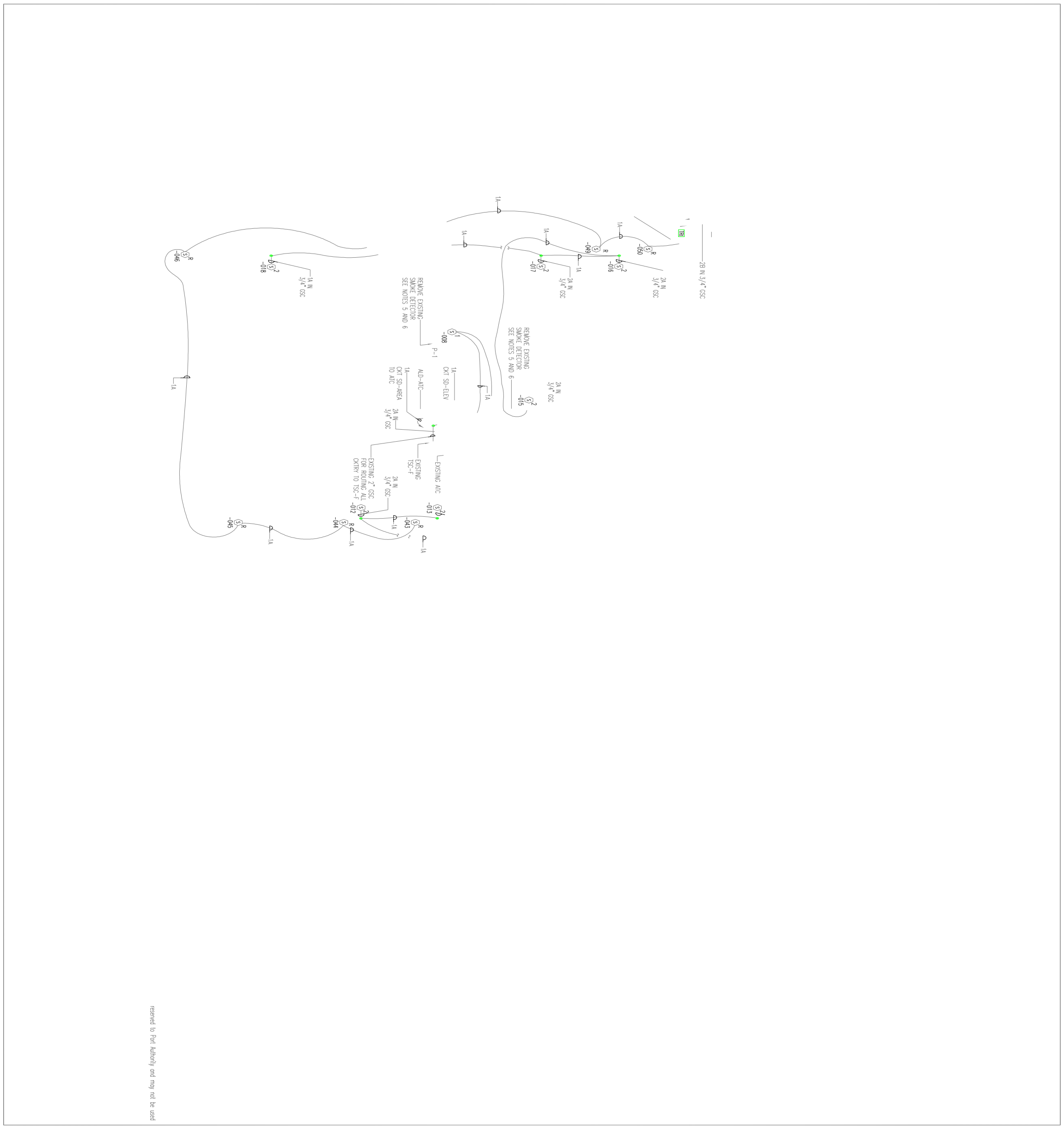


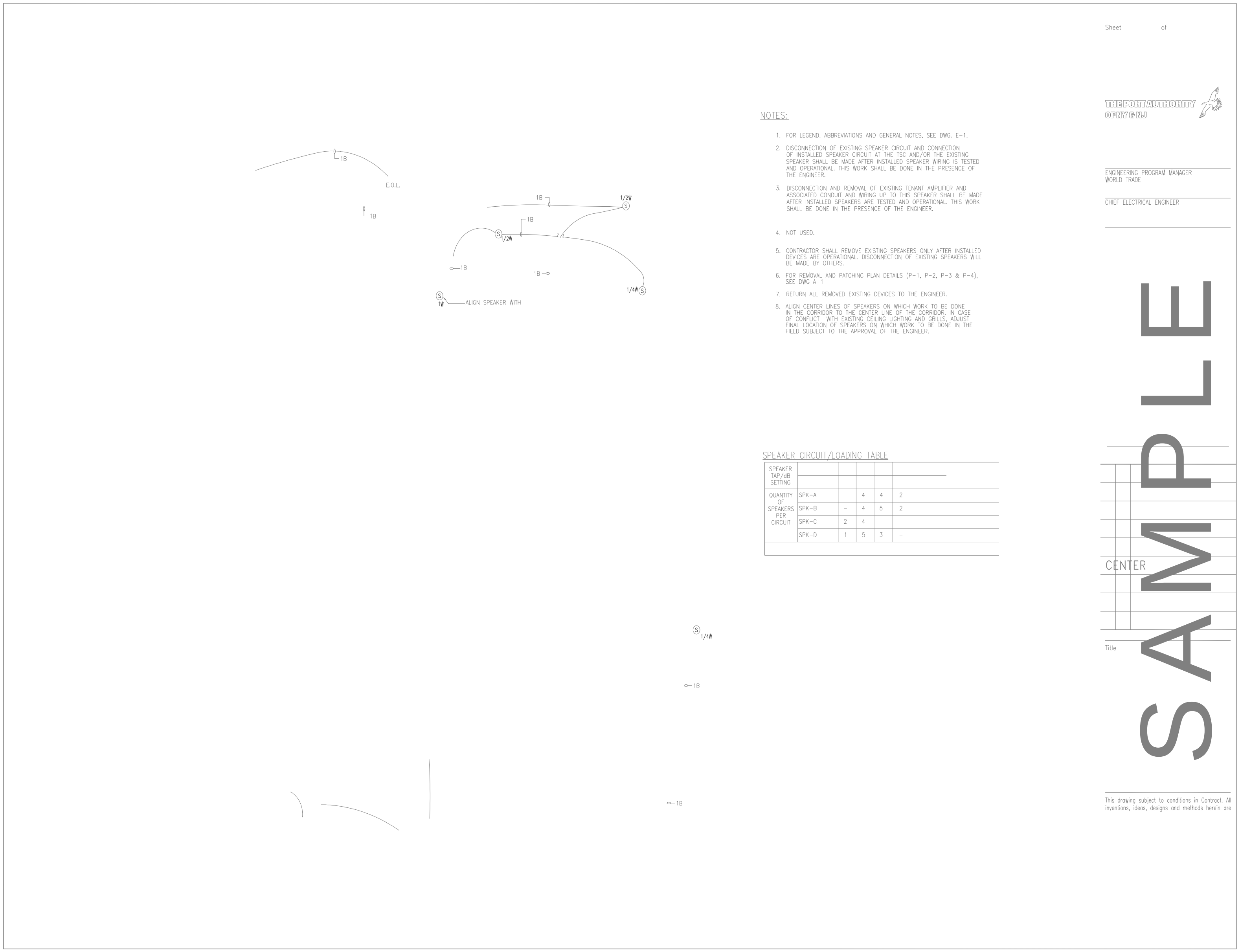
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–8. Standard routing for fire alarm circuit.

5.1.10 Typical Fire Alarm Device Design Detail

Typical drawings were developed to provide a submittal format for architects, engineers, and contractors. The intent was to set a standard on what information was required, and how the information was to be presented on a drawing submitted for approval. Typical drawings were developed for the fire detection, speaker, and strobe design submittals (see Figs. 5–9 to 5–11).


REMOVE EXISTING SMOKE DETECTOR SEE NOTES 5 AND 6
REMOVE EXISTING SMOKE DETECTOR SEE NOTES 5 AND 6
2B IN 3/4" OSC
EXISTING ATC
EXISTING TSC-F
EXISTING 2" OSC FOR ROUTING ALL CKTRY TO TSC-F
CKT SD-ELEV
CKT SD-AREA TO ATC
AUD-ATC
-046
-018
-049
-050
-017
-016
-008
-015
-013
-012
-043
-044
-045
reserved to Port Authority and may not be used



NOTES:

1. FOR LEGEND, ABBREVIATIONS AND GENERAL NOTES, SEE DWG. E-1.
2. DISCONNECTION OF EXISTING SPEAKER CIRCUIT AND CONNECTION OF INSTALLED SPEAKER CIRCUIT AT THE TSC AND/OR THE EXISTING SPEAKER SHALL BE MADE AFTER INSTALLED SPEAKER WIRING IS TESTED AND OPERATIONAL. THIS WORK SHALL BE DONE IN THE PRESENCE OF THE ENGINEER.
3. DISCONNECTION AND REMOVAL OF EXISTING TENANT AMPLIFIER AND ASSOCIATED CONDUIT AND WIRING UP TO THIS SPEAKER SHALL BE MADE AFTER INSTALLED SPEAKERS ARE TESTED AND OPERATIONAL. THIS WORK SHALL BE DONE IN THE PRESENCE OF THE ENGINEER.
4. NOT USED.
5. CONTRACTOR SHALL REMOVE EXISTING SPEAKERS ONLY AFTER INSTALLED DEVICES ARE OPERATIONAL. DISCONNECTION OF EXISTING SPEAKERS WILL BE MADE BY OTHERS.
6. FOR REMOVAL AND PATCHING PLAN DETAILS (P-1, P-2, P-3 & P-4), SEE DWG A-1
7. RETURN ALL REMOVED EXISTING DEVICES TO THE ENGINEER.
8. ALIGN CENTER LINES OF SPEAKERS ON WHICH WORK TO BE DONE IN THE CORRIDOR TO THE CENTER LINE OF THE CORRIDOR. IN CASE OF CONFLICT WITH EXISTING CEILING LIGHTING AND GRILLS, ADJUST FINAL LOCATION OF SPEAKERS ON WHICH WORK TO BE DONE IN THE FIELD SUBJECT TO THE APPROVAL OF THE ENGINEER.

SPEAKER CIRCUIT/LOADING TABLE

SPEAKER TAP/dB SETTING					
QUANTITY OF SPEAKERS PER CIRCUIT	SPK-A		4	4	2
	SPK-B	–	4	5	2
	SPK-C	2	4		
	SPK-D	1	5	3	–

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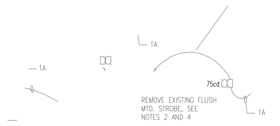
THE PORT AUTHORITY
OF NY & NJ

ENGINEERING PROGRAM MANAGER
WORLD TRADE

CHIEF ELECTRICAL ENGINEER

This drawing subject to conditions in Contract. All inventions, ideas, designs and methods herein are



NOTES:

1. FOR LEGEND, ABBREVIATIONS AND GENERAL NOTES, SEE DWG. E-1.
2. DISCONNECT STROBE AND ABANDON WIRING IN PLACE (TAG & TAPE CONDUCTOR ENDS).
3. REPLACE EXISTING STROBE WITH THE SHOWN CANDELA RATED STROBE, AND REWIRE AS SHOWN. (EXISTING BACKBOX AND CONDUIT STUB CAN BE UTILIZED IF IT IS SIMILAR TO THE TYPICAL FLUSH MOUNTED STROBE, SPEAKER OR COMBINATION INSTALLATION DETAIL "B") ON DWG. E-2.
4. ONLY AFTER INSTALLED STROBES ARE TESTED AND OPERATIONAL, SHALL CONTRACTOR REMOVE EXISTING STROBE IN THE PRESENCE OF THE ENGINEER. FOR PAINTED DRY WALL, REMOVE EXISTING STROBE, BACK BOX AND PATCH TO MATCH EXISTING WALL FINISH.

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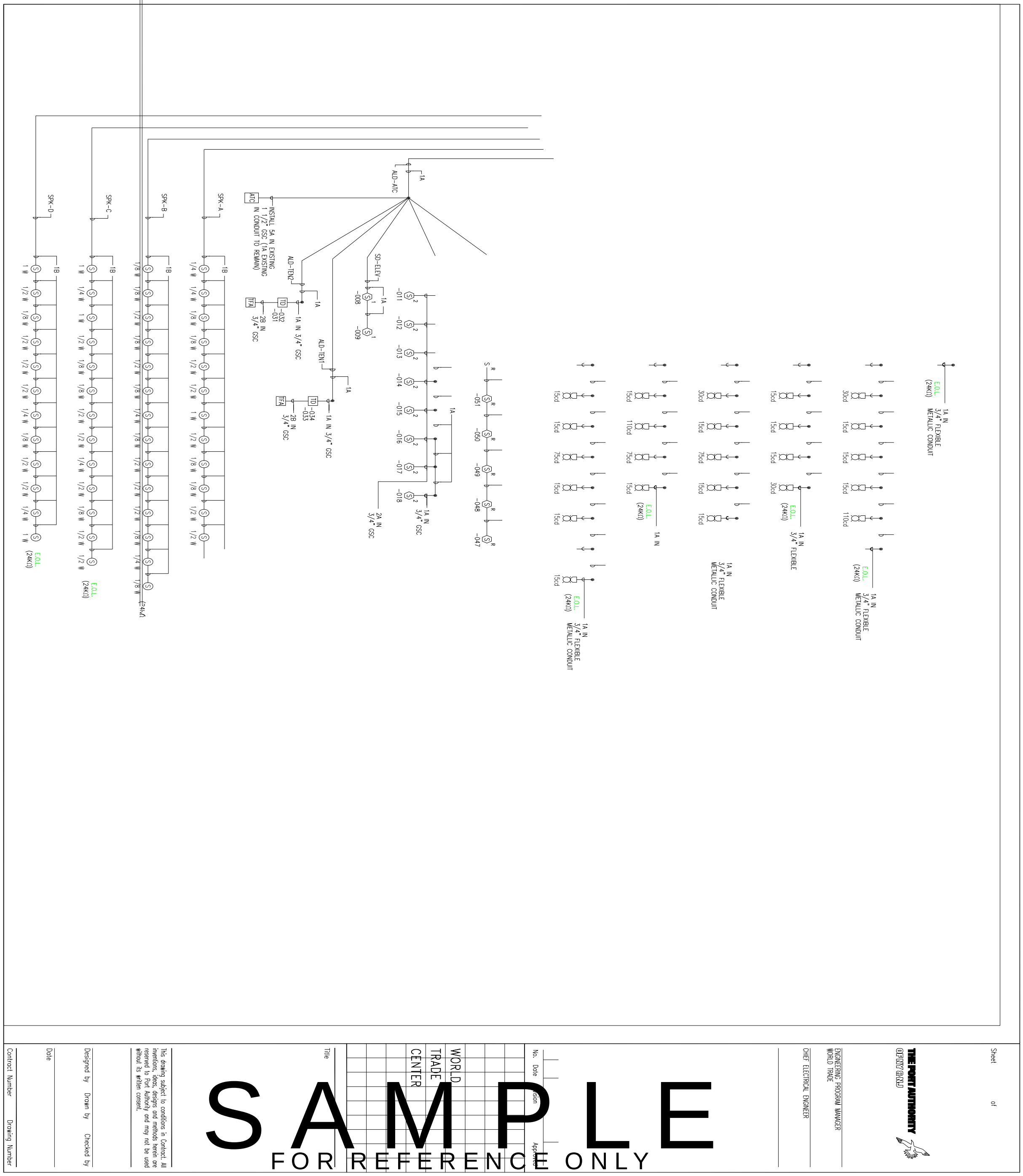
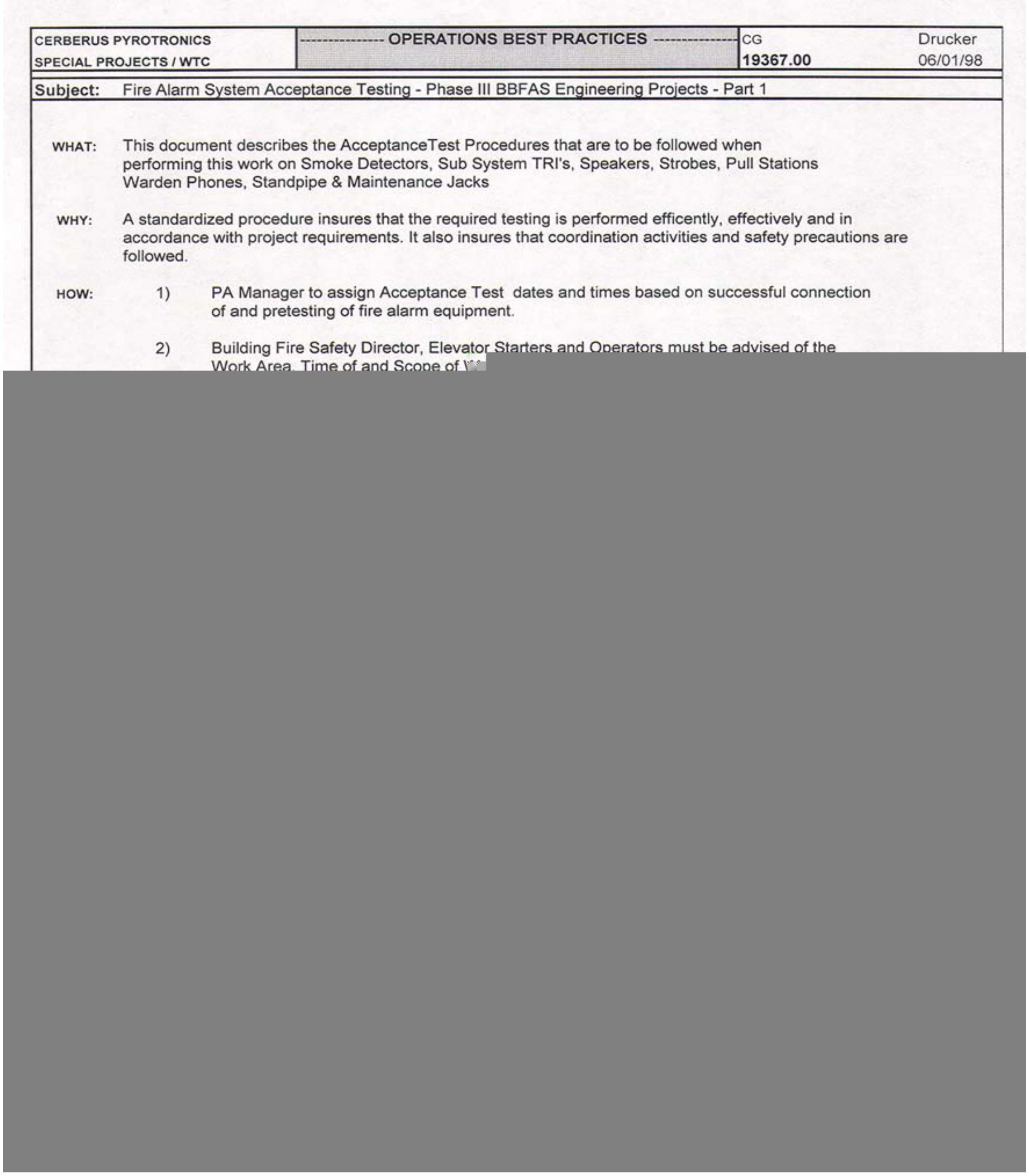
5.1.11 Typical Fire Alarm Device Riser Detail

Typical fire alarm riser drawings were developed to provide a standard on what information was required and how the proposed system installation or expansion would interface with or affect the existing system's performance and capabilities (see Fig. 5–12).



