



## **56-Year-Old Fire Fighter Suffers Cardiac Arrest at Brush Fire— New Hampshire**

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### **Executive Summary**

On July 24, 2016, a 56-year-old male volunteer fire fighter (FF) collapsed as he was pumping the engine at a brush fire. Emergency medical services (EMS) trained personnel and the EMS Medical Director immediately initiated cardiopulmonary resuscitation (CPR) and followed advanced cardiac life support (ACLS) myocardial infarction protocols, shocking the FF multiple times. Care continued en route to the hospital. Hospital emergency department (ED) personnel continued to treat the FF without success for over 30 minutes and pronounced him dead at 1632 hours.

The Medical Examiner’s report listed the cause of death as arteriosclerotic cardiovascular disease. The report documented evidence of arteriosclerotic cardiovascular disease, including previous myocardial infarction (heart attack), multiple stent procedures, evidence of multi-vessel coronary artery bypass grafting (CABG), high-grade arteriosclerotic plaque in the coronary arteries, and a severely enlarged and dilated heart. NIOSH investigators concluded that the physical stress of the emergency response might have triggered the cardiovascular event.

The FF had an extensive history of coronary artery disease, including two previous heart attacks. The more recent one had occurred just months earlier (January 2016), after which he underwent CABG surgery to treat multiple arteries having severe blockage. An echocardiogram revealed the pumping function of his main chamber (left ventricle) was reduced. The FF had several ongoing risk factors for coronary artery disease, including smoking, high blood pressure, unhealthy cholesterol levels, and obesity [AHA 2016; NHLBI 2016].

### **Key Recommendations**

- *Ensure that all fire fighters receive an annual medical evaluation consistent with National Fire Protection Association (NFPA) 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments.*
- *Ensure fire fighters are cleared for duty by a physician knowledgeable about the physical demands of fire fighting, the personal protective equipment used by fire fighters, and the various components of NFPA 1582.*
- *Phase in a mandatory comprehensive wellness and fitness program for fire fighters.*
- *Perform an annual physical performance (physical ability) evaluation.*

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The National Institute for Occupational Safety and Health (NIOSH), an institute within the Centers for Disease Control and Prevention (CDC), is the federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. In 1998, Congress appropriated funds to NIOSH to conduct a fire fighter initiative that resulted in the NIOSH Fire Fighter Fatality Investigation and Prevention Program, which examines line-of-duty deaths or on-duty deaths of fire fighters to assist fire departments, fire fighters, the fire service, and others to prevent similar fire fighter deaths in the future. The agency does not enforce compliance with state or federal occupational safety and health standards and does not determine fault or assign blame. Participation of fire departments and individuals in NIOSH investigations is voluntary. Under its program, NIOSH investigators interview persons with knowledge of the incident who agree to be interviewed and review available records to develop a description of the conditions and circumstances leading to the death(s). Interviewees are not asked to sign sworn statements and interviews are not recorded. The agency's reports do not name the victim, the fire department or those interviewed. The NIOSH report's summary of the conditions and circumstances surrounding the fatality is intended to provide context to the agency's recommendations and is not intended to be definitive for purposes of determining any claim or benefit.

For further information, visit the program website at [www.cdc.gov/niosh/fire](http://www.cdc.gov/niosh/fire) or call toll free 1-800-CDC-INFO (1-800-232-4636).



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### **Introduction**

On July 24, 2016, a 56-year-old volunteer FF suffered a cardiac arrest while he was operating an engine at a brush fire. The U.S. Fire Administration (USFA) notified NIOSH of this fatality on July 26, 2016. NIOSH contacted the affected fire department (FD) on August 15, 2016, and again on May 26, 2017, to gather additional information and to initiate the investigation. On June 9, 2017, a contractor for the NIOSH Fire Fighter Fatality Prevention and Investigation Program (the NIOSH investigator) conducted an on-site investigation of the incident.