5.1.12 Installation Acceptance Testing and Commissioning Procedures

The installation of the approved fire alarm design required the contractor to perform specific quality control procedures. Since any system modifications would affect both the building occupants and the contractor's safety, specific testing and acceptance practices were developed to address these issues (see Fig. 5–13).



CERBERUS PYROTRONICS **SPECIAL PROJECTS / WTC**	**OPERATIONS BEST PRACTICES**	CG **19367.00**	Drucker 06/01/98

Subject: Fire Alarm System Acceptance Testing - Phase III BBFAS Engineering Projects - Part 1

WHAT: This document describes the AcceptanceTest Procedures that are to be followed when performing this work on Smoke Detectors, Sub System TRI's, Speakers, Strobes, Pull Stations Warden Phones, Standpipe & Maintenance Jacks

WHY: A standardized procedure insures that the required testing is performed efficently, effectively and in accordance with project requirements. It also insures that coordination activities and safety precautions are followed.

HOW:

1) PA Manager to assign Acceptance Test dates and times based on successful connection of and pretesting of fire alarm equipment.

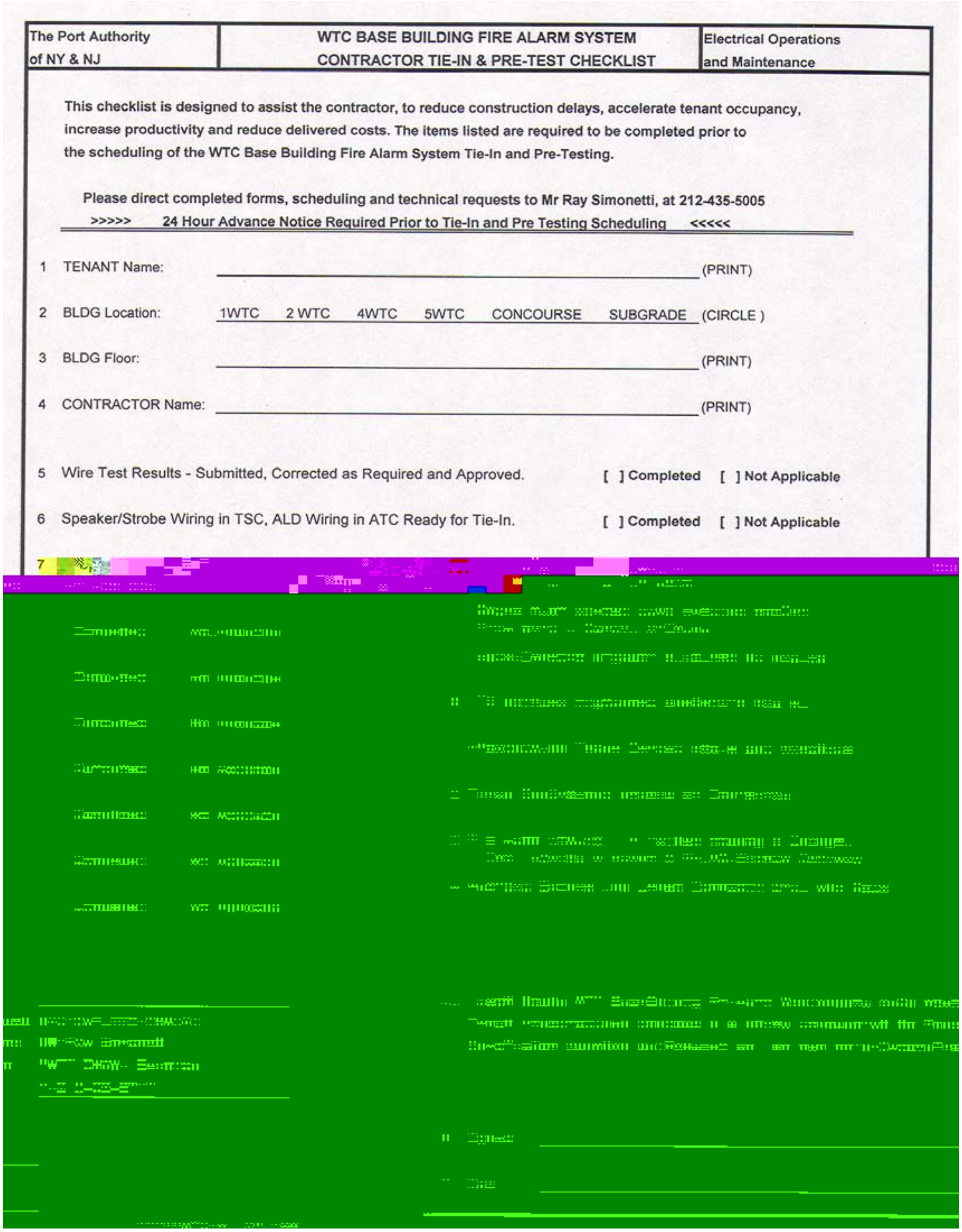
2) Building Fire Safety Director, Elevator Starters and Operators must be advised of the Work Area, Time of and Scope of [redacted]

Source: PANYNJ 1999a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–13. New work acceptance best practices.

5.1.13 Quality and Performance Assurance Forms

New fire alarm work was required to be tested to ensure its compliance with adopted performance criteria. Quality assurance forms were developed to provide testing accountability (see Figs. 5–14 and 5–15).



The Port Authority of NY & NJ	WTC BASE BUILDING FIRE ALARM SYSTEM CONTRACTOR TIE-IN & PRE-TEST CHECKLIST	Electrical Operations and Maintenance

This checklist is designed to assist the contractor, to reduce construction delays, accelerate tenant occupancy, increase productivity and reduce delivered costs. The items listed are required to be completed prior to the scheduling of the WTC Base Building Fire Alarm System Tie-In and Pre-Testing.

Please direct completed forms, scheduling and technical requests to Mr Ray Simonetti, at 212-435-5005

\>>>>> 24 Hour Advance Notice Required Prior to Tie-In and Pre Testing Scheduling <<<<<

1 TENANT Name: ________________________ (PRINT)

2 BLDG Location: 1WTC 2 WTC 4WTC 5WTC CONCOURSE SUBGRADE (CIRCLE)

3 BLDG Floor: ________________________ (PRINT)

4 CONTRACTOR Name: ________________________ (PRINT)

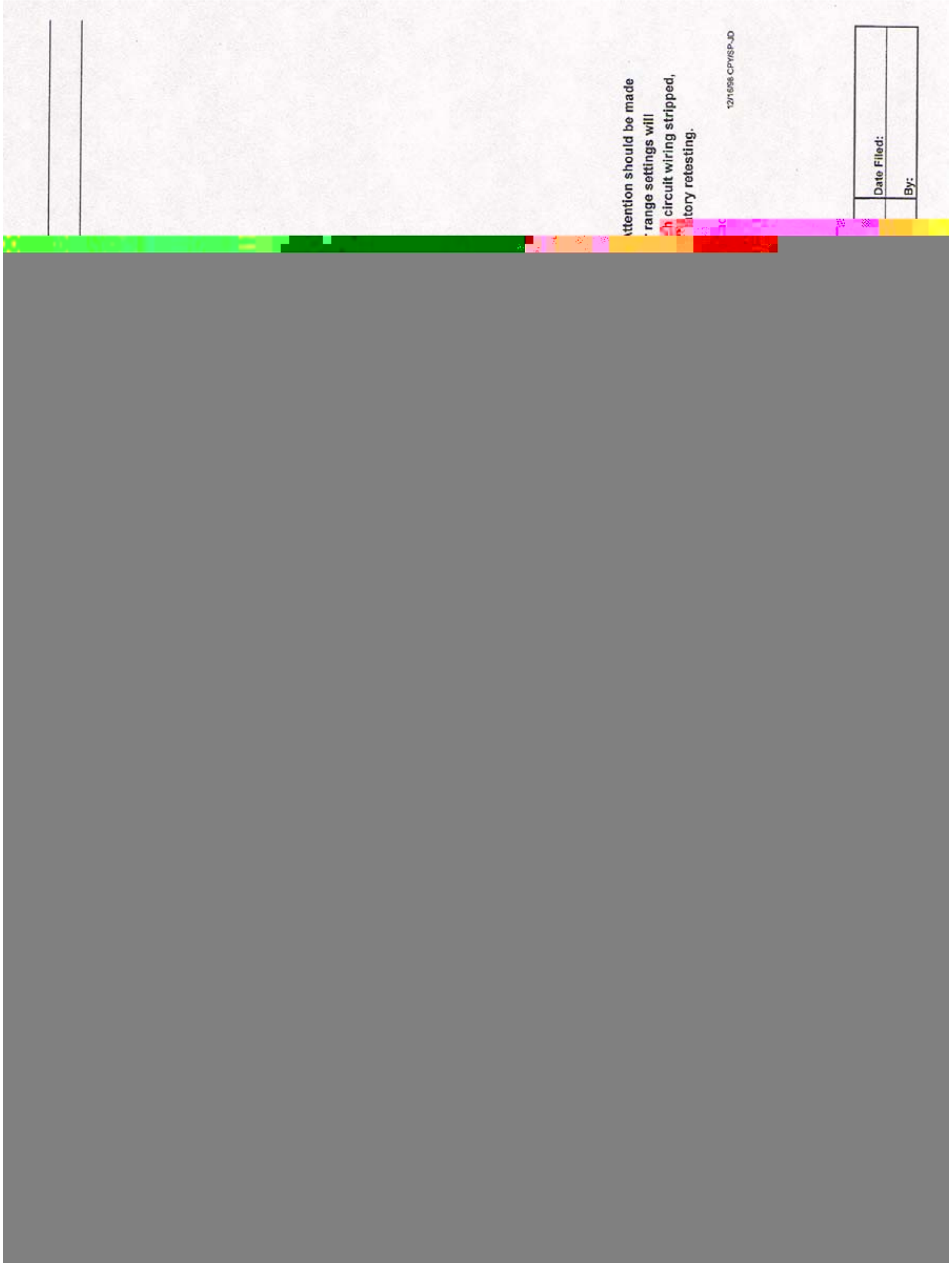
5 Wire Test Results - Submitted, Corrected as Required and Approved. ☐ Completed ☐ Not Applicable

6 Speaker/Strobe Wiring in TSC, ALD Wiring in ATC Ready for Tie-In. ☐ Completed ☐ Not Applicable

7 [illegible]

Source: PANYNJ 1999a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–14. Contractor tie-in and pre-test checklist.



Attention should be made

range settings will

circuit wiring stripped,

tory retesting.

12/16/98 CPY/SP-JD

Date Filed:

By:

Source: PANYNJ 1999a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–15. Contractor tie-in and pre-test checklist.

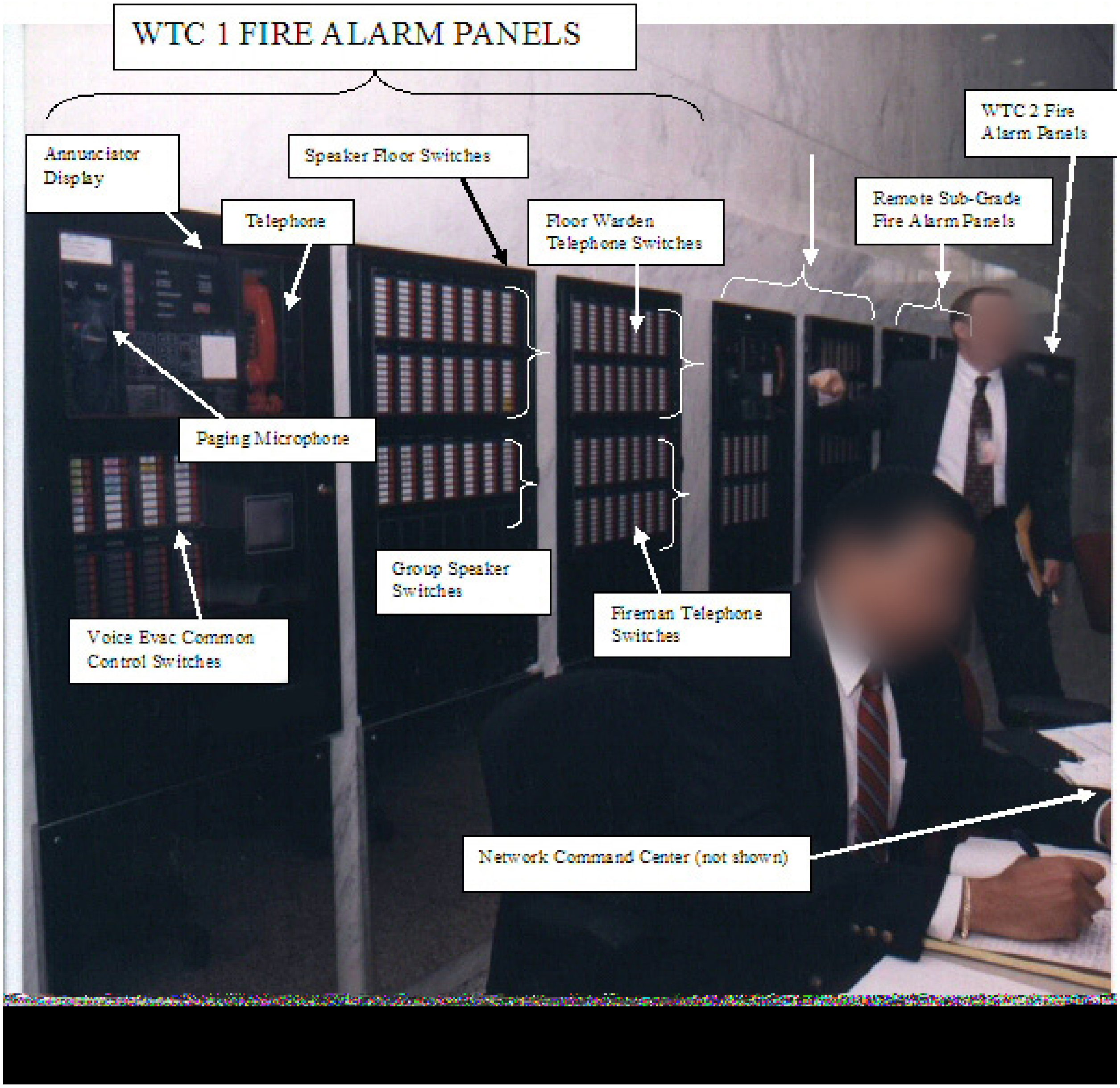
5.1.14 Fire Command Station Performance Standard

The FCS for Class E high-rise office buildings over 100 ft tall is required to be located in the lobby of the building on the entrance floor and contains the following components to monitor and annunciate the status of the fire alarm system and its devices (PANYNJ 1999a; PANYNJ 1999b; Drucker 2001; Drucker 2004):

1. An audible alarm signal.
2. Emergency voice and alarm communication capability.
3. Means for silencing the audible alarm signals when the loud speakers are in use and for activating the audible alarm system automatically when use of the loud speakers is terminated.
4. A means to control the alarm sounding devices on any floor throughout the building.
5. A manually reset information display to indicate the floor where the alarm was activated.
6. Manual controls and display lamps to include on/off condition of air-handling systems.
7. A Standpipe Fire Line Telephone system for the firefighters with the capability to make announcements over the emergency voice and alarm communication system.
8. A two-way communication system connected to a designated floor warden station on each floor, the mechanical control center, elevators, air-handling control rooms, and elevator machine rooms.
9. Means to manually transmit a fire alarm signal to the Fire Department via a central station of a franchised operating company.
10. Means for testing the display, alarms, and connection to the central station.

5.1.15 Fire Command Station Equipment

After the 1993 bombing, the Port Authority built FCS for WTC 1 and WTC 2 based upon the Building Code of New York code requirements as the baseline for design and performance (see Figs. 5–16 and 5–17). A master MXL-V and primary Network Command Center (NCC) for each building was installed in the building's FCS as the fire alarm system's main monitoring and control center. The master MXL-V consisted of numerous panels, with each providing specific functions required to meet the FCS performance criteria. The master fire alarm panels located in the FCS contained an alpha/numeric annunciator with switches for acknowledging the system alarms and for controlling system functions. These functions were also monitored, displayed, and controlled by the NCC located within the FCS. Additional panels contained the microphone and controls for the emergency voice/alarm communication (EVAC) system and controls for the firefighter and warden telephone communication systems.



Source: PANYNJ 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–16. WTC 1 fire command station.

Source: PANYNJ 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–17. WTC 2 fire command station.

5.1.16 Fire Command Station Design, Installation, and Operation

Although the history of the overall fire alarm design development indicates that there was detailed design documentation for the FCS architecture and fire alarm equipment layout, only limited pictures and schematic representations were located. The pictures and documentation indicate that the FCS was designed in a professional manner, met the adopted performance requirements for the systems installed, and was ergonomically designed for monitoring and control of the equipment by operating personnel.

The majority of fire alarm monitoring and control operation was performed at the NCC monitor. The NCC monitor provided an interactive display of the system's status and the options available to the responding operator in relation to the system's status. In addition to the NCC monitor, the fire alarm panels mounted on the FCS wall provided the following controls (PANYNJ 1999a; PANYNJ 1999b; Drucker 2001; Drucker 2004):

1. Manual controls and alphanumeric display that provided NCC redundancy.
2. The microphone for the emergency voice alarm communication system.

3. The control switches and status indicators for the emergency voice alarm communication system.
4. The telephone handset for the floor warden and firefighter telephones.
5. The control switches and status indicators for the floor warden and firefighter telephone system.

5.2 BASE BUILDING FIRE ALARM EQUIPMENT PERFORMANCE STANDARD

The backbone of the WTC 1 and WTC 2 fire alarm system was designated as the "Base Building Fire Alarm System" (BBFAS). The BBFAS provided the basic support structure and interface components for the fire alarm system throughout each building. The NYC Code provided the baseline performance standards for the equipment, electrical power, and wiring requirements for the design and installation of the BBFAS equipment (PANYNJ 1999a; PANYNJ 1999b; Drucker 2001; Drucker 2004; NIST NCSTAR 1-1H).

5.2.1 Base Building Fire Alarm System Equipment

The FCS monitored and controlled the BBFAS. The system chosen as the BBFAS was the Cerberus Pyrotronics MXL-V integrated fire detection system with EVAC capabilities. The original BBFAS contained a MXL-V master panel located in the FCS and 34 slave PSR (Pyrotronics Remote Transponder) panels distributed throughout each tower. Although the system architecture introduced survivability improvements through the introduction of redundant signal transmission network risers and command centers, the centralized intelligence of each tower's system resided in the FCS's MXL-V master panel. The manufacturer developed an improved network configuration that would improve survivability and overall signal processing time through the introduction of an additional distributed intelligence network. The installation of the new distributed intelligence network was performed during the end of Phase II and Phase III. The system improvement caused minimal impact to the overall planning and execution of ongoing projects since the original BBFAS installation included spare cables that were used for the new signal transmission network.

The final system architecture consisted of the main head-end MXL-V panel located at the FCS; distributed MXL-VR remote control panels which were located within both towers on levels B6, 7, 41, 75, and 108; and PSR panels that were monitored and controlled by the MXL-VR panels (see, for example, Fig. 5–18). The MXL-VR panels provided localized intelligence and acted as the master over the PSR slave panels. Each master MXL-VR monitored and controlled up to 8 PSR slave panels, which were located every third floor (typically) and contained system transponders, amplifiers, terminal cabinets, and interface points that provided access to the BBFAS platform. Each PSR provided the central monitoring and control point for fire alarm cabinets located on their respective floors.