During the investigation, the NIOSH investigator interviewed the following people:

- Fire Chief
- Incident Commander (from neighboring career department)
- Fire Chief of Department in town where fire occurred
- Physician/EMS Medical Director who provided care on-scene, en route, and in hospital
- State Fire Marshall Investigator

The NIOSH investigator reviewed the following documents:

- FD incident report
- FD injury/illness investigation report
- FD medical evaluation records
- FD standard operating guidelines
- EMS (ambulance) report
- Hospital ED records
- Death certificate
- Autopsy report

### **Investigation**

On July 26, 2016, at 1410 hours a 56-year-old male volunteer FF responded to a mutual aid call to assist with a brush fire in a neighboring town. The FF responded as the driver/engineer of Engine 1

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(brush truck). Smoke from the brush fire had been spotted earlier (approximately 1330 hours) by fire personnel who were in the area doing storm clean-up following a severe storm that had downed many trees and caused power outages across the township. Because the fire was in a remote area, fire personnel had difficulty establishing the precise location of the fire and they did not know whether it was a prescribed burn or a brush fire. Fire personnel from different towns sought high ground to observe the smoke and communicated with each other to identify where the fire was located. Once it was determined which town the fire was in, the Fire Chief in that town had all available fire fighters in his town respond to the fire station. At 1446 hours, the precise location of the fire was determined and fire fighters were dispatched. Because the Fire Chief of the town in which the fire was located was operating an emergency command center to respond to the storm's damage, he asked a neighboring Chief (who was in the area and had been working with him to determine the location of the smoke) to assume incident command of the brush fire.

The Incident Commander (IC) arrived on scene at 1408 hours and found a small brush fire approximately 100 yards from the road with driveway access to the fire. The fire was slow burning, involving ground and leaf clutter and a few trees. There was green vegetation and the fire posed a low fire threat. The IC called for a first alarm brush fire that automatically dispatched mutual aid from 3 neighboring departments (two volunteer departments and one career department), including his own career department.

The FF and 5 other fire fighters from a volunteer FD providing mutual aid departed from their FD and arrived at the scene at 1430 hours. (Weather conditions around that time included an ambient temperature of 87° Fahrenheit [°F], 39% relative humidity, heat index of 87°F, partly cloudy skies, and winds around 9 miles per hour [mph] with gusts to 24 mph [Weather Underground no date]). They were the second engine on scene but were moved up to provide a base pump for fire attack hoselines due to a problem with the first engine. The FF's engine (Engine 1) was positioned about 20 feet from the command vehicle and other fire fighters were operating a handline from Engine 1 to fight the fire. At 1448 hours, the FF and his Chief were at Engine 1 and exchanged a joke when the FF suddenly collapsed. The Chief shouted to the IC that he had a medical emergency. The IC immediately radioed dispatch and notified them a fire fighter was down and requested an ambulance on scene as soon as possible. An emergency medicine physician (EMS Medical Director/volunteer fire fighter) and a paramedic were working in the wooded area with hand tools and immediately responded to the FF. (They reported that they were at the FF's side within approximately 1 minute).

The paramedic, physician, and other personnel on the scene immediately began chest compressions. The FF was moved about 35 feet from his location near Engine 1 to a site that permitted better delivery of care. CPR was provided with bag-valve mask. An electrocardiogram (EKG) monitor/defibrillator was retrieved from a local rescue vehicle and applied to the FF. The initial rhythm obtained was ventricular fibrillation (v-fib). The FF was defibrillated and ACLS algorithms were followed. The FF was shocked four times in the field. At one point, the FF converted to ventricular tachycardia and received a synchronized shock. Shortly thereafter, the FF went into pulseless electrical activity (PEA) with a bradycardic wide complex rhythm.

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The ambulance was dispatched at 1452 hours and arrived on scene at 1508 hours. The emergency medical technicians (EMTs) arrived to find the FF on a backboard. He was unresponsive, had an oropharyngeal airway in place, and bag-valve (BV) mask ventilations were being provided. Paramedics attempted a laryngoscopy but were unsuccessful on the first attempt due to the scope being occluded with secretions and the FF clenching his teeth against the device. Intravenous (IV) and intraosseus (IO) access were obtained and cardiac medications were administered. The FF was loaded into the ambulance and a LifePak® monitor/defibrillator was attached to the FF. In the ambulance, an endotracheal tube (ETT) was successfully inserted and BV-ETT ventilations were provided. Placement of the ETT was confirmed with symmetric chest rise and fall, breath sounds in all fields, misting in the ETT, and waveform capnography (exhaled CO<sub>2</sub>). Ventilation and oxygenation via BV-ETT were continuously monitored for end-tidal CO<sub>2</sub> (ETCO<sub>2</sub>) waveforms. The ambulance departed for the hospital ED at 1538 hours. En route to the hospital, mechanical ventilation was initiated. The FF remained in PEA and thus received no additional shocks during transport. Additional rounds of cardiac medications were administered throughout transport with the EMS Medical Director overseeing medical care. The ambulance arrived at the hospital at 1557 hours and care was transferred to ED staff.

When the FF arrived at the hospital ED, the cardiac monitor revealed that he was in v-fib. ACLS measures were continued and occasionally an organized rhythm was seen, but only briefly. The FF primarily remained in v-fib despite cardiac medications. Pulse oximetry readings were good (sometimes as high as 100%), but the FF never regained spontaneous circulation. Blood gases revealed acidosis and elevated blood lactate levels. After nearly 2 hours of chest compressions, and with profound acidosis and worsening lactate, resuscitation efforts were discontinued as the FF's condition and lab results were not compatible with life or meaningful recovery. The FF was pronounced dead at 1632 hours.

### **Medical Findings**

The Chief Medical Examiner for the State performed the autopsy. The autopsy and death certificate identified the cause of death as arteriosclerotic heart disease. The autopsy also noted cardiac enlargement (774 grams [g]), biventricular dilation, left ventricular hypertrophy (1.5 centimeters [cm]), recent and remote myocardial infarction, evidence of multi-vessel CABG, diffuse high-grade arteriosclerotic stenosis by calcified arteriosclerotic plaque, and history of coronary artery stent placement. His height and weight were measured as 73 inches tall and 261 pounds. See Appendix A for a more detailed description of autopsy findings.

The FF had an extensive history of coronary artery disease. On January 13, 2016, he was hospitalized with chest pain (angina) and found to have had a myocardial infarction. The hospital notes indicated that he had coronary artery disease, hypertension (high blood pressure), dyslipidemia, a family history of cardiovascular disease, and he was a smoker. (He was also obese, based on a body mass index of 34.4 kilograms per meter squared [kg/m<sup>2</sup>]; a BMI >30 kg/m<sup>2</sup> is considered obese [NHLBI no date]). An echocardiogram showed a dilated left ventricle with moderately decreased function (left ventricle ejection fraction of 35%; normal is in the range of 50% to 70%) [AHA 2015]. Portions of the left ventricle were found to be hypokinetic (weakened contraction) and some sections were akinetic (no

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movement), likely related to scar tissue replacing cardiac muscle after a heart attack. The day after his admission to the hospital, he underwent cardiac catheterization. The physician's notes indicated a history of unstable angina, recent myocardial infarction, positive troponin (a protein released by damaged heart muscle), and remote myocardial infarction. Catheterization revealed multiple vessel coronary artery disease. The left anterior descending artery had severe diffuse disease and total occlusion of the mid segment of the second diagonal branch (D2), the left circumflex was 85% occluded, and the right coronary artery had moderate to severe calcified plaque.