Source: PANYNJ 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–18. Mechanical equipment room (MER) MXL-VR location.

The FCS head-end MXL-V fire alarm panel provided the main point of processing and control for the fire alarm functions. Although the NCCs provided a video interface for the fire alarm system operator, the actual operation, control and monitoring of device status, identity, and network communications was performed by the MXL-V panel. The configuration of the MXL-V modules that provided these capabilities consisted of:

- The main board for information processing (model MMB-1)
- The display and keyboard for redundant status display and control (model MKB-2)
- Floor warden and firefighter telephone master module (TMM-1)
- Emergency voice alarm microphone master module (MMM-1)
- 40 switch and status light modules for the control of the emergency voice alarm communication system and telephone system. Each module contained 8 individual switches with status lights, for a total of 320 separate control zones (VSM-1).
- Audio control module for alarm tone generation and overall control of the voice alarm transmission signals (ACM-1)
- XNET Style 7 Network Interface module (NIM-1R)
- Power supply rated at 6.5 amps (MPS-6)
- Battery back-up supply (BP-61)

The MXL-VR remote panels distributed through the towers provided intelligence and gateways for signal transmission and action between the MXL-V panels. They also provided a remote location to interrogate the system status when performing system maintenance and repairs. The configuration of the MXL-VR modules that provided these capabilities consisted of:

- The main board for information processing (model MMB-1)
- The display and keyboard for redundant status display and control (model MKB-2)
- XNET Style 7 Network Interface module (NIM-1R)
- Style 7 Communication Modules (NET-7)
- Power supply rated at 6.5 amps (MPS-6)
- Battery back-up supply (BP-61)

The PSR slave panels performed the main fire alarm device monitoring and control functions for each building's fire alarm system. To perform these functions, each PSR contained power supplies, battery chargers, audio amplifiers, network transponder, initiating, notification, control, and communication modules. The typical PSR panel configuration consisted of:

- Three 10 Amp Power Supplies (model PS-35)
    - Power Supply #1 was for the strobes on the floor above the fire alarm closet.
    - Power Supply #2 was for the strobes on the floor containing the fire alarm closet.
    - Power Supply #3 was for the strobes on the floor below the fire alarm closet.
- Battery backup for 4 h standby followed by 15 min of alarm capability.
- Three 100 watt amplifiers (model EL-410D)
    - Amplifier #1 was for Channel #1 – page/alert messaging.
    - Amplifier #2 was for Channel #2 – EVAC messaging.
    - Amplifier #3 was for backup – standby function.
- Backup tone generator (BTC-1)
- Four addressable initiating device loops – one loop for each floor with one spare (ALD-2)
- 16 audible speaker circuits – five circuits for each floor with one spare (ZC2-8B-70)
- 24 visual strobe circuits - six circuits for each floor with six spare (ZC1-8B-25)
- Fire Fighters and Warden Telephone Communication (ZCT-8B)

A fire alarm closet was designed to support the new fire alarm equipment and hardware, and was built into the existing sprinkler closets (see Fig. 5–19). The designated fire alarm closet contained the PSR, supporting an amplifier cabinet, a TSC, and Network Terminal Cabinet (NTC). The fire alarm closets were only built (typically) on every third floor. The NTC supported the vertical signal transmission network risers interconnecting the distributed MXL-VR and PSR panels.

Source: PANYNJ 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–19. Fire alarm closet with PSR location.

Additional TSC cabinets were installed on each floor and were interfaced through a PSR. Each TSC supported four speaker circuits and six strobe circuits for each floor.

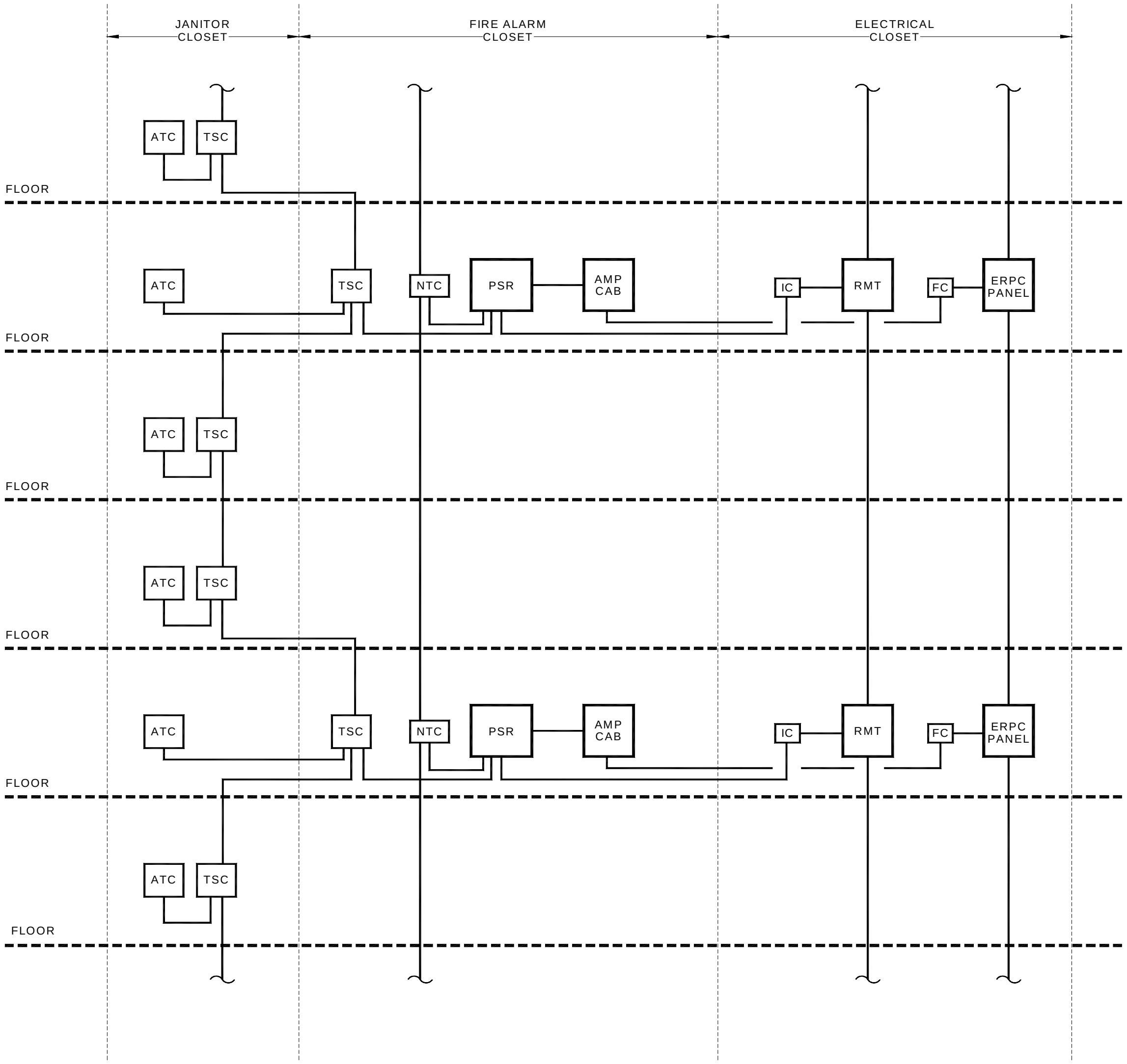
The PSR also supported an Interface Cabinet (IC), located in the electrical closet containing the Remote Monitoring Transponder (RMT) for monitoring the existing American Multiplex fire alarm system during the transition to the new MXL-V fire alarm system. The electrical closet also contained the emergency power panel that supplied power to the MXL-VR, PSR, and amplifier cabinets through a dedicated fused circuit.

In addition, the PSR supported Addressable Terminal Cabinets (ATC), which were located on each floor. The ATC cabinets provided one device loop sub-divided into five branch circuits (see Fig. 5–20). Each branch circuit was assigned specific monitoring functions:

1. ELEV Branch – Smoke detectors for passenger and freight elevators.
2. AREA Branch – Open area smoke detectors for the phone, electrical, and fire alarm closets
3. HVAC Branch – Ventilation smoke detectors for plenums and ducts.

4. TEN1 Branch – Dedicated branch for monitoring any tenant subsystems.
5. TEN2 Branch – Dedicated branch for monitoring tenant subsystems.

The floors without a fire alarm closet had their ATC and TSC located in the sprinkler closet on that floor.



LEGEND			
ATC	ADDRESSABLE DEVICE TERMINAL CABINET	IC	INTERFACE CABINET
TSC	TERMINAL STRIP CABINET	RMT	REMOTE MONITORING TRANSPONDER
NTC	NETWORK TERMINAL CABINET	FC	FUSED CUTOUT
PSR	PYROTRONICS REMOTE TRANSPONDER PANEL		
AMP CAB	PYROTRONICS AMPLIFIER CABINET	ERPC PANEL	EMERGENCY PANEL

Figure 5–20. Fire alarm closet with PSR location.

5.2.2 Base Building Fire Alarm System Design, Installation, and Operation

The Port Authority standardized the design and criteria, equipment configuration and layout, which was critical to maintain quality controls. Equipment locations were also standardized, and dedicated fire alarm closets were constructed to support the equipment. The overall design, equipment layout, and installation of the BBFAS were consistent with applicable codes and standards.

The FCS NCCs provided the main point of control for the BBFAS equipment. The MXL-VR panels located at floor levels B6, 7, 41, 75, and 108 provided a redundant point of monitoring and control of the individual MXL-VR and its slave PSR panels. The FCSs provided the main point of monitoring for all alarms and fault conditions, with the MXL-VR providing remote status query capability.

5.3 SYSTEM NETWORK TRANSMISSION PATHS PERFORMANCE STANDARDS

The WTC 1 and WTC 2 fire alarm systems consisted of numerous panels located throughout each tower. The interconnection of the distributed panels within each tower was accomplished through multiple vertical system network transmission paths commonly referred to as risers. The NYC Code provided the baseline performance for the risers. This baseline was very limited in scope, as are all model building codes when regulating the performance and installation of risers.

A fire alarm riser may contain numerous transmission paths for multiple functions associated with the system. The WTC 1 and WTC 2 system risers controlled functional capabilities that included:

1. Fire detection
2. Life safety system monitoring
3. Life safety system control
4. Occupant notification
5. Floor warden and firefighter telephone communication capability
6. System display and control of the fire alarm system

The type and performance of fire alarm transmission paths within a riser are not dictated by building codes or standards. The type and performance of the communication paths are defined by the National Fire Alarm Code (NFAC) (NFPA 72), and their capabilities verified through testing by nationally recognized laboratories. The NFAC, which is developed by the National Fire Protection Association (NFPA) through a consensus standards development process approved by the American National Standards Institute, provides performance requirements for multiple types of transmission paths for accomplishing the system’s functions. The requirements establish different levels of performance. The owner and system designer determine the expected level of performance.

5.3.1 Detection, Monitoring, and Control Network Transmission Path Performance

The fire alarms systems for WTC 1 and WTC 2 were very large systems with distributed panels located throughout each tower. Although each panel performed specific functions, the monitoring and control of the functions was performed as a single, holistic fire alarm system for the protected premises. The sharing of intelligence, monitoring, and control between the panels within the protected premises were accomplished through the system's network transmission paths. Tables within the NFAC define the performance requirements for the transmission paths. The Signaling Line Circuit table relates to the performance of the network transmission paths dealing with fire detection, life safety system monitoring and control functions.

These circuits support the fire detection, life safety system monitoring and control, occupant notification functions of the protected premises as a whole, and provide network interconnection to, monitor and control the distributed panels within each tower.

The performance criteria within the tables provide multiple levels of circuit performance, with each succeeding level proving increased survivability and endurance characteristics. All model building codes reference the NFAC, but the survivability and endurance performance of the network transmission paths as defined by the tables within the NFAC are not dictated by any model building code. It is the responsibility of the system designer to determine and specify signaling communication path performance requirements based upon the system architecture and performance goals. The Port Authority specified the most stringent circuit class and technical style available for all circuits including the Signaling Line Circuits (Class A, Style 7) and Notification Appliance Circuits (Class A, Style Z), which will be discussed in detail later in the report. The intent for using the most stringent class of circuits was to enhanced network survivability and endurance performance.

The performance criteria for the circuits are provided in Table 5–1.

Table 5–1. Performance of Signaling Line Circuits (SLC).

Class	**B**			**B**			**A**			**B**			**B**		
Style	**0.5**			**1**			**2α**			**3**			**3.5**		
	Alm	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**
Abnormal Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Single open	—	X	—	—	X	—	—	X	R	—	X	—	—	X	—
Single ground	—	X	—	—	X	R	—	X	R	—	X	R	—	X	—
Wire-to-wire short	—	—	—	—	—	—	—	—	M	—	X	—	—	X	—
Wire-to-wire short & open	—	—	—	—	—	—	—	—	M	—	X	—	—	X	—
Wire-to-wire short & ground	—	—	—	—	—	—	—	X	M	—	X	—	—	X	—
Open and ground	—	—	—	—	—	—	—	X	R	—	X	—	—	X	—
Loss of carrier (if used)/channel interface	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
Class	**B**			**B**			**A**			**A**			**A**		
Style	**4**			**4.5**			**5α**			**6α**			**7α**		
	Alm	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**	**Alm**	**Trbl**	**ARC**
Abnormal Condition	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Single open	—	X	—	—	X	R	—	X	R	—	X	R	—	X	R
Single ground	—	X	R	—	X	—	—	X	R	—	X	R	—	X	R
Wire-to-wire short	—	X	—	—	X	—	—	X	—	—	X	—	—	X	R
Wire-to-wire short & open	—	X	—	—	X	—	—	X	—	—	X	—	—	X	—
Wire-to-wire short & ground	—	X	—	—	X	—	—	X	—	—	X	—	—	X	—
Open and ground	—	X	—	—	X	—	—	X	—	—	X	R	—	X	R
Loss of carrier (if used)/ channel interface	—	X	—	—	X	—	—	X	—	—	X	—	—	X	—

Alm = Alarm.
Trbl = Trouble.
ARC = Alarm receipt capability during abnormal condition.
M = May be capable of alarm with wire-to-wire short.
R = Required capability.
X = Indication required at protected premises and as required by Chapter 8.

α = Style exceeds minimum requirements of Class A.

5.3.2 Detection, Monitoring, and Control Network Transmission Path Design, Installation, and Control

The fire alarm system's detection, monitoring, and control network transmission paths consisted of multiple limited area networks which consisted of 8 PSR slave panels connected to a MXL-VR master panel (see Figs. 5–21 and 5–22). The transmission path between the panels in this typical arrangement was referred to as the MNET by the manufacturer. The MXL-VR master panel monitored and controlled the PSR slave panels and their fire alarm initiating and indicating appliances (PANYNJ 1999a; PANYNJ 1999b; Drucker 2001; Drucker 2004).

In addition to the limited area networks, there was also a system network, which the manufacturer referred to as the XNET (see Figs. 5–23 and 5–24). The XNET provided an interface for the multiple MXL-VR master panels and the multiple NCC, which together operated as a single fire alarm system. The distribution of the MXL-VR master panels within each tower allowed each MXL-VR to act independentlyR(ork, which eClTe XTD esppliprov, o(ansm) 21.9926 71 the panels i30004 Tw [[(The d]TJ (looll

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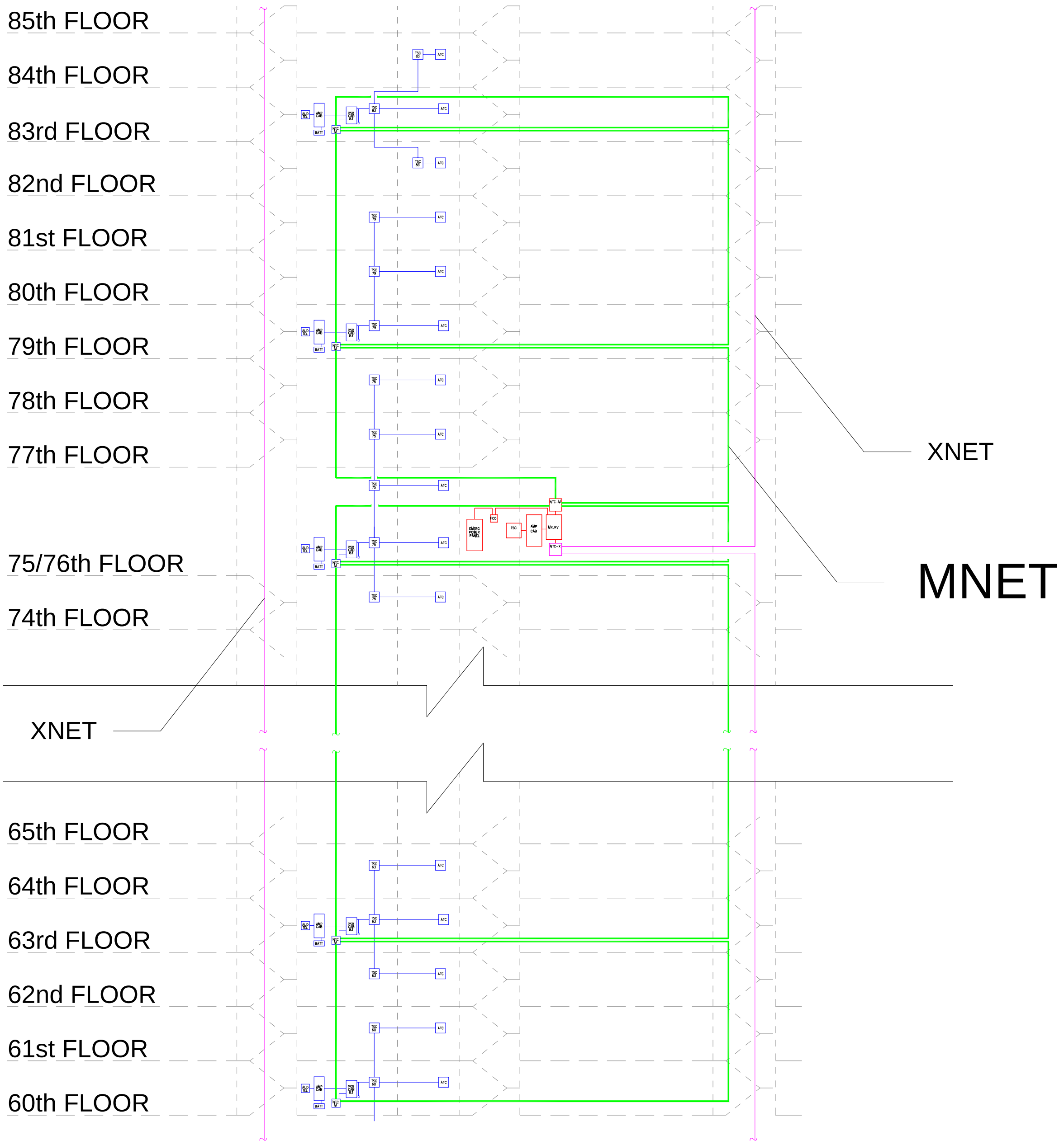

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Figure 5–22. Locations of typical MNET network equipment.