Based on the results of the catheterization, the FF underwent CABG of four coronary arteries on January 18, 2016. Blood work performed in January 2016 indicated blood glucose was slightly elevated (107 milligrams per deciliter [mg/dL]; normal fasting <100 mg/dL) [ADA 2014]. In late February 2016, the FF returned to his surgeon's office for a follow-up visit. At this time, his blood pressure was 116/68 millimeters of mercury (mm Hg) (normal resting values are 90–119 mm Hg systolic and 60–79 diastolic) [NHLBI 2010; NHLBI 2015]. The FF was taking cholesterol-lowering and antihypertensive medications and an aspirin for anticoagulation. At this visit, the FF was cleared to resume driving and was given no activity restrictions with the exception of not lifting more than 20 pounds.

In March 2016, the FF had an exercise stress test to determine his functional status. The FF exercised for 7.2 minutes on a Bruce treadmill protocol and achieved 7.2 metabolic equivalents (METs). He did not have any EKG abnormalities during the test. An echocardiogram performed in the same month revealed a dilated left ventricle with impaired left ventricular function (left ventricle ejection fraction = 26%). In April, the FF obtained a letter from his physician clearing him to return to work as a caretaker of a large estate doing physical work such as cutting wood and maintaining cabins. In June, the FF had a cardiac magnetic resonance imaging (MRI) evaluation that showed a severely dilated left ventricle, reduced systolic function (left ventricle ejection fraction = 30%), and regional wall motion abnormalities. The FF saw his cardiologist for a follow-up on July 21, 2016 at which time he reported shortness of breath with exertion, and chest pain which did not increase with exertion, which the FF thought was due to a pulled muscle.

### **Fire Department**

At the time of the NIOSH investigation, the FD consisted of 20 uniformed personnel working out of a single fire station. It served a population of approximately 1,300 in a geographic area of 48 square miles. In 2016, the FD responded to approximately 120 calls.

### **Employment and Training**

To join the department, an applicant must be at least 18 years of age, submit a written application, complete an interview with the membership board, pass a background check, pass a driver's history check, and attend training sessions. A candidate becomes a probationary fire fighter after being voted in by a majority of the membership at a regular business meeting. Probationary fire fighters must take fire fighter I certification training, complete an emergency vehicle operator course, demonstrate basic

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fire fighting skills, and be a probationary fire fighter for at least 180 days before becoming a member of the department. The FF had been with the FD for over 10 years.

### **Medical Evaluations and Wellness/Fitness Programs**

The FD does not require preplacement medical evaluations for applicants or annual medical evaluations for members. Members are required to provide medical clearance from their personal physician following a serious injury or illness. The FD does not have exercise equipment available for members. It does not offer a comprehensive wellness/fitness program as recommended by the International Association of Fire Fighters/International Association of Fire Chiefs (IAFF/IAFC) Wellness Fitness Initiative [IAFF/IAFC 2008].

### **Discussion**

#### **Sudden Cardiac Events**

In the United States, arteriosclerotic coronary heart disease is the most common risk factor for cardiac arrest and sudden cardiac death [Myerburg and Castellanos 2008]. Risk for its development is grouped into non-modifiable and modifiable risk factors. Non-modifiable risk factors include age older than 45, male gender, and family history of coronary artery disease. Modifiable risk factors include diabetes mellitus, smoking, hypertension, unhealthy blood cholesterol levels, and obesity/physical inactivity [AHA 2016; NHLBI 2016]. The FF had four of these modifiable risk factors: current smoking, hypertension, unhealthy cholesterol levels, and obesity.

Narrowing (stenosis) of coronary arteries by arteriosclerotic plaques occurs over many years, usually decades [Libby 2013]. However, the growth of these plaques probably occurs in a nonlinear, often abrupt fashion. Arterial plaque preventing sufficient blood flow to the heart (ischemia) can cause chest pain, particularly with physical exertion. A heart attack can result if complete blockage (occlusion) suddenly occurs in an artery that has not developed a collateral blood supply. This abrupt blockage is primarily due to a blood clot (thrombosis) forming on top of a ruptured arteriosclerotic plaque [Libby 2013].