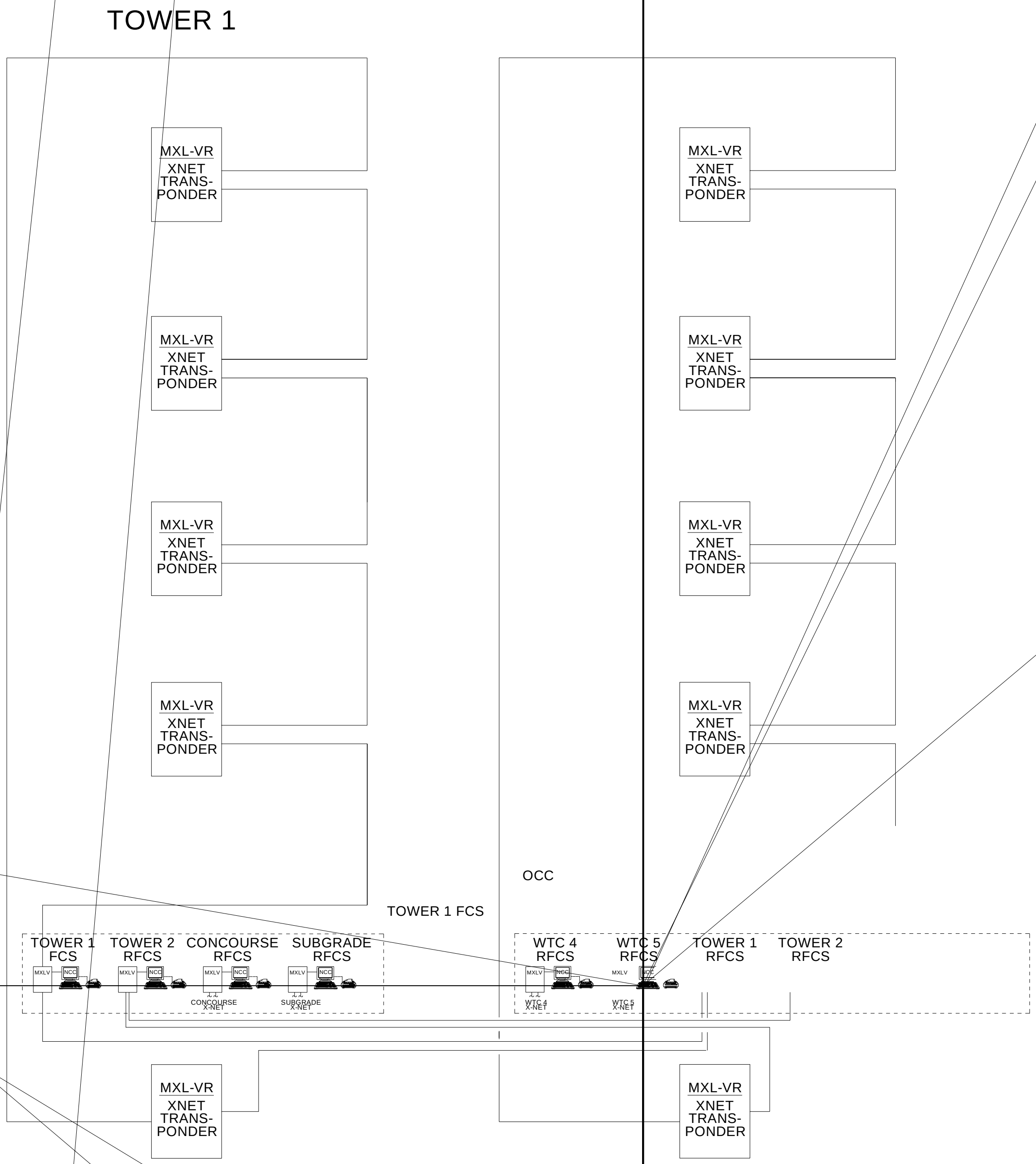

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Figure 5–23. Single-line schematic of XNET network configuration.

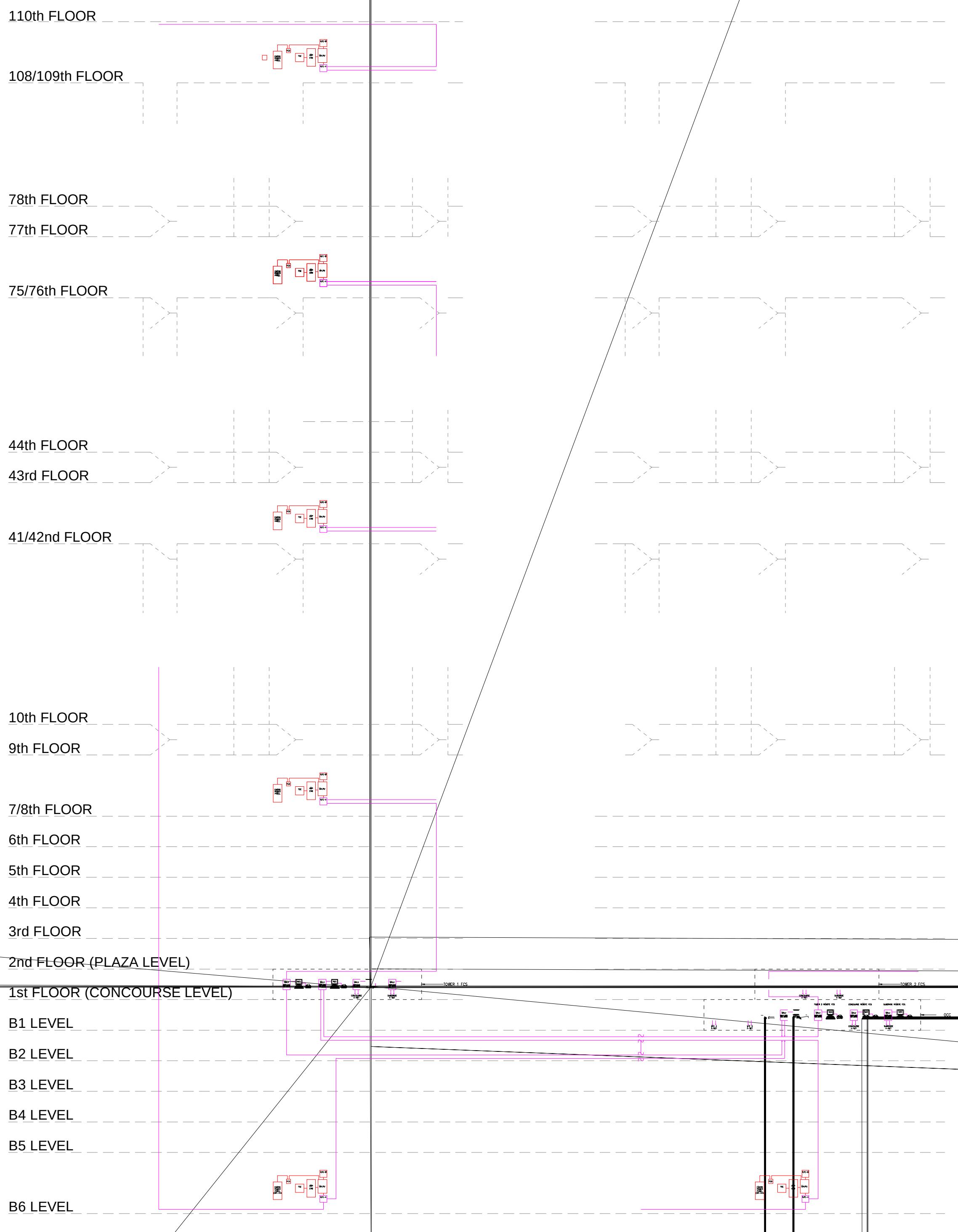

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Figure 5–24. Locations of XNET network equipment.

Source: PANYNJ 2000. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–25. Operation Control Center located on the B1 Level below WTC 2 with redundant fire alarm system controls.

The NCC for each tower contained central monitoring and master control through the MXL-V for the building's protected premises. The master MXL-V provided monitoring and control of the MXL-VR remote fire alarm panels through a Style 7 XNET network (see Fig. 5–22). The PSR slave panels (along with the MXL-VR panels) monitored and controlled fire alarm devices and communicated their status through a Style 7 MNET back to their Master MXL-VR panel. The XNET provided a communication path for the FCS and OCC to monitor the fire alarm and life safety system supervisory signals and control the interfaced life safety systems to the distributed MXL-VR panels and through the MXL-VR panels via the MNET (see Fig. 5–23) to the PSR panels.

The controlled life safety systems included the speaker circuits that provided the EVAC messages serving each floor and the stairways and also included controls for the switching of the warden and firefighter telephone calls. The XNET provided a pathway for the main MXL-V (located at the FCS) to control the distribution of the EVAC and telephone communication messages and calls, but did not transmit the EVAC messages or telephone calls. The EVAC and telephone transmission path circuits were separate and independent of the XNET and MNET transmission paths. The EVAC and telephone circuits provided the actual voice messages and calls when in use, and the XNET and MNET directed the distribution of the messages and calls. Figures 5–24 and 5–25 show the locations of XNET and MNET network equipment in WTC 1 and WTC 2.

The XNET and MNET design and installation provided enhanced network integrity and reliability through a loop wiring topology configuration that provided separate network communication path risers (primary and secondary) installed in three different locations (fire alarm closet and stairways "A" and "C"). Due to the excessive length of the network risers (each tower was approximately 1,350 ft high), the network was designed with #14 AWG Teflon cables (twisted pair 600 V, 200 ^{o}C). The intent of the Style 7 networks was to accommodate any type of single circuit fault, such as a cut wire, short between wires, or grounding of a wire on any section of the network. Fiber optic cable was originally presented for the network during meetings with The Fire Department of the City of New York (FDNY) Technology Management, but was rejected by FDNY electrical supervisors as not compliant with the NYC Code (CUMMISKEY 1993).

Fourteen pairs of cables were installed within the stairway "A" and "C" risers. The system only required five cables per riser, but the Port Authority intentionally installed additional cables for future use. The intent was to provide enough cables for the eventual replacement of the new fire alarm system. The additional cables would allow the installation of a redundant system during the transition from the existing system to a new system.

The system was designed to automatically compensate for faults on its XNET communication path by allowing MXL-VR systems to remain in communication with each other as a subsystem if a catastrophic failure were to separate a portion of the system from the head-end MXL-V panel at the FCS. The separated portion of the system would dynamically retain all communication and control logic associated with the remaining remote panels in communication with each other. Or, if a MXL-VR panel experienced catastrophic network failure, the panel would act as a fully independent control unit performing monitoring, notification, and control function assigned to the stand-alone control unit.

Design documents indicate that the Port Authority specified the most stringent performance criteria for the fire alarm network communication paths and installed the network cable and hardware in a manner that would enhance survivability and endurance from the risk of fire and physical damage. The XNET and MNET riser consisted of Teflon sheathed cables rated at 200 ^{o}C and was installed in rigid conduit between the distributed panels. In addition to these stringent criteria for cable and hardware survivability, the separation of the risers provided physical protection of the network circuits from any localized fire or physical damage. The intent of the design criteria was to provide enhanced survivability through: robust circuit performance, cable and hardware with enhanced protection characteristics, and the physical separation of the risers. At the time of installation, this criteria exceeded all applicable code requirements for survivability and endurance characteristics for fire alarm systems within high-rise buildings.

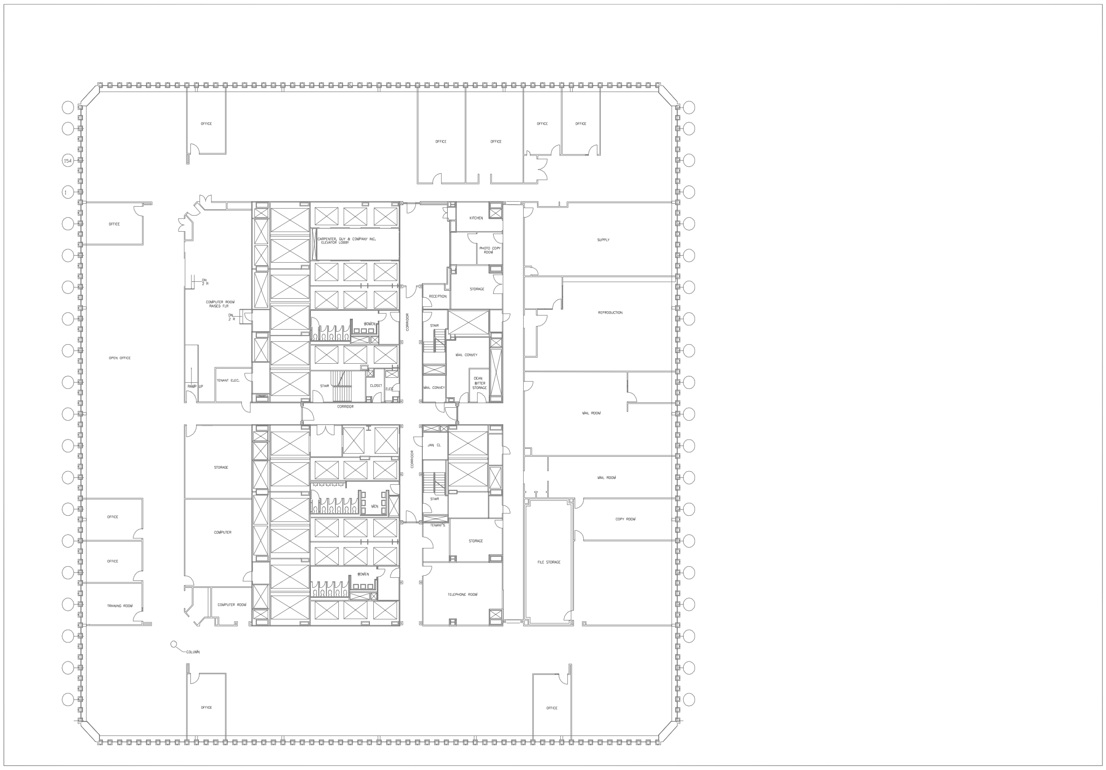
5.3.3 Typical Detection, Monitoring, and Control Devices

The Siemens Pyrotronics devices used for detection, monitoring, and control represented state-of-the-art technology at the time of system design and installation. The devices included (PANYNJ 1999a):

- Addressable open area ionization smoke detectors (ILI-1)
- Addressable high-air velocity open area ionization smoke detectors (ILI-1A)
- Addressable duct ionization smoke detectors – high air velocity (ILI-1B)
- Addressable open area photoelectric smoke detectors (ILP-1)
- Addressable open area photoelectric smoke detectors with fixed heat detector (ILPT-1)
- Addressable open area rate compensated heat detectors (ID-60T-135)
- Addressable single input monitor modules (TRI-60)
- Addressable dual input monitor modules (TRI-60D)
- Addressable single input with relay control output modules (TRI-60R)
- Addressable single-action pull stations (MS-MI)

5.3.4 Typical Detection, Monitoring, and Control Device Design and Installation

As a minimum, the WTC mandated design guidelines (PANYNJ 1999a) required smoke detector protection in each elevator lobby, electrical closet, telephone closet, fire alarm closet, and at each HVAC air return (see Fig. 5–26). Also, manual stations were installed next to the three stairway access doors, and sprinkler water flow and tamper switches were monitored for alarm and trouble conditions, respectively. Additional fire alarm protection could be added by a tenant if their fire protection needs exceeded the life safety goals set by the Port Authority. If a tenant installed a fire alarm subsystem, an addressable monitor module (model TRI-60D) was required to monitor the subsystem for general alarm and system malfunction (trouble) conditions by the BBFAS.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FILE STORAGE
WOMEN
TRAINING ROOM
COMPUTER ROOM
TELEPHONE ROOM
COLUMN
OFFICE
OFFICE

detector installed within the air handling unit, past the unit's filter, and another duct detector installed in the supply duct exiting the unit. The activation of both of these detectors would activate a deluge fire sprinkler system dedicated to suppressing an air handling unit filter fire. In addition, area smoke detectors were installed in front of the air return units on each floor, which would shut down the air handling unit associated with the air return duct upon activation.

The Style 4 addressable device loop monitoring and controlling the fire alarm devices provided a custom message identifying each addressable device at the monitoring stations (FCS and OCC) whenever the device went into an alarm, was activated, or experienced a fault mode. The performance of the Style 4 circuit was compromised whenever the circuit experienced a single open (cut wire), wire-to-wire short, and loss of fire alarm communication to the device. Although the Style 4 performance serving each floor's detection, monitoring and control devices was not as robust as the network Style 7, the performance was consistent with the requirements in the building codes, fire alarm standards and codes, and product safety standards.

5.3.5 Notification Appliance Circuit Network Transmission Path Performance

The Notification Appliance Circuit performance table relates to the performance of the occupant notification network transmission paths, as opposed to the Signaling Line Device Circuit table which relates to the performance of the network transmission paths dealing with fire detection, life safety system monitoring, and control functions. The Notification Appliance Circuits used were Class A, Style Z, which requires stringent performance for the circuits as shown in Table 5–2 (NFPA 2002).

Table 5–2. Notification Appliance Circuits (NAC).

Class	**B**		**B**		**B**		**A**	
Style	**W**		**X**		**Y**		**Z**	
	Trouble indication at protected premises	**Alarm capability during abnormal conditions**	**Trouble indication at protected premises**	**Alarm capability during abnormal conditions**	**Trouble indication at protected premises**	**Alarm capability during abnormal conditions**	**Trouble indication at protected premises**	**Alarm capability during abnormal conditions**
Abnormal Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Single open	X	—	X	R	X	—	X	R
Single ground	X	—	X	—	X	R	X	R
Wire-to-wire short	X	—	X	—	X	—	X	—

X = Indication required at control equipment.
R = Required capability.

5.3.6 Notification Appliance Circuit Network Transmission Path Design, Installation, and Control

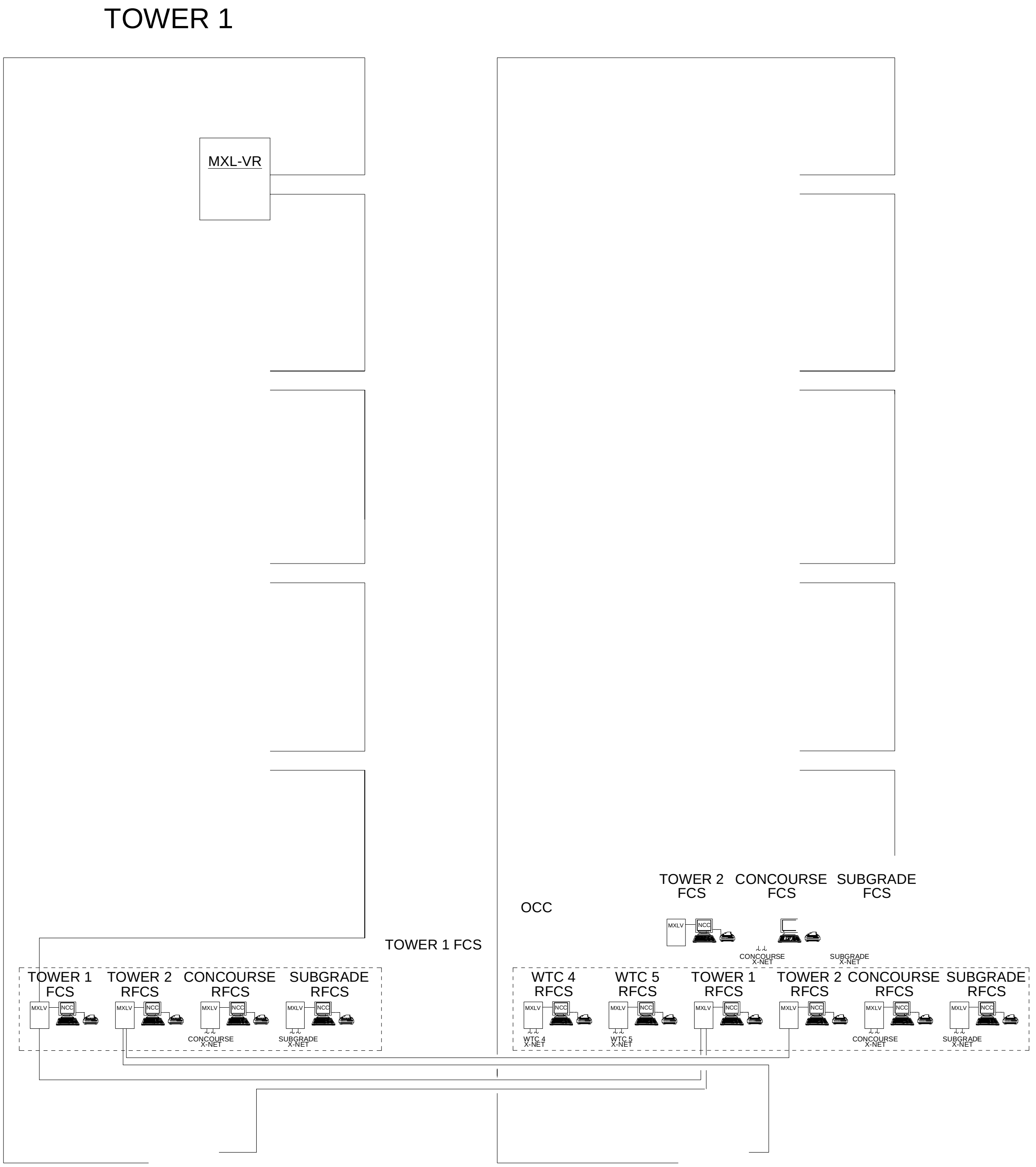
The EVAC speakers and strobes were manually controllable and operable at the FCS or the OCC, depending on which station had operational rights to the system. The control equipment consisted of a microphone and switches for turning on individual audio and visual notification zones, or the all-call capability to broadcast on all speaker zones. The speaker and strobe zones were segregated by floor and also grouped by elevator zones. The elevator speaker grouping provided a switch that would activate the floors served by the low zone of elevators serving floors 9 through 40; a separate switch would activate the floors served by the mid zone of elevators serving floors 44 through 74; and a third elevator group switch would activate the floors served by the high zone of elevators serving floors 78 through 107. In addition, the stairways were on a separate speaker zone, controlled by a switch (PANYNJ 1999a; Drucker 2001; Drucker 2004).

The switches also allowed the voice message to include an alarm tone associated with evacuation or an alert tone. Both tones would be a preamble to an advisory voice message when the microphone was activated. In addition, there was a switch to use a floor warden or firefighter telephone as a remote microphone to broadcast a voice message over selected or all zones. The status of all of these functions was visually displayed via indicator lamps. The visual display, and a distinct audible tone, also provided an indication if a specific zone or function was experiencing a technical fault that would affect its performance.

The fire alarm system’s audio notification network transmission paths consisted of two separate circuits that provided two channels for emergency voice and alarm communication (see Figs. 5–27 and 5–28). The separate channels allowed the operator to broadcast separate messages or tones simultaneously. The intent was to be able to provide instructions for evacuation to the fire floor while simultaneously alerting the occupants of adjacent floors to stand by for further instructions.

The fire alarm system’s emergency voice communication messages were transmitted on a network path to all the MXL-VR and PSR panels containing amplifiers and their associate speaker circuits (see Fig. 5–27). The intent of the Style Z notification appliance circuit network design and installation was to provide enhanced network integrity and reliability through a loop wiring topology configuration that provided separate network communication path risers (primary and secondary) installed in two different locations (fire alarm closet and stairway “C”). The network was designed with #14 AWG Teflon cables (twisted pair 600 V, 200 °C). The performance characteristics of the Style Z network allowed continued service if the circuit experienced a single circuit fault, such as a cut wire, or grounding of a wire on any section of the network. But, the network would not provide continued service if it were to experience a wire-to-wire short.

As with the other communication network paths, the Port Authority specified stringent performance criteria for the notification appliance circuit network communication paths (Class A, Style Z) and installed the network cable and hardware in a manner that would enhance survivability and endurance from the risk of fire and physical damage. The notification appliance riser consisted of two Teflon sheathed cables rated at 200 °C, each containing a shielded twisted pair of wires. The cables were installed in rigid conduit between the distributed amplifier panels (see Fig. 5–28). In addition to these stringent criteria for cable and hardware survivability, the separation of the risers provided physical protection of the network circuits from any localized fire or physical damage. The intent of the design criteria was to provide enhanced survivability through: robust circuit performance, cable and hardware with enhanced protection characteristics, and the physical separation of the risers. At the time of installation, these criteria exceeded all applicable code required survivability and endurance characteristics for fire alarm systems within high-rise buildings.



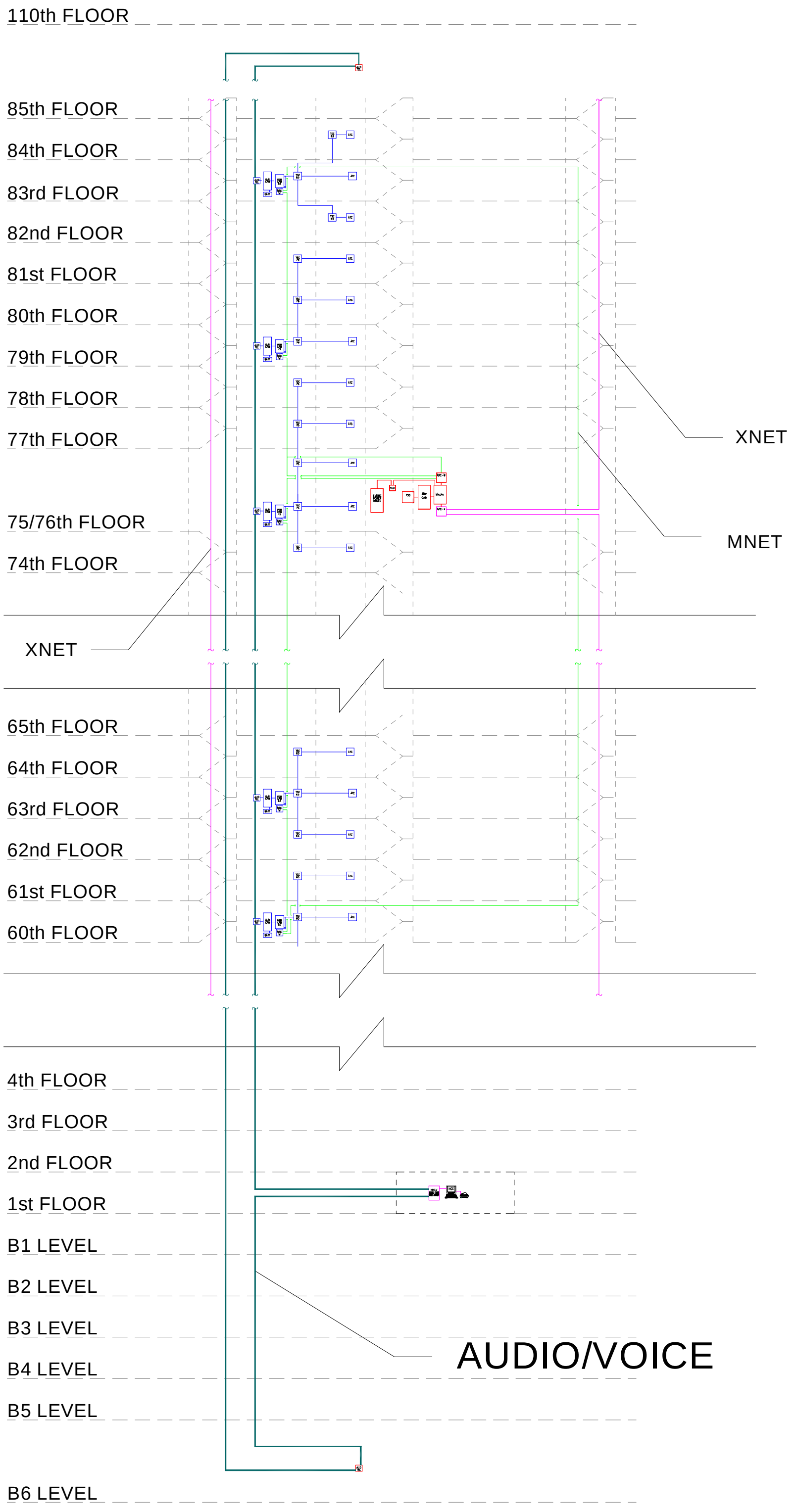


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Figure 5–28. Locations of audible notification appliance network equipment.

5.3.7 Typical Speaker Notification Appliance Devices

The Siemens Pyrotronics devices used for audio notification included (PANYNJ 1999a; PANYNJ 1999b; Drucker 2001):

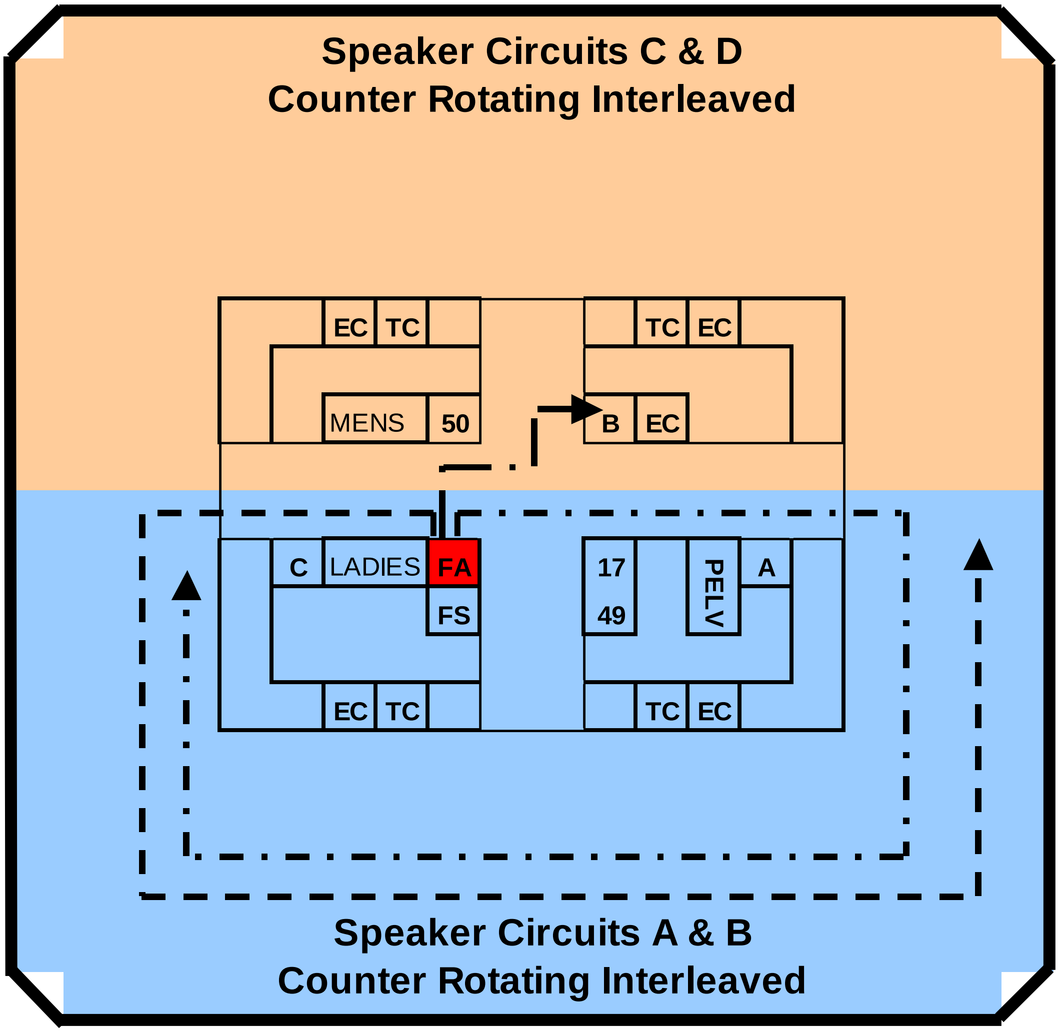
- Ceiling mounted round speakers, 70 V (SPK-9070)
- Wall mounted square speakers, 70 V (SPK-7070)
- Wall mounted speakers, 25/70 V (SPK-1070)
- Wall mounted speakers, 70 V, with 24 V 15/75 cd strobe (SS70-15/75)

The Port Authority performed an in-depth analysis on speaker intelligibility and audibility for the WTC (Drucker 2001). The intent of the analysis was to develop a speaker location guideline that would ensure an acceptable level of intelligibility (message clarity) and audibility (loud enough to be heard.).

The audible alarm requirements were based upon the American with Disabilities Act and NFPA requirement for the alarm signal to maintain a 15 dBA sound pressure level above the average ambient sound level measured 5 ft above the floor in the occupied area (NFPA 2002). To establish the ambient sound level, the Port Authority conducted an extensive sound level survey to establish a baseline for design. Testing results indicated that the average ambient sound level in office areas and in occupied corridor areas was 55 dBA and 60 dBA, respectively. Based upon computations for sound loss and reverberation (echo effect), a standard was established that the distance between speakers would not exceed 40 ft.

A TSC was located in a typical floor's Sprinkler Closet or Fire Alarm Closet, and provided four Style Z speaker circuits. The speaker circuits were designated SPK –A, B, C, D, and a single stairway circuit designated SPK-E was provided for the three stairways, typically every four to five floors. Each circuit used as a minimum14 AWG, shielded twisted pair 150 °C Teflon cable assemblies. Each circuit was rated for a maximum load of 25 W at 70.7 VRMS, with a maximum combined load of 25 W for all four circuits. The three stairways each had a dedicated speaker circuit with a speaker installed every four to five floors.

Enhanced survivability was incorporated through counter-rotating interleaved speaker circuits (see Fig. 5–29). This approach required alternating speakers to be serviced by separate circuits. The intent was to insure that a loss of a single circuit would not cause the complete loss of audible signals within the area. This concept exceeded building code requirements.



Class B- 70.7 V - 150 / 200C Teflon FPLP Free Air
4 Circuits Provided Per Floor + Additional Stairway Only
Circuit typically every 4-5 Floors. Coordinated with Reentry
Points.

Source: Drucker 2001.

Figure 5–29. Speaker circuit configurations.

5.3.8 Typical Strobe Notification Appliance Devices

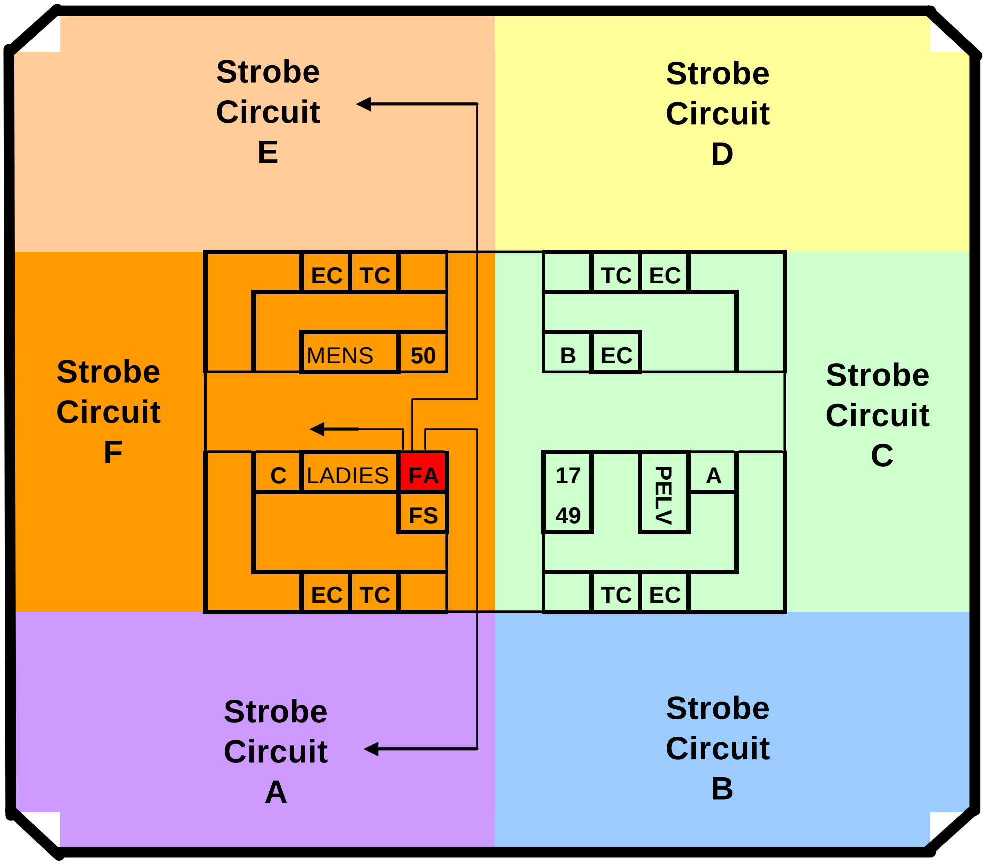
The Siemens Pyrotronics devices used for audio notification included:

- Wall mounted strobes, 24 V 15/75 cd (S15/75-SGL)
- Wall mounted combination speaker, 70 V, with 24 V 15/75 cd strobe (SS70-15/75)

5.3.9 Typical Strobe Circuits Equipment and Installation

The visual notification requirements were based upon the ADAAG, NFPA, and maintaining 0.0375 ft-candles illumination within the protected area (NFPA 2002).

A TSC was located in a typical floor's Sprinkler Closet or Fire Alarm Closet and provided six Class B speaker circuits for each floor (see Fig. 5–30). Each circuit used as a minimum14 AWG, shielded twisted pair 150 °C Teflon cable assemblies. Each circuit was rated for a maximum load of 1.5 Amps at 24 VDC, with a maximum combined load of 7.2 Amps for all six circuits. The circuits were installed based upon an assigned quadrant.



Class B- 24 V - 150 / 200C Teflon FPLP Free Air
6 Circuits Provided per Floor

Source: Drucker 2001.

Figure 5–30. Strobe circuit configurations.

5.3.10 Floor Warden and Firefighter Telephone Network Transmission Paths

The WTC 1 and WTC 2 fire alarm systems were provided with two-way telephone communication between the FCS and the floor warden telephone stations, along with the standpipe fire line telephone stations. The two-way telephone network transmission path originated in the FCS and served each floor within the towers (PANYNJ 1999a; PANYNJ 1999b; Drucker 2004). The NFAC does not directly define the two-way telephone circuit performance. The NFAC telephone performance requirements define the number of units that can simultaneously operate and the control parameters for their use. The ability of the telephone network transmission circuit to indicate an abnormal condition was not dictated by the NFAC. Neither the building codes nor the present ULI testing standards defines the performance of the telephone circuit. This abnormal condition monitoring of a single wire-to-wire fault, single open circuit, or single ground fault for telephone/intercom signaling circuits is scheduled to be a Underwriter Laboratory Inc. testing standard requirement effective October 1, 2005. The two-way telephone communication circuits serving WTC 1 and WTC 2 did have this circuit monitoring capability, which provided a visible and audible indication whenever the circuit experienced an open, short, or ground. This circuit monitoring capability exceeded codes and testing standards.