Establishing the occurrence of an acute heart attack requires any of the following: characteristic EKG changes, elevated cardiac enzymes (biomarker), or coronary artery thrombus/plaque rupture. In this case, blood drawn in the ED indicated the FF had an elevated level of Troponin-T, a biomarker for myocardial damage (0.68 nanograms per milliliter; normal  $\leq 0.03$ ) [Mayo 2017]. At autopsy, there was no evidence of a thrombus; however, microscopic examination revealed changes consistent with a recent heart attack. The FF also had a severely enlarged heart.

#### **Left Ventricular Hypertrophy/Cardiomegaly**

Left ventricular hypertrophy (thickening of the heart's main pumping chamber) is a common finding among individuals with long-standing hypertension, a heart valve problem, obesity, or chronic myocardial ischemia [Cramariuc and Gerdt 2016; Cuspidi et al. 2014; Korre et al. 2016; Siegel 1997; Tavora et al. 2012]. Left ventricular hypertrophy and cardiomegaly (an enlarged heart) are structural

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changes to the heart that increase the risk for arrhythmias and sudden cardiac death [Chatterjee et al. 2014; Kahan and Bergfeldt 2007; Spirito et al. 2009; Tavora et al. 2012]. The FF had left ventricular hypertrophy and cardiomegaly, with his heart weighing nearly twice the normal weight for a man of his size. The FF also had biventricular dilation and substantially reduced contractility function.

### **Physiological Stress and Fire Fighter Duties**

Heart attacks and sudden cardiac death can be triggered by heavy physical exertion, and the risk is higher among persons who are physically inactive (e.g., sedentary or exercise infrequently) [Albert et al. 2000; Mittleman et al. 1993; Willich et al. 1993]. Among fire fighters, activities associated with a triggering effect for sudden cardiac events include fire suppression, responding to an alarm, returning from an alarm, and physically demanding training, such as live fire drills, search and rescue, or physical fitness training [Kales et al. 2003, 2007; NIOSH 2007]. Fire fighters with underlying risk factors for cardiovascular disease are much more susceptible to triggers, including fire fighters who smoke, have hypertension, are 45 years or older, or have evidence of underlying arterial occlusive disease (e.g., history of angina, angioplasty, heart attack, or carotid stenosis) [Kales et al. 2003].

In this incident, the FF responded to an alarm, and collapsed approximately 18 minutes after arriving at the scene. It is possible the hot weather that day may have played a contributory role; environmental heat can strain the cardiovascular system, particularly among individuals with underlying heart disease [Crandall and González-Alonso 2010; Wilker et al. 2012].

### **Occupational Medical Standards for Structural Fire Fighters**

To reduce the risk of sudden cardiac events or other incapacitating conditions among fire fighters, NFPA developed 1582, *Standard on Comprehensive Occupational Medical Program for Fire Departments*. This voluntary industry standard outlines medical fitness for duty criteria for fire fighters and the specific components that should be included in their medical evaluations [NFPA 2013a, 2018a]. The FD does not require preplacement or annual medical evaluations of personnel. The department did require a return to work note from the FF's personal physician following his recent heart attack and CABG surgery in early 2016.

#### Coronary Artery Disease

Guidance in NFPA 1582 regarding coronary artery disease states that a history of myocardial infarction, coronary artery bypass surgery, coronary angioplasty with stent placement, or similar procedures compromises the ability of a fire fighter to safely perform a number of essential fire fighting duties. For example, reduced cardiac function or ischemia could compromise the ability to carry out physically demanding tasks under stressful conditions. Sudden incapacitation while responding to an emergency could jeopardize the mission and put other team members or civilians at risk [NFPA 2013a, 2018a].