5.3.11 Floor Warden and Firefighter Telephone Network Transmission Path Design, Installation, and Control

The fire alarm system's floor warden and firefighter telephone transmissions were carried on a single, dedicated telephone network communication path to all the MXL-VR and PSR panels that served the telephones within each tower (see Figs. 5–31 and 5–32). The telephone network consisted of a single pair of #14 AWG Teflon cables (twisted pair 600 V, 200 °C). The single pair of wires did not have the enhanced survivability characteristics associated with the Class A, Style 7 Signaling Line Circuit or Class A, Style Z Notification Appliance Circuit. The Class B, Style Y circuit performance allowed a single open (cut wire) or wire-to-wire short to disrupt service between the head-end MXL-V panel and beyond where the wire fault occurred.

Although the circuit performance for the telephones was not as robust as the Signaling Line Circuits and Notification Appliance Circuit Networks, the telephone circuit's performance contained survivability capabilities that exceeded performance requirements for fire alarm systems. The applicable building codes, fire alarm codes, and testing standards did not require the telephone circuits to have the performance monitoring and survivability characteristics, inherent to the telephone circuits. The manufacturer provided the enhanced performance characteristics and the Port Authority selected to utilize the system for their floor warden and firefighter telephone communication needs.

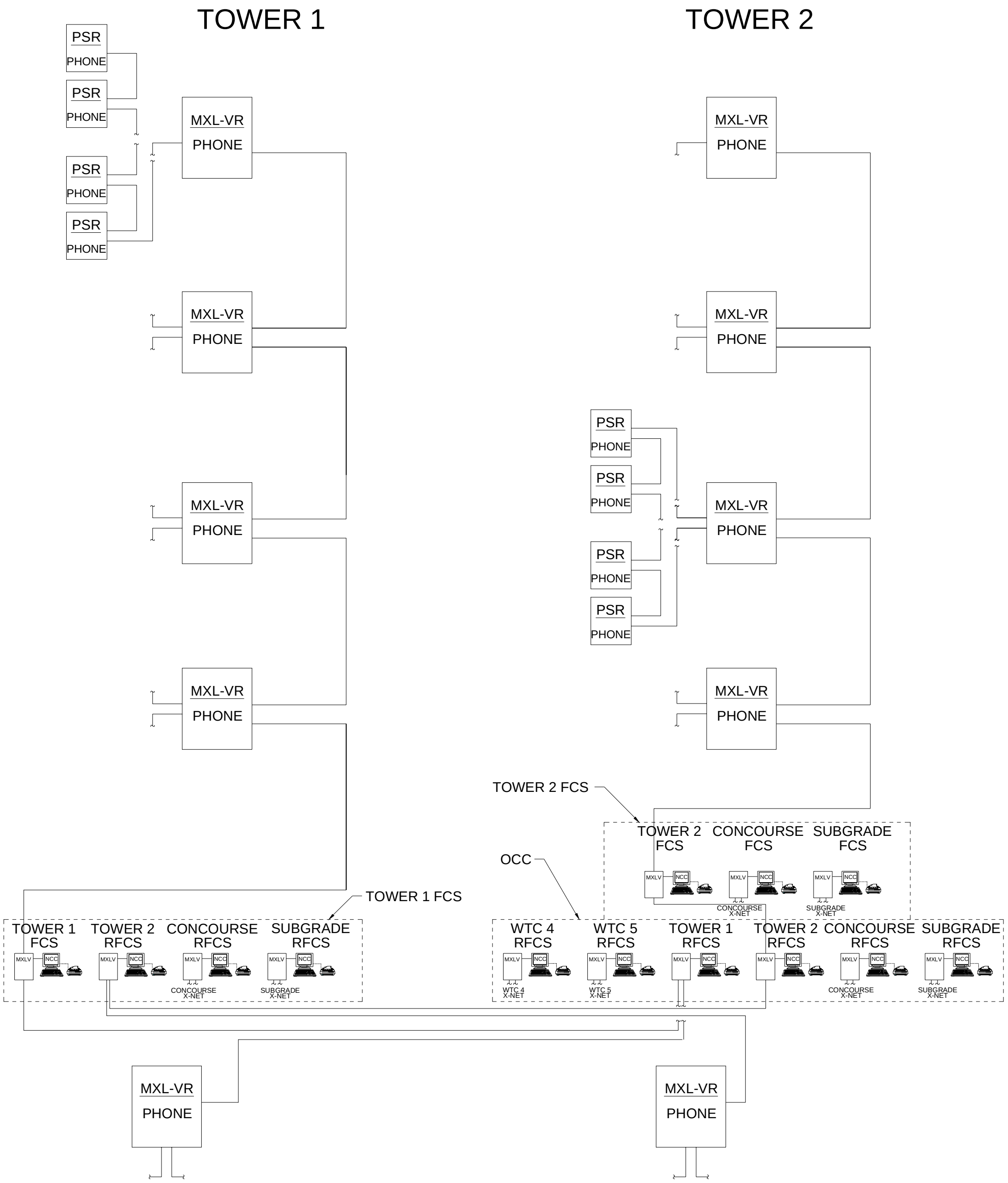


Figure 5–31. Single-line schematic of floor warden and firefighter telephones.

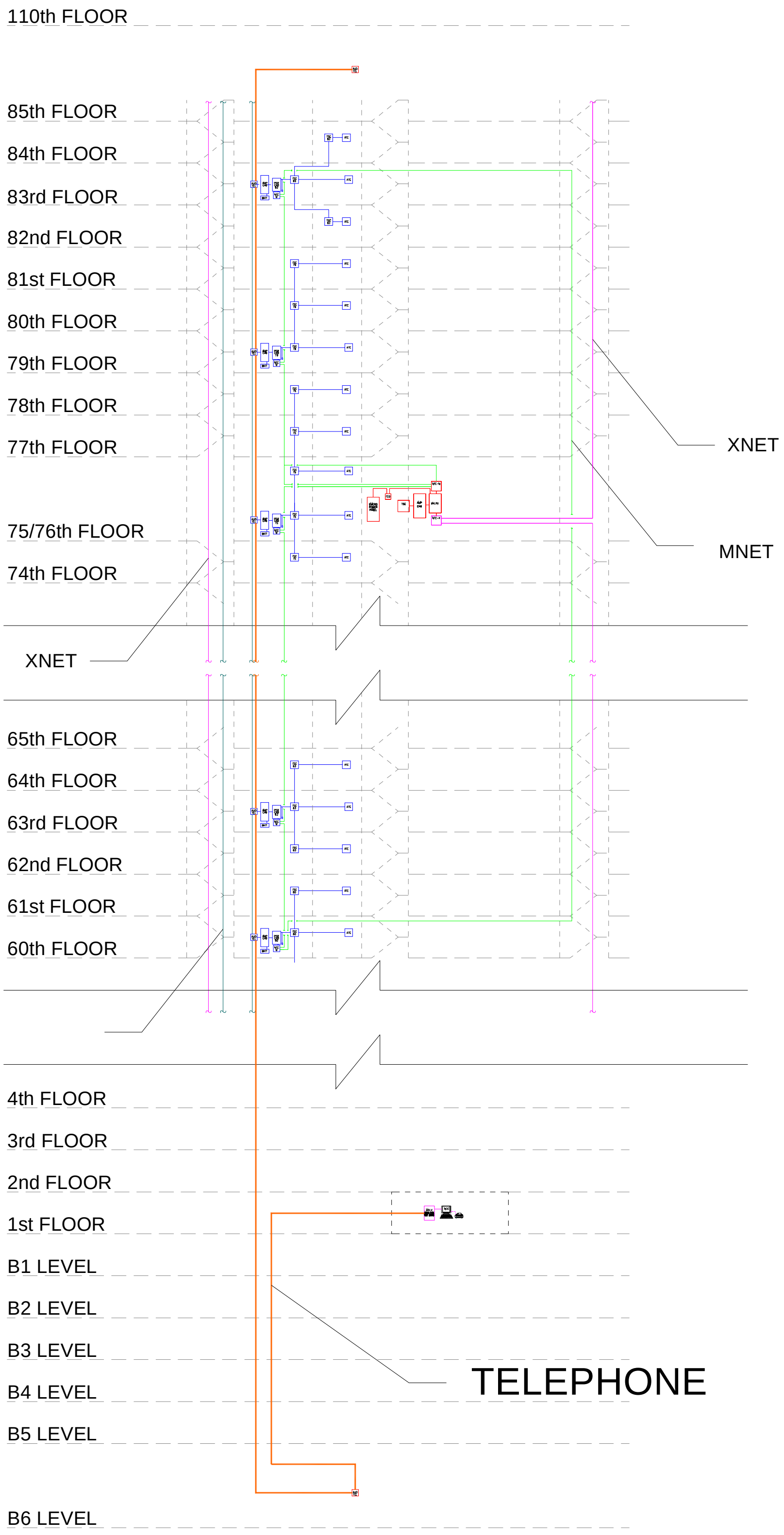


Figure 5–32. Locations floor warden and firefighter telephone network equipment.

5.3.12 Typical Floor Warden and Firefighter Telephone Devices

The Siemens Pyrotronics devices used for audio notification included:

- Flush wall mounted floor warden telephone station (FB-300)
- Surface wall mounted floor warden telephone station (FB-301S)
- Remote firefighters telephone station with armored cable (FT-301CL)
- Surface box for firefighter standpipe or maintenance jack (PUR17)
- Firefighters telephone jack (FJ-303)
- Portable firefighters telephone (PT-304)

5.3.13 Floor Warden and Firefighter Telephone Station System Design and Installation

The floor warden and firefighter telephone system consisted of the main telephone handset and controls located at the FCS and OCC, remote firefighter telephone stations located within the stairways, and floor wardens telephone stations located within the central cross-corridor on each floor. In addition to these stations, a maintenance telephone station was provided at each of the MXL-VR panel locations for maintenance personnel use (PANYNJ 1999a; PANYNJ 1999b; Drucker 2001; Drucker 2004).

The firefighter telephone station consisted of a connection point (jack) for a telephone handset. The intent was to provide responding firefighters with a handset before they were dispatched to the fire emergency. A call-in signal would be transmitted to the FCS whenever a handset was connected to the jack located at the station. The signal would indicate which floor initiated the call. Permanent handsets were not installed within the stairways. The jack connections were installed within metal boxes with locks that could only be opened by a standard FDNY key.

The floor warden station consisted of a handset that would automatically initiate a call-in signal at the FCS when the handset was removed from its cradle. The signal would indicate which floor had initiated the call.

The maintenance telephone station consisted of a connection jack for a telephone handset. The MXL-VR maintenance telephone station was connected to the same zone as the firefighter station. Separate zones were not provided since the maintenance station would not be in use during a fire emergency. As with the firefighter station, a call-in signal would be transmitted to the FCS whenever a handset was connected to the jack at the station. The signal would indicate which floor initiated the call.

The head-end FCS telephone controls, with redundant controls at the OCC, consisted of a handset and operator controls. The controls consisted of a push button switch and dual color light to indicate the status of the telephone station. When a call was placed on a telephone zone, the light would flash, and an audible tone would sound to indicate the telephone communication request. Once the operator selected the call, the telephone circuit was patched into a “party line” mode where up to five telephone stations could be on the line without loss of audio quality.

5.4 MAINTENANCE PERFORMANCE STANDARD

Fire alarm system availability and performance is dependant on four basic factors:

1. Equipment.
2. Design
3. Installation
4. Maintenance

Since the maintenance of the system affects of any system's life-cycle, its impact on the overall system availability and performance is a major consideration during the selection of equipment, design of the system, and the installation of the equipment and devices. The documentation found suggests that maintenance of the system was considered during system development and was carried out regularly after the system was installed (PANYNJ 1984; PANYNJ 1986).

A team was contracted from Siemens Pyrotronics to perform fire alarm maintenance and repair functions for the WTC. The maintenance procedures included scheduled testing of the fire alarm system's detection, controls, communication, and notification capabilities. The testing was scheduled by area and included all the fire alarm functions within the area. Before testing was performed, notices were posted informing the occupants of the pending testing. Specific testing procedures were performed by specific team members during the system test. The results of the testing were recorded for reference.

5.5 SYSTEM DESIGN AND INSTALLATION CRITERIA FOR WTC 7

WTC 7 was built in 1985. It was located across Vesey Street from the main WTC complex. It was a steel building which had forty-four floors. WTC 7 collapsed on September 11, 2001, roughly seven hours after WTC 1 and WTC 2 collapsed.

The fire alarm system for WTC 7 appears to have been the original system installed when the building was built (Syska 1984). Modifications were performed as needed to accommodate renovations and tenant fit outs. Project development documentation found and analyzed has been limited to specifications, riser diagrams, and a limited number of tenant fit out drawings that included fire alarm work. The design criteria were based on the requirements set by the Basic Design Criteria revised November 5, 1984, proposed by Syska & Hennessy, which reference the applicable local building codes at the time of construction. The only performance criteria in the design criteria that exceeds the minimum requirement was the statement requiring "All monitoring, communication and control for the fire alarm system shall be on a separate multiplex channel with its own processor" (S&K 1984). Based on the information reviewed, the overall design and installation was consistent with the applicable code requirements. Inspection, testing, and maintenance of the fire alarm system for WTC 7 was provided on a regular basis.

5.5.1 System Arrangement

The baseline for defining the fire alarm system's performance is derived from the specifications, which referred to the applicable local building codes. The basic system was required to contain the following components to monitor and annunciate the status of its devices and initiate an appropriate response (Syska 1984):

1. FCS located in the lobby of the building on the entrance floor.
2. Manual Fire Alarm Stations provided in each story along the path of escape with additional stations installed so that the maximum travel distance between stations would not exceed 200 ft.
3. Speakers located on all floors, and stairways that could be operated in the FCS. The elevator intercommunication system was provided separately.
4. Visual Alarm Devices (strobes) were provided in spaces used by people having physical disabilities during more recent renovations. When the strobes were first introduced and what areas contain strobes is unknown.
5. Floor Warden Stations on each floor that provided two-way communication with the FCS.
6. Standpipe Fire Line Telephone System with communication stations provided at FCS, each floor near the standpipe riser, gravity tank rooms, and fire pump rooms.
7. Fire Sprinkler water flow alarm and malfunction monitoring.
8. Tenant fire alarm panels monitoring for alarm and system fault conditions.
9. Fan shutdown and restart system for smoke control.
10. Elevator recall upon its smoke detector activation.
11. Fire stair door releases.
12. Smoke and heat detection

5.5.2 Design Approach

Documentation found consisted of modified riser as-built diagrams, and floor plans with fire alarm device locations. Comprehensive as-built drawings for the system were not located.

The modified riser diagrams were conceptual in nature, and provided the installation contractor with the number of devices installed on each floor, type of fire alarm equipment on each floor, and the number and type of wire interconnecting the devices and equipment. The modified riser diagram had areas crossed off, which was an indication that the area had undergone renovation. Additional renovation drawings provided a section of the riser with its modifications. The final drawings consisted of the partially modified riser diagrams with areas crossed out, separate drawings containing a revised section of the riser, and floor plans with the locations of the devices on the designated floor.

It appears that the contractor was responsible for determining the final circuit configurations for the devices and equipment based upon the drawings found.

5.5.3 Typical Fire Alarm Equipment and Device Locations

The documentation found provided limited information on the specific location of the fire alarm control equipment, initiating devices, and communication equipment (Syska 1984). The base fire alarm system was a Firecom 8500 series fire alarm and voice communication system.

The Third Floor Lobby was found to be designated as the FCS. The FCS contained the Firecom 8500 Fire Command Center with printer and video monitor. On a typical floor, a system transponder/terminal cabinet was provided for monitoring the manual pull stations located at each stair entrance and smoke detectors in the electrical/telephone closets and elevator lobbies. Sprinkler water flow switch and valve supervisory switch in each stairwell were also monitored by fire alarm transponder/terminal cabinets. In addition, duct smoke detectors were installed in HVAC systems over 2,000 cfm and located at the main supply duct and the return air duct and were monitored by the transponder/terminal cabinets. The fire warden stations were installed separately on the north wall outside the elevator lobby.

5.5.4 Typical Fire Alarm Cabinet Connections

A mechanical room was located in the core area of each floor (Syska 1984). The south wall of the mechanical room was the designated location for fire alarm transponder/terminal cabinets, which supported and distributed the system’s monitoring, control, and communication circuits. The initiation device circuits, speaker circuits, and the notification appliance circuits serving that floor were terminated at the transponder/terminal cabinet at this location. Bulk amplification for the entire building was located on the fifth floor and distributed through the transponder/terminal cabinets located on each floor. Documentation was not located that provided a standard for the equipment or device connections.

5.5.5 Typical Fire Alarm Installation Detail

Drawings were not located that provided guidance on the installation of the devices to meet tolerances required by code and the manufacture.

The riser diagrams indicate that the smoke detector, manual pull station, speaker and strobe circuits were configured to be a Class B type (Syska 1984). The use of a Class B circuit was consistent with the minimum requirements for performance, but did not have the higher level of survivability capabilities associated with a Class A circuit.

5.5.6 Fire Alarm Device Design Detail

Drawings were not located that provided design detail showing the number of wires required to run between each device and between the device and equipment.

5.5.7 Fire Alarm Power Calculations

Fire alarm power calculations were not located that would document the capability of the fire alarm equipment to power the number and type of devices connected to the equipment.

5.5.8 Quality and Performance Assurance Forms

Quality control documentation was not found for the installation.

5.5.9 Installation Acceptance Testing and Commissioning Procedures

Documentation was not found that documented the testing and commissioning procedures.

5.5.10 Inspection, Testing, and Maintenance

Inspection, testing and maintenance are mandated by the applicable building codes after a fire alarm system is installed, and in commission.[3] The building owner is responsible for inspection, testing, and maintenance of the systems. This above work is permitted to be done by qualified and experienced personnel.

It appears that the inspection, testing, and maintenance for WTC 7 was performed by an outside contractor. The inspection, testing, and maintenance records were well-documented between 2000 and 2001.

5.6 COMPARISON OF WTC 7 FIRE ALARM SYSTEM TO WTC 1 AND WTC 2 FIRE ALARM SYSTEM

The fire alarm systems installed in WTC 1, 2, and 7 were consistent with the performance criteria as adopted by the Port Authority, but there were significant differences in approach in meeting these requirements. The development and implementation of the WTC 1 and WTC 2 alarm systems was approached in a methodical way. The overall fire alarm goals were identified and systematic steps developed and used for system design and installation. In comparison, documents available on the WTC 7 fire alarm system indicate that the design development for the system did not follow the approach used for WTC 1 and WTC 2. The WTC 7 fire alarm design documents consisted of basic working documents used by construction personnel for the equipment layout, which allowed the installation contractor more leeway in determining what materials were used, where devices and equipment were located, and how the system would ultimately perform. This approach does not indicate that the system design or product was substandard, it only shows that the design, hardware, and equipment layout did not follow the strict development requirements set forth by the Port Authority for WTC 1 and WTC 2. No documents were found that would indicate that the WTC 7 fire alarm system were not consistent with the performance standards required for the building.

The differences between the systems begin with the system goals. The WTC 1 and WTC 2 fire alarm system criteria placed a strong emphasis on system survivability, which was not apparent in the WTC 7

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[3] Fire Service Incorporated, inspection and maintenance records for the WTC over the life of the building.

system. The survivability enhancements present in the WTC 1 and WTC 2 systems that were not found in the WTC 7 system included the distribution of the fire alarm intelligence, monitoring, and controls on seven different levels. The WTC 7 fire alarm system did not use distributed intelligence. Also, the WTC 1 and WTC 2 fire alarm systems required all fire alarm riser circuits to be installed in three separate locations and within rigid conduit for additional physical protection. The WTC 7 fire alarm system documents did not indicate that this was required for the WTC 7 system. The survival of the fire alarm functions within WTC 1 and WTC 2 after impact can be directly attributed to these enhancements.

Another significant difference between the systems was the design development. Whereas the WTC 1 and WTC 2 systems had "MANDATED Fire Alarm Guidelines" (WTC 1999) as the basis for the installation of new equipment, there was no documentation available that indicated that the same controls were developed for the WTC 7 system. The advantages gained from the use of adopted guidelines are increased reliability and known performance through design and installation controls. This is especially true for large systems that undergo frequent renovations, maintenance, and repairs.

The final major difference was the commissioning and acceptance controls. The WTC 1 and WTC 2 fire alarm systems had comprehensive quality assurance procedures to maintain established performance levels for the fire alarm systems. The procedures included specific design, installation, and maintenance requirements. An example of the controls was the verification of the voice loudspeaker system capability to ensure fifty percent of the system remained operable on a floor if there was a loudspeaker circuit failure. The WTC 1 and WTC 2 design criteria provided typical circuit diagrams, design documentation, and quality assurance procedures to make sure this requirement was met. These strict quality controls were implemented because it is extremely difficult without disabling the voice circuit to verify this capability after the system is installed. The WTC 7 documentation does not indicate that this level of quality assurance was performed. The maintenance of the records for these processes provided a baseline for determining performance levels at the time of acceptance in comparison to any future date. This baseline is a major factor in maintaining system performance and availability.

The approach taken for the design, installation, and acceptance of the fire alarm system in WTC 7 was an approach that is commonly taken for commercial high rise construction. The absence of design, installation, and commissioning controls mentioned above does not indicate that common practices were not used in the development and installation of the fire system. This comparison shows the differences and enhanced measures that fire alarm system installation followed during its life-cycle to increase performance and survivability.

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Chapter 6

ESTIMATES OF PERFORMANCE OF THE FIRE ALARM SYSTEM ON SEPTEMBER 11, 2001

6.1 ANALYSIS DEVELOPMENT

Documenting the actual performance of the World Trade Center (WTC) 1 and WTC 2 fire alarm systems was significantly hampered by the loss of all historic documentation stored within the buildings and the loss of electronic files that were generated by the fire alarm system during the events of September 11, 2001. The analysis of the fire alarm's performance was limited to brief images of illuminated status lamps on the fire alarm system's panels located in the WTC 1 Fire Command Station (FCS), which were filmed by Goldfish Pictures during the event in 2001. Additional information was provided through interviews by National Institute of Standards and Technology (NIST) which provided information from interviews of individuals in the buildings, or in contact with people in the building during the event. The former project manager for the fire alarm installation in WTC 1 and WTC 2 was instrumental in clarifying system architecture nuances.

The performance of the WTC 7 fire alarm system was limited to the printout of the remote monitoring of the fire alarm system's alarm and condition status. The printout indicates that the system registered an alarm at 10:00 a.m.[4] No other information has been found on the performance of the system during the event.

6.2 OBSERVATIONS

The review of the WTC 1 and WTC 2 fire alarm system performance indicated that the systems did work, but not all functions performed as intended. The factors that directly influenced the performance were which building experienced the alarm condition, WTC 1 or WTC 2, and the location of the fire alarm function in relation to the impact damage in the building.

As a baseline for understanding, the first plane impacted WTC 1 at 8:46 a.m., and floors 93 through 99 experienced extensive, immediate impact damage. The second plane impacted WTC 2 at 9:03 a.m., and floors 77 through 85 experienced extensive, immediate impact damage. The following provides observations of the fire alarm performance based upon the interviews and film documentation.

WTC 1 Interviews – NIST interviews of survivors often included discussion of whether the occupant heard or did not hear various alarm system functions during their evacuation (NIST NCSTAR 1-7[5]). The WTC 1 interviews provided the following observations on the fire alarm functions:

- There was no confirmation that audible fire alarms were broadcast above the floors of impact.

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[4] Letter from Richard Kleinman, President, AFA Protective Systems, dated July 16, 2003, based on a request by NIST.

[5] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

- There was no confirmation that the emergency voice communication system functioned on any floor within WTC 1 after the impact.

- Confirmation was provided that alarm tones (not voice messages) were heard on the floors below impact.[6] Fourteen percent of occupants in WTC 1 and 11 percent in WTC 2 reported hearing alarm tones in the building (NIST NCSTAR 1-7).

- There was no confirmation that the floor warden or firefighter telephone system functioned after impact.

WTC 1 Film Observations- The Goldfish Picture video provided brief images of the fire alarm visual status indicators, along with a timeline to reference the observations. Although the images were limited, the following provides a timeline of the observations:

- 8:59 a.m. – The WTC 1 Fire alarm panel general alarm visual indication and system fault visual indications are illuminated. Speaker zones 84 and 89 also indicate that they are in a fault condition. The majority of speaker zone lamps on the WTC 1 fire alarm panel are illuminated solid red, which indicates that the speaker zones illuminated are in use. Floors 1 through 84 appear to have their zones illuminated, which indicates activated speakers. The exact floors may not be correct because the analysis of the visual indicators was from the personal memory of the fire alarm project manager and was not in comparison with as-built documentation (Drucker 2004). It is not known if a voice command, or an alarm tone was broadcast over the activated speaker zones. It is not known if all speaker zones were activated, but the interview transcripts indicate that no alarm tones or voice messages were heard above the floors of impact.

- 9:06 a.m. – The alarm slow whoop tone was heard in the lobby.

- 9:58 a.m. – The visual indicators on the Concourse and Sub-Grade fire alarm panels indicate that they are in alarm and their notification appliances have been silenced.

- 9:59 a.m. – WTC 2 collapsed, and all video of the fire alarm panels ceased.

WTC 2 911 Call Recordings – 911 calls from WTC 2 provided the following observations on the fire alarm functions:

- Confirmation was provided that voice messages and alarm tones were broadcast before and after the impact, and were heard above the impact floors.[7]

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[6] NIST Interview data set 2004 and New York City 911 Emergency Call Recording, 2001.

[7] New York City 911 Emergency Call Recordings, 2001.

WTC 2 Film Observations- The Goldfish Pictures video (Fig. 6–1) taken inside WTC 1 also provided brief images of the fire alarm visual status indicators, along with a timeline to reference the observations. Although the images were limited, the following provides a timeline of the observations:

- 9:58 a.m. – The WTC 2 fire alarm panels indicate that the floor warden telephones on floors 64, 71, 73, 93, and 99 are in use. Also, zones 76 through 84 on the speaker zones, warden telephone zones and fireman telephones zones are in a fault condition (see Fig. 6–1). Again, the zone numbers are based upon the fire alarm project manager's memory and may not be exactly correct (Drucker 2004). But, the sequential number of the zones correspond closely with the floors served by the PSR panels located on floors 74, 79, and 83. It is believed that the PSR panels were damaged, and the MXL-VR remote panel supporting the PSR panels maintained communication with the head-end MXL-V in the FCS to report the damage.

- 9:59 a.m. – WTC 2 collapsed, and all video of the fire alarm panels ceased.

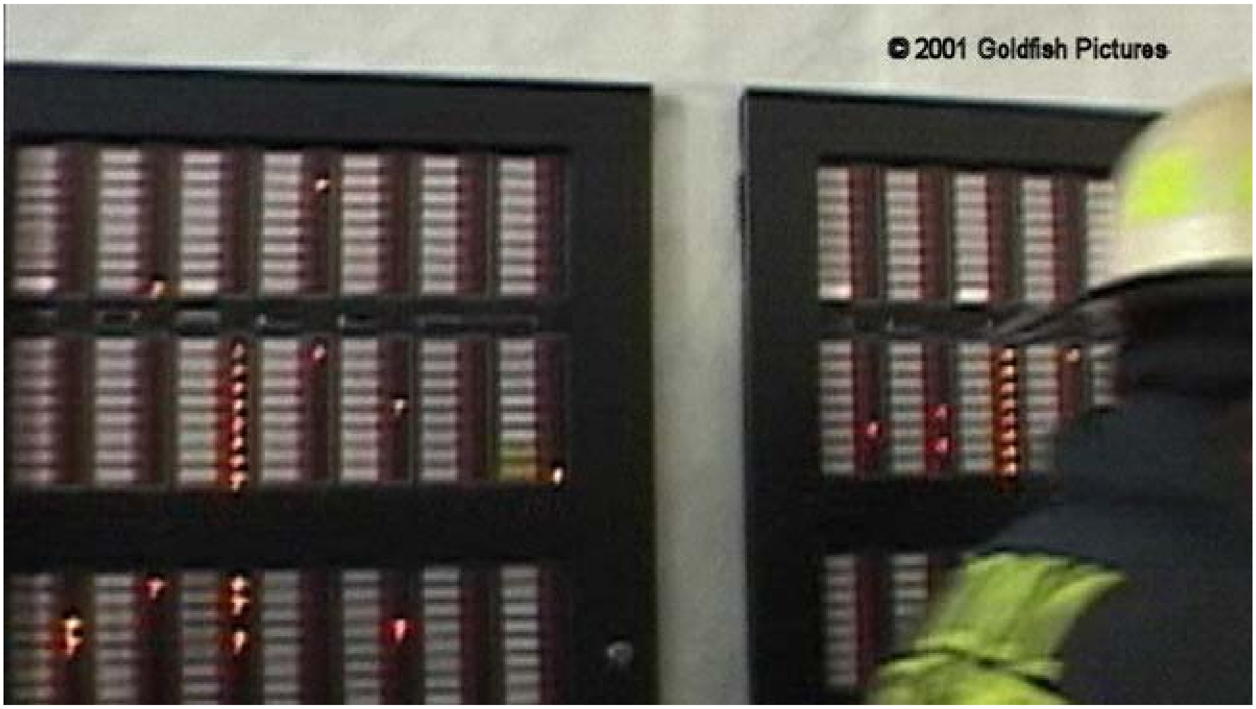


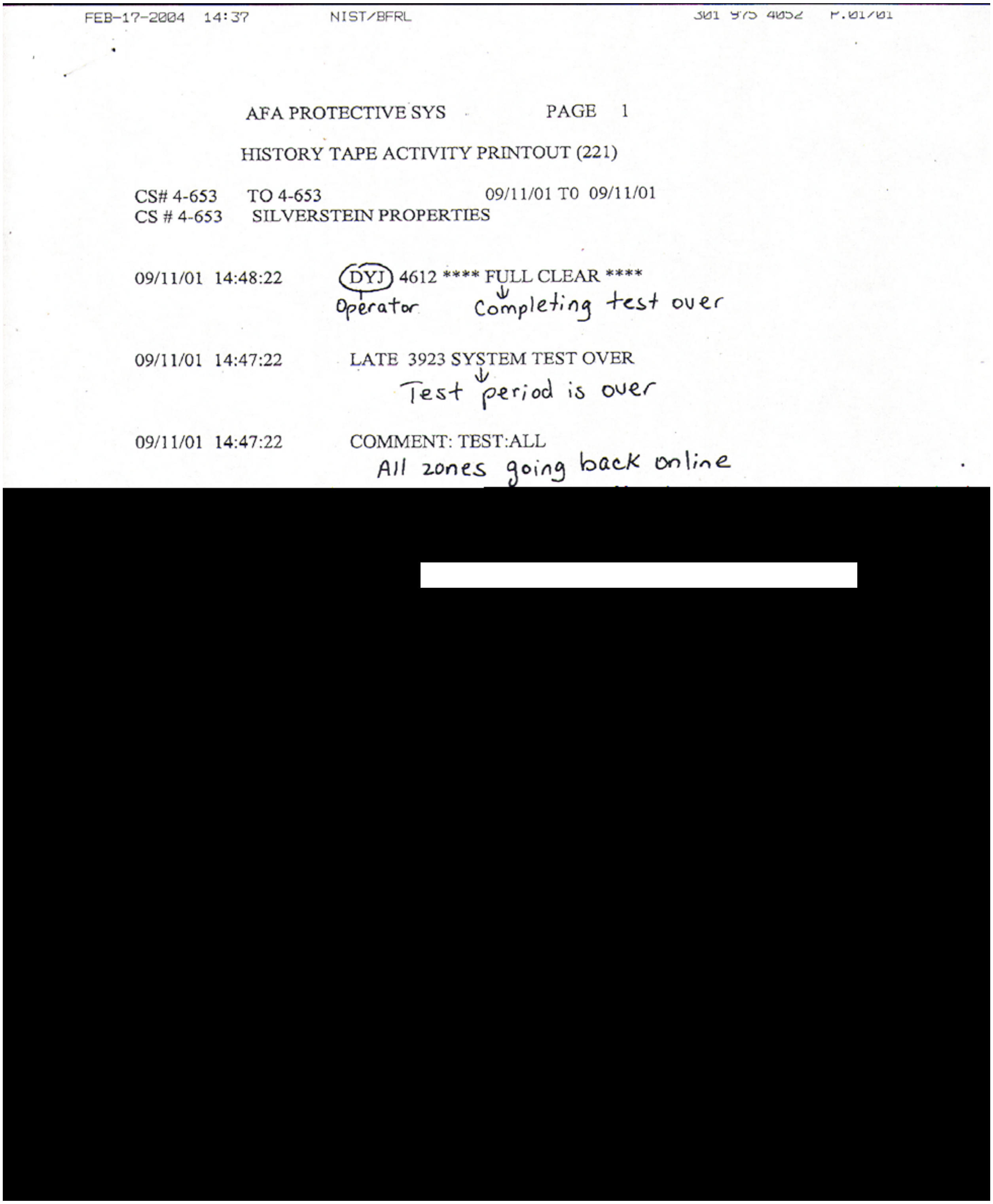
Figure 6–1. WTC 2 speaker and telephone circuit faults.

Other images of the fire alarm panels for both buildings did not indicate fault conditions on the impact floors or the floors above. This absence of numerous visual indicators may have been due to the loss of the communication paths to the remote MXL-VR panels, or PSR panels, or the loss of the panels themselves. The fact that the WTC 2 fire alarm system was able to continue to provide voice communication capability and floor warden telephones after the impact was probably due to Stair C remaining partially intact after the impact, which was where a portion of the audible riser was located, and the survival of the riser in the core area where the telephone riser was located. Of further interest is the visual indication on the FCS fire alarm panel that indicated that the WTC 2 fire alarm system lost communication to a group of PSR panels. Why the PSR panels lost communication is not known, but it would be reasonable to expect physical damage to the circuits. If the MNET circuits were damaged beyond use, survival of the audible circuits is difficult to explain. The audible circuit did survive since some occupants did hear voice announcements. The performance of other system functions and components within the system were not verifiable without the recovery of records lost with the buildings.

6.2.1 Summary of Results

The analysis of the fire alarm systems performance has led to the following results:

- Remote monitoring of the WTC 7 fire alarm systems only provided a time and date of the alarm condition (see Fig. 6–2)[4].
- The WTC 1 and WTC 2 fire alarm system required manual activation of the alarm signal to notify building occupants. This signal was delayed by 12 minutes after the impact in WTC 1.
- Although there is evidence that the floor warden telephones were used, the after action interviews of the firefighters conducted by NIST did not find that there was any attempt to use the firefighter telephone system. This is not uncommon since the firefighters are trained to use their radios as the preferred means of communication.
- Although the fire alarm systems in WTC 1 and WTC 2 used multiple communication path risers, the systems experienced performance degradation, especially in WTC 1 where all fire alarm notification and communication functions appears to have been lost above the floors of impact.



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AFA PROTECTIVE SYS PAGE 1

HISTORY TAPE ACTIVITY PRINTOUT (221)

CS# 4-653 TO 4-653 09/11/01 T0 09/11/01
CS # 4-653 SILVERSTEIN PROPERTIES

09/11/01 14:48:22 DYJ 4612 **** FULL CLEAR ****
Operator Completing test over

09/11/01 14:47:22 LATE 3923 SYSTEM TEST OVER
Test period is over

09/11/01 14:47:22 COMMENT: TEST:ALL
All zones going back online

[redacted]

Figure 6–2. WTC 7 central station alarm log.

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Chapter 7
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NIST NCSTAR 1-4D

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Smoke Management Systems

Michael J. Ferreira
Steven M. Strege

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

NIST NCSTAR 1-4D

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Smoke Management Systems

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September 2005

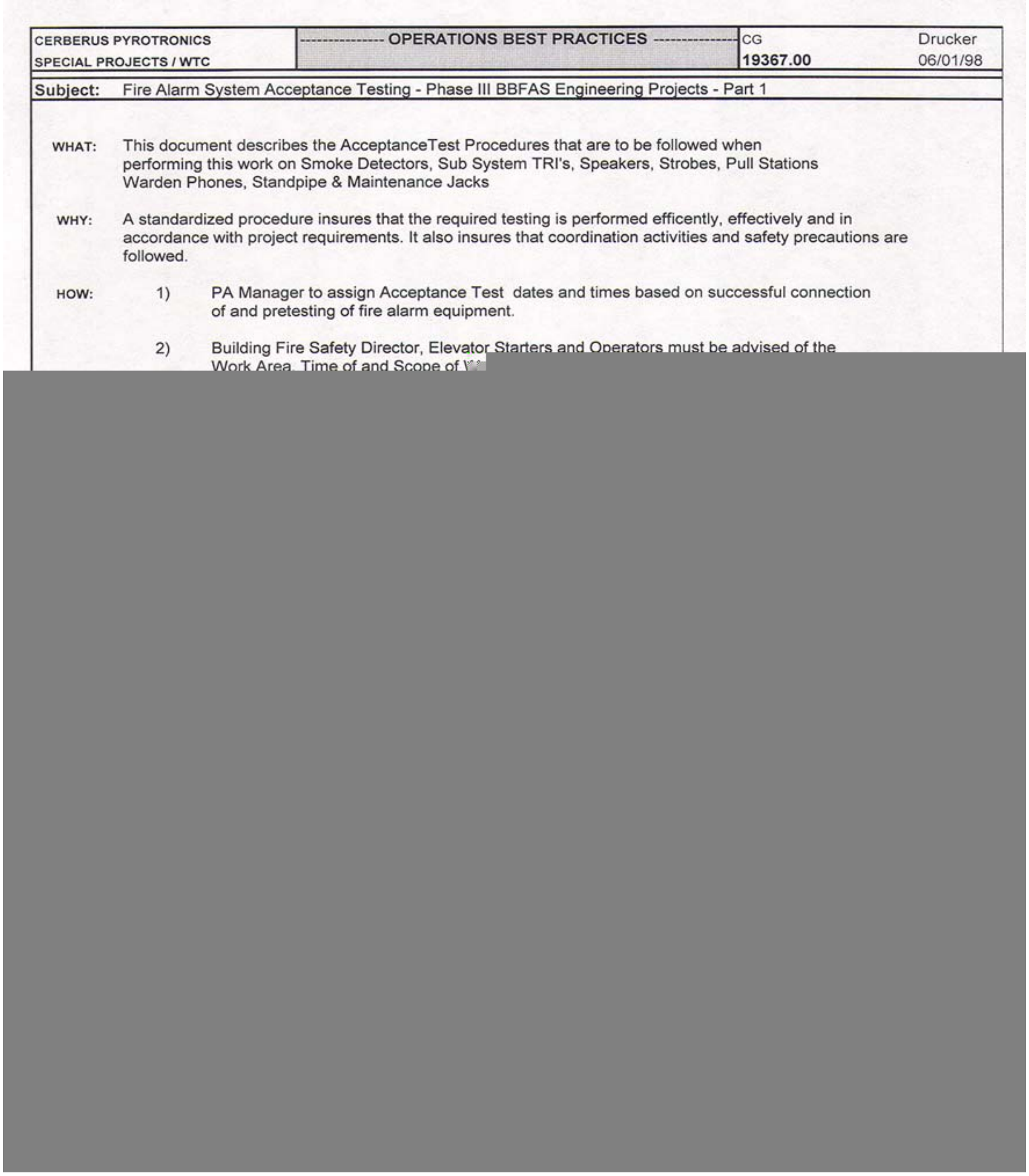
U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

5.1.12 Installation Acceptance Testing and Commissioning Procedures

The installation of the approved fire alarm design required the contractor to perform specific quality control procedures. Since any system modifications would affect both the building occupants and the contractor's safety, specific testing and acceptance practices were developed to address these issues (see Fig. 5–13).