If any of the following are present, NFPA 1582 advises that the evaluating physician report applicable duty limitations to the fire department:

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- (1) Current angina pectoris (chest pain) even if relieved by medication
- (2) Persistent significant stenosis in any coronary artery (>70%) following treatment
- (3) Lower than normal left ventricular ejection fraction as measured by echocardiography, radionuclide scan, or contrast ventriculography.
- (4) Maximal exercise tolerance of less than 12 METs
- (5) Exercise-induced ischemia or ventricular arrhythmias observed by radionuclide stress test during an evaluation reaching a workload of at least 12 METs
- (6) History of myocardial infarction, angina, or coronary artery disease with persistence of modifiable risk factor(s) for acute coronary plaque rupture (e.g., tobacco use, hypertension despite treatment, hypercholesterolemia with total cholesterol  $\geq 180$  mg/dL or low-density lipoproteins (LDL)  $\geq 100$  despite treatment, or glycosylated hemoglobin A1C >7% despite exercise and/or weight reduction) [NFPA 2013a, 2018a].

The information available to the NIOSH investigator indicates the FF did not meet the medical criteria for unrestricted fire fighting duties according to NFPA 1582 guidance. The FF had severe arteriosclerotic heart disease with ongoing risk factors. The pumping function of his left ventricle was substantially reduced, and he did not have 12 METs of exercise tolerance.

### **Recommendations**

***Recommendation #1: Ensure that all fire fighters receive an annual medical evaluation consistent with NFPA 1582, Standard on Comprehensive Occupational Medical Program for Fire Departments.***

Discussion: Guidance regarding the content and frequency of these medical evaluations can be found in NFPA 1582 [NFPA 2013a, 2018a]. These evaluations are performed to determine a fire fighter's medical ability to perform duties without presenting a significant risk to the safety and health of self or others. This medical evaluation should be consistent with the recommendations of NFPA 1582. Implementing this standard may be particularly challenging for small volunteer fire departments with limited budgets. Although a department is not legally required to follow NFPA 1582, preplacement and annual evaluations are highly encouraged. A tool for primary care providers is now available to assist them to provide occupational exams for fire fighters. The *Healthcare Provider's Guide to Firefighter Physicals* was developed by physicians and fire service experts and can be found on the International Association of Fire Chiefs' website [IAFC 2016].

The fire department does not offer evaluations for candidates or members. The FF received medical care from private physicians. It is not known if his physicians were aware of his fire fighting duties or the evaluation components recommended in NFPA 1582.

***Recommendation #2: Ensure fire fighters are cleared for duty by a physician knowledgeable about the physical demands of fire fighting, the personal protective equipment used by fire fighters, and***

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*the various components of NFPA 1582.*

Discussion: According to NFPA 1582, the fire department should require that physicians are familiar with the physical demands of fire fighting and the risks that fire fighters encounter and should guide, direct, and advise members with regard to their health, fitness, and suitability for duty [NFPA 2013a, 2018a]. A physician caring for fire fighters should become familiar with their essential duties to better understand the physiological, psychological, and environmental demands placed on fire fighters, as well as the personal protective equipment required for various types of emergency operations.

In February 2016 the FF's surgeon cleared him for driving and unrestricted activity except lifting over 20 pounds. It is not clear if the surgeon was aware of the FF's work as a fire fighter. For fire departments without a designated physician to provide or review duty clearances, the IAFC's *Healthcare Provider's Guide to Firefighter Physicals* [IAFC 2016] may be a helpful resource to assist private providers who are evaluating and treating fire fighters, in addition to NFPA 1582.

### ***Recommendation #3: Phase in a mandatory comprehensive wellness and fitness program for fire fighters.***

Discussion: Guidance for fire department wellness/fitness programs to reduce risk factors for cardiovascular disease and improve cardiovascular capacity is found in NFPA 1583, *Standard on Health-Related Fitness Programs for Fire Fighters* [NFPA 2015], the IAFF/IAFC *Fire Service Joint Labor Management Wellness/Fitness Initiative* [IAFF/IAFC 2008], the National Volunteer Fire Council (NVFC) *Health and Wellness Guide for the Volunteer Fire and Emergency Services* [USFA 2009], and *Firefighter Fitness: A Health and Wellness Guide* [Schneider 2010]. Health promotion programs have been shown to be cost effective by increasing productivity, reducing absenteeism, and reducing the number of work-related injuries and lost workdays [Aldana 2001; Stein et al. 2000]. Health promotion programs for fire fighters have reduced their coronary heart disease risk factors and improved their fitness levels, with mandatory programs showing the most benefit [Blevins et al. 2006; Dempsey et al. 2002; Womack et al. 2005].