CERBERUS PYROTRONICS **SPECIAL PROJECTS / WTC**	-------------- **OPERATIONS BEST PRACTICES** --------------	CG **19367.00**	Drucker 06/01/98

Subject: Fire Alarm System Acceptance Testing - Phase III BBFAS Engineering Projects - Part 1

WHAT: This document describes the AcceptanceTest Procedures that are to be followed when performing this work on Smoke Detectors, Sub System TRI's, Speakers, Strobes, Pull Stations Warden Phones, Standpipe & Maintenance Jacks

WHY: A standardized procedure insures that the required testing is performed efficently, effectively and in accordance with project requirements. It also insures that coordination activities and safety precautions are followed.

HOW:

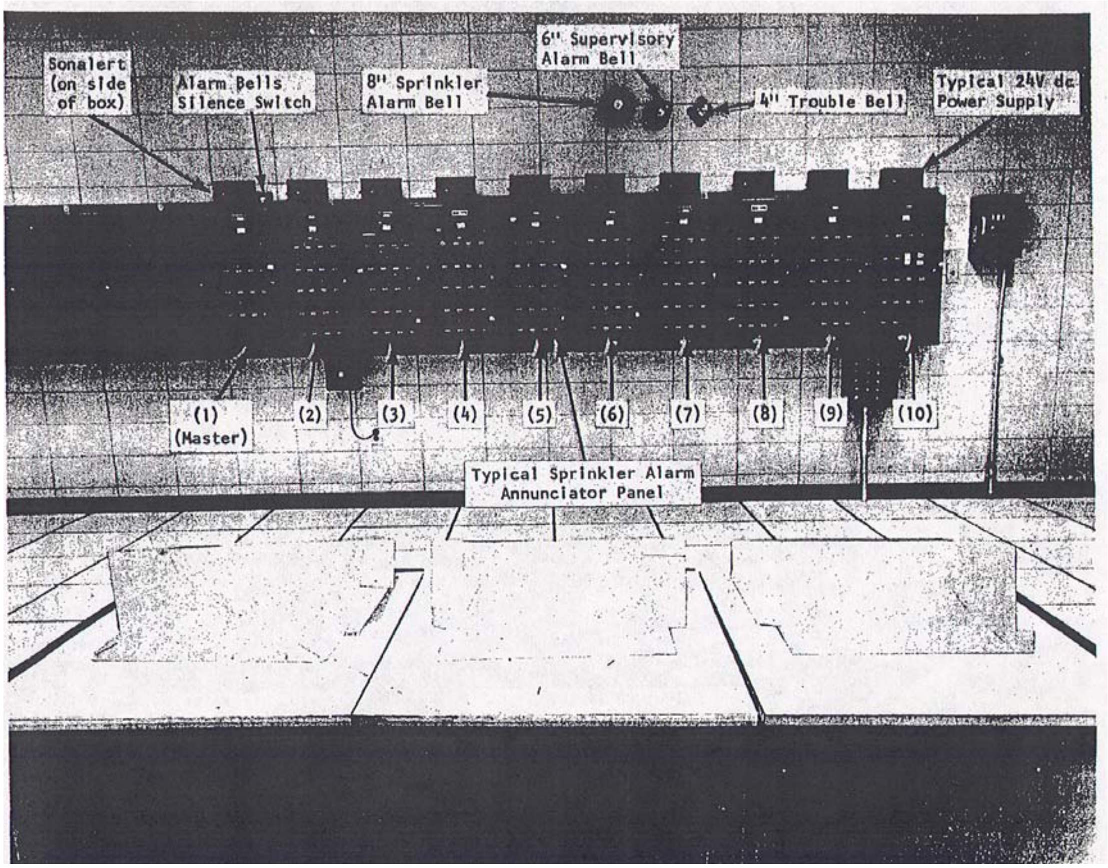
1) PA Manager to assign Acceptance Test dates and times based on successful connection of and pretesting of fire alarm equipment.

2) Building Fire Safety Director, Elevator Starters and Operators must be advised of the Work Area, Time of and Scope of

[redacted]

Source: PANYNJ 1999a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–13. New work acceptance best practices.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–16. Sprinkler alarm annunciator in HVAC computer room.

Sprinkler Alarm Annunciator Panel

The sprinkler alarm annunciator panel was in the old HVAC computer room on Level B4. The panel contained sprinkler waterflow and supervisory alarms. The supervisory alarms indicated when and if the conditions of certain equipment in the sprinkler system were abnormal. The conditions monitored were: the level of water in the fire reserve tanks; and the operating status of the fire standpipe pumps, the sprinkler fire pumps, the combination sprinkler/fire standpipe pumps, and the sprinkler jockey pump.

3.6 STANDPIPE FIRELINE COMMUNICATION SYSTEM

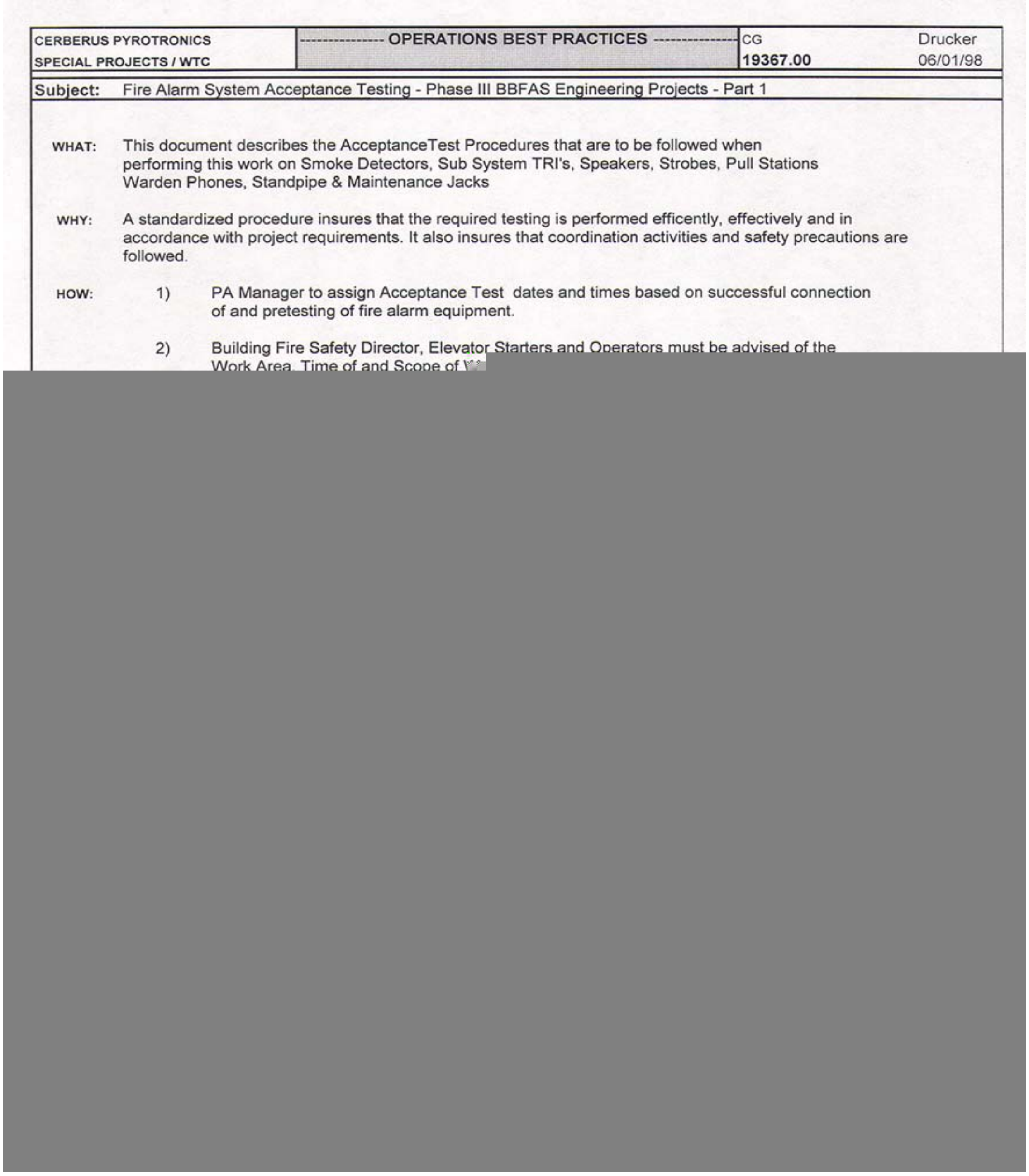
The Standpipe Fireline Communication System in the WTC is dealt with in this subsection (PANYNJ 1986). Included are verbal descriptions of the system, photos of the equipment utilized, and block diagrams of the entire system.

The Standpipe Fireline Communication System in the WTC was provided for firefighter use during operation of the standpipe system. This system included two-way telephone communications.

The Standpipe Fireline Communication System was a selective-ringing, common-talking system that was comprised of a Master, Submasters, and Outlying Stations, with a power supply, and an amplifier. The

5.1.12 Installation Acceptance Testing and Commissioning Procedures

The installation of the approved fire alarm design required the contractor to perform specific quality control procedures. Since any system modifications would affect both the building occupants and the contractor's safety, specific testing and acceptance practices were developed to address these issues (see Fig. 5–13).



CERBERUS PYROTRONICS **SPECIAL PROJECTS / WTC**	-------------- **OPERATIONS BEST PRACTICES** --------------	CG **19367.00**	Drucker 06/01/98

Subject: Fire Alarm System Acceptance Testing - Phase III BBFAS Engineering Projects - Part 1

WHAT: This document describes the AcceptanceTest Procedures that are to be followed when performing this work on Smoke Detectors, Sub System TRI's, Speakers, Strobes, Pull Stations Warden Phones, Standpipe & Maintenance Jacks

WHY: A standardized procedure insures that the required testing is performed efficently, effectively and in accordance with project requirements. It also insures that coordination activities and safety precautions are followed.

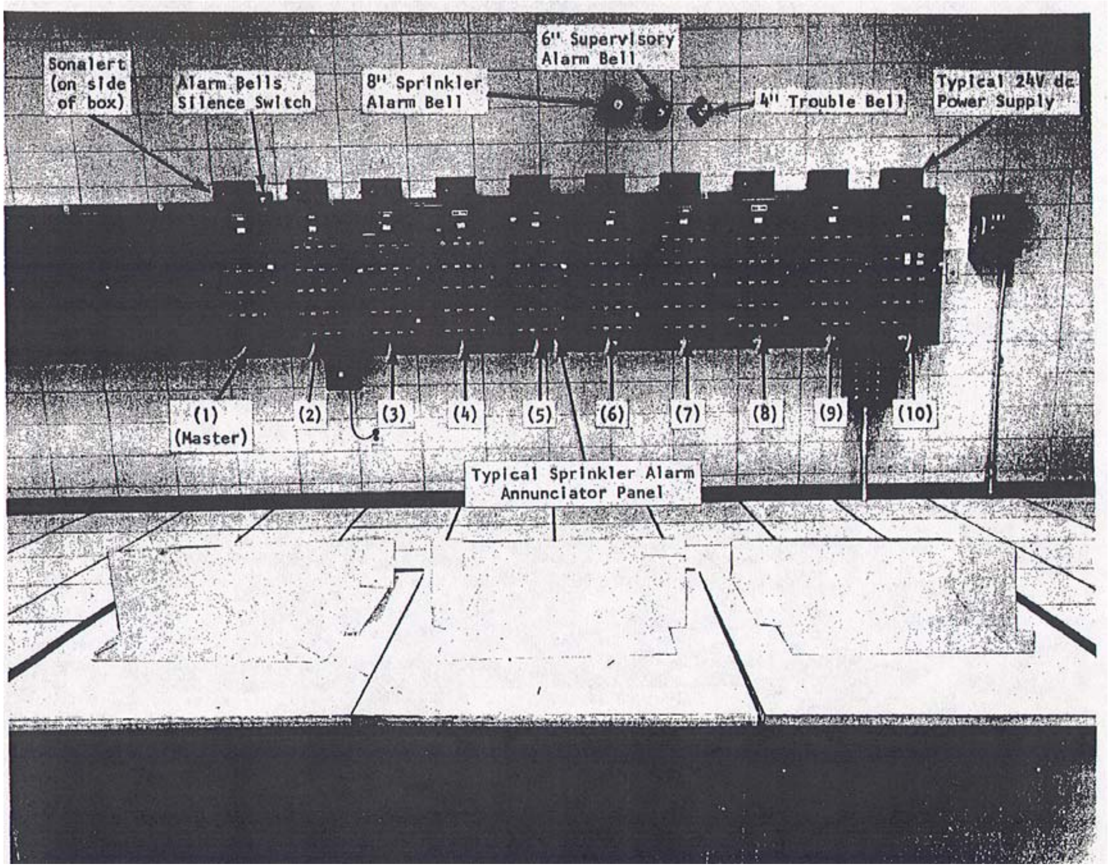
HOW:

1) PA Manager to assign Acceptance Test dates and times based on successful connection of and pretesting of fire alarm equipment.

2) Building Fire Safety Director, Elevator Starters and Operators must be advised of the Work Area, Time of and Scope of [redacted]

Source: PANYNJ 1999a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–13. New work acceptance best practices.



Source: PANYNJ 1986. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–16. Sprinkler alarm annunciator in HVAC computer room.

Sprinkler Alarm Annunciator Panel

The sprinkler alarm annunciator panel was in the old HVAC computer room on Level B4. The panel contained sprinkler waterflow and supervisory alarms. The supervisory alarms indicated when and if the conditions of certain equipment in the sprinkler system were abnormal. The conditions monitored were: the level of water in the fire reserve tanks; and the operating status of the fire standpipe pumps, the sprinkler fire pumps, the combination sprinkler/fire standpipe pumps, and the sprinkler jockey pump.

3.6 STANDPIPE FIRELINE COMMUNICATION SYSTEM

The Standpipe Fireline Communication System in the WTC is dealt with in this subsection (PANYNJ 1986). Included are verbal descriptions of the system, photos of the equipment utilized, and block diagrams of the entire system.

The Standpipe Fireline Communication System in the WTC was provided for firefighter use during operation of the standpipe system. This system included two-way telephone communications.

The Standpipe Fireline Communication System was a selective-ringing, common-talking system that was comprised of a Master, Submasters, and Outlying Stations, with a power supply, and an amplifier. The

5.1.12 Installation Acceptance Testing and Commissioning Procedures

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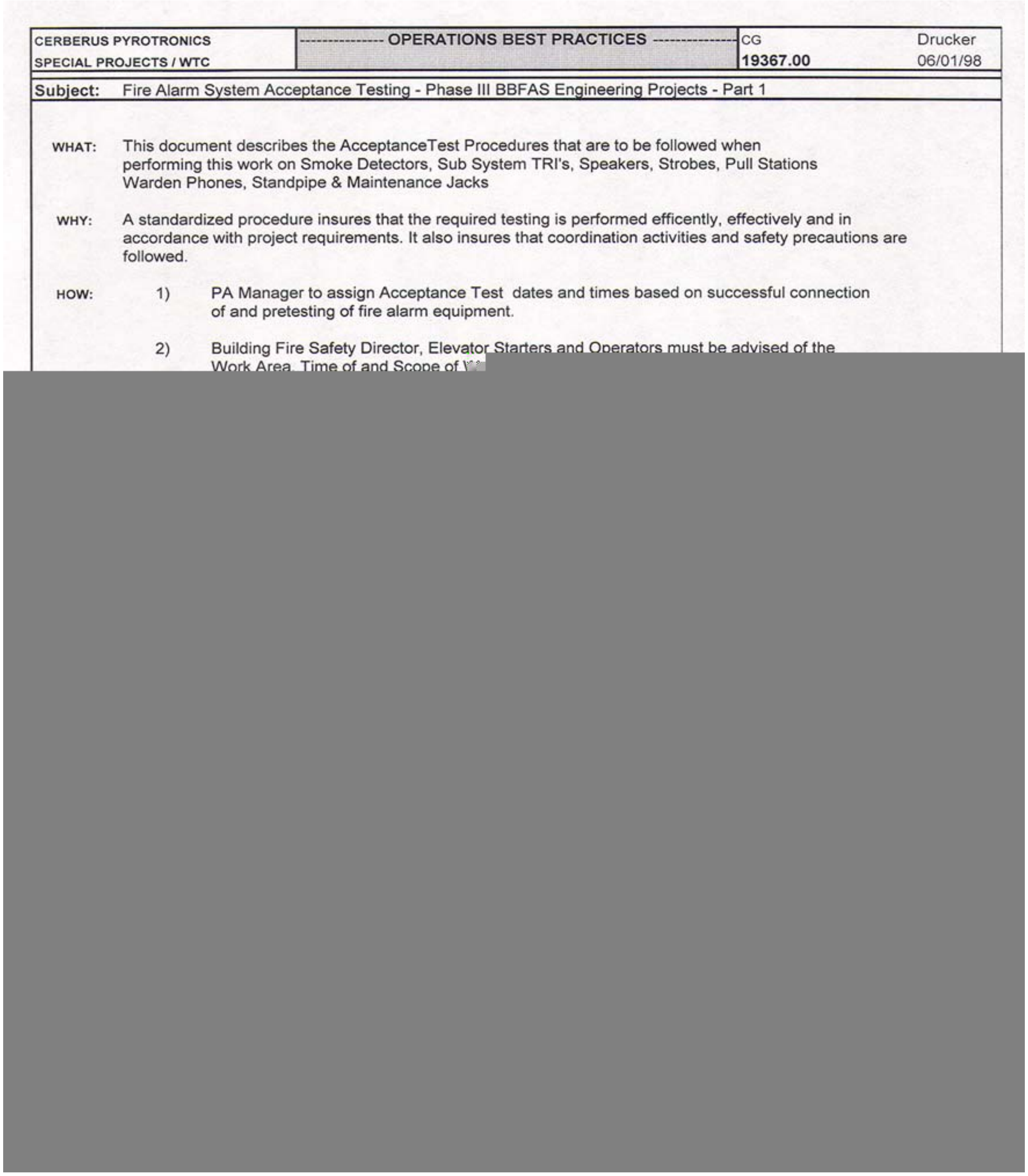

CERBERUS PYROTRONICS SPECIAL PROJECTS / WTC	---------------- OPERATIONS BEST PRACTICES ----------------	CG **19367.00**	Drucker 06/01/98

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Figure 5–13. New work acceptance best practices.