The FD does not have a wellness/fitness program. Given the FD's structure and budget limitations, helpful resources for starting a program may include the NVFC *Heart-Healthy Firefighter Program* [NVFC no date] and the NVFC *Health and Wellness Guide for the Volunteer Fire and Emergency Services* [USFA 2009].

### ***Recommendation #4: Perform annual physical performance (physical ability) evaluation.***

Discussion: NFPA 1500 recommends that members who engage in emergency operations be annually evaluated and certified by the fire department as having met the physical performance requirements identified in paragraph 10.2.3 of the standard [NFPA 2013b, 2018b]. This is recommended to ensure fire fighters are physically capable of performing essential job tasks of structural fire fighting. The physical ability test could be performed as part of the FD's annual training program.

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### **Investigator Information**

This incident was investigated by the Cardiac and Medical Line-of-Duty Deaths (LODD) Investigations Team, Fire Fighter Fatality Investigation and Prevention Program, Hazard Evaluations and Technical Assistance Branch, in the Division of Surveillance, Hazard Evaluations and Field Studies at the National Institute for Occupational Safety and Health (NIOSH) located in Cincinnati, Ohio. Denise L. Smith, PhD, led the investigation and authored the report. Dr. Denise L. Smith is Director of the First Responder Health and Safety Laboratory and Professor of Health and Exercise Sciences at Skidmore College, where she was recently awarded the Tisch Family Distinguished Professorship. Dr. Smith is also a member of the NFPA Technical Committee on Occupational Safety and Health. Dr. Smith was working as a contractor with the Cardiac and Medical LODD Investigations Team in the NIOSH Fire Fighter Fatality Investigation and Prevention Program during this investigation. Wendi Dick, MD, MSPH, provided medical consultation and contributed to the report. Dr. Dick leads the Cardiac and Medical LODD Investigations Team at NIOSH in Cincinnati.

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### **Appendix A Autopsy Findings**

- Structural heart disease
  - Hypertrophy with biventricular dilation (heart weighed 774 g; predicted normal weight is 425 g [range of 322 g–561 g] as a function of sex and body weight [Silver and Silver 2001])
  - Left ventricular wall – 1.5 cm
    - Normal at autopsy is 0.76 cm–0.88 cm [Colucci and Braunwald 1997]
  - Right ventricular wall – 0.5 cm
    - Normal at autopsy is 0.2 cm–0.7 cm with an average of 0.35 cm–0.39 cm [Hutchins and Anaya 1973; Murphy et al. 1988]
- Coronary artery and aortic arteriosclerosis
  - Diffuse, high-grade arteriosclerotic stenosis by calcified arteriosclerotic plaque
  - Multiple coronary artery bypass grafts identified
    - Bypass graft to left anterior descending coronary artery appears patent
    - Remaining bypass grafts could not be fully tracked
- The posterior free wall of the myocardium has a transmural, grayish white scar with more recent appearing extension to the posterolateral free wall
- No emboli present in the atria or pulmonary trunk
- Normal cardiac valves
- Abdominal aorta shows numerous, complicated arteriosclerotic plaques
- Microscopic examination
  - Sections of posterior free wall show a transmural, acellular scar with more recent appearing infarction along the periphery in posterolateral sections
  - Epicardial coronary arteries show high-grade stenosis by calcified arteriosclerotic plaque
  - Sections from the anterior free wall (left ventricle) and right ventricle show nonspecific interstitial and slight perivascular fibrosis
- No evidence of a pulmonary embolus (blood clot in the lung arteries)
- Blood analysis negative for drugs of abuse

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