# Evaluation of Oxygen Cylinder Overpacks Exposed to Elevated Temperature

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June 1999

DOT/FAA/AR-TN98/30

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# NOTICE

**Technical Report Documentation Page**

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|---|---|---|
| **1. Report No.**<br>DOT/FAA/AR-TN98/30 | **2. Government Accession No.** | **3. Recipient's Catalog No.** |
| **4. Title and Subtitle**<br>EVALUATION OF OXYGEN CYLINDER OVERPACKS EXPOSED TO ELEVATED TEMPERATURE | | **5. Report Date**<br>June 1999 |
| | | **6. Performing Organization Code** |
| **7. Author(s)**<br>Timothy R. Marker and Ricardo Diaz | | **8. Performing Organization Report No.** |
| **9. Performing Organization Name and Address**<br>Fire Safety Section, AAR-422<br>Federal Aviation Administration<br>William J. Hughes Technical Center<br>Atlantic City International Airport, NJ 08405 | | **10. Work Unit No. (TRAIS)** |
| | | **11. Contract or Grant No.** |
| **12. Sponsoring Agency Name and Address**<br>U.S. Department of Transportation<br>Federal Aviation Administration<br>Office of Aviation Research<br>Washington, DC 20591 | | **13. Type of Report and Period Covered**<br>Technical Note |
| | | **14. Sponsoring Agency Code**<br>AFS-200 |
| **15. Supplementary Notes** | | |

**16. Abstract**

Tests were conducted inside a large industrial convection furnace to determine the temperature and time required to cause pressure relief activation of three different size oxygen cylinders commonly used in commercial transport aircraft. The cylinders were first emptied of gaseous oxygen for safety reasons and refilled with nitrogen to the original pressure. The furnace temperature was ramped to 400°F, which represented the temperature reached during a Halon 1301 suppressed deep-seated cargo compartment fire. Cylinder pressure relief activation typically occurred after the surface temperature had reached only 300°F.

Additional tests were conducted using a 76.5-cubic-foot oxygen cylinder placed inside several types of cylinder cases, commonly referred to as overpacks. The overpacks were available in a variety of constructions, all for the purpose of protecting the cylinder from impact damage that may occur during shipment. The tests were run to determine the level of thermal protection, if any, that the overpacks might provide when the cylinders are subjected to elevated temperatures. Two custom-made overpacks were also tested that contained insulating materials aimed specifically at providing thermal protection. Tests showed that some common overpacks have the ability to protect the cylinder from pressure relief activation for nearly 60 minutes while other types designed specifically for thermal insulation can provide significant additional protection.

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| **17. Key Words**<br>Pressurized oxygen cylinder, Rupture disc, Overpack | | **18. Distribution Statement**<br>This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. | |
| **19. Security Classif. (of this report)**<br>Unclassified | **20. Security Classif. (of this page)**<br>Unclassified | **21. No. of Pages**<br>19 | **22. Price**<br>N/A |

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# EXECUTIVE SUMMARY

Since the fatal in-flight fire accident on May 11, 1996, attributed to the improper shipment of chemical oxygen generators, the shipment of oxidizers and pressurized oxygen has been restricted. In early 1998, at Public Hearings convened by the Research and Special Programs Administration (RSPA), interested parties proposed that the transport of pressurized and medical oxygen cylinders be permitted in cargo compartments protected with fire detection and suppression systems (Class C cargo compartments). During the meeting it became apparent that appropriate test data did not exist regarding the performance of oxygen cylinder overpacks in cargo compartments. Consequently, the FAA committed to performing two different test protocols. One protocol entitled “Oxygen Enhanced Fires in LD-3 Cargo Containers” demonstrated the inadequacy of the LD-3 cargo container in controlling the spread of an oxygen fed fire. The second test protocol entitled “Evaluation of Oxygen Cylinder Overpacks Exposed to Elevated Temperature” evaluated the performance of various cylinder overpacks to determine whether a specially designed overpack would prevent a cylinder from overheating and releasing the oxygen into the cargo bin, thus creating a catastrophic fire.

Two series of tests were undertaken in a large industrial furnace to examine the response on unprotected oxygen cylinders and cylinders encased in overpacks, when subjected to elevated temperatures representative of a suppressed Class C cargo compartment fire. In the first test series, unprotected oxygen cylinders were subjected to a furnace temperature of 400°F. When the surface temperature of the cylinder reached approximately 300°F, the pressure relief disc failed and the stored oxygen was discharged. In the second test series, several types of overpacks were tested in a similar manner to determine the degree of thermal protection that the overpacks might provide. The overpacks were designed to carry a 76.5-cubic-foot oxygen cylinder and were the largest size that could be tested in the convection furnace. These overpacks, which are designed mainly to protect oxygen cylinders against impact damage during shipment, prevented pressure relief activation for nearly 60 minutes. By contrast, an unprotected 76.5-cubic-foot oxygen cylinder experienced pressure relief in less than 10 minutes. Two overpacks designed specifically for thermal insulation provided significant additional protection. The tests demonstrated that oxygen cylinder overpacks, particularly when designed to provide thermal insulation, would prevent cylinder overpressurization during a suppressed cargo fire and the potential increase in fire hazards associated with the release of oxygen.

## BACKGROUND

On May 11, 1996, a fatal in-flight fire occurred onboard a ValuJet DC-9. During this accident, an extremely intense fire fueled by solid oxygen generators erupted in the class D compartment, burned out of control into the passenger cabin, and eventually caused the aircraft to crash, resulting in 110 fatalities. In the wake of this accident, the FAA issued a ban on the shipment of oxidizers in all transport aircraft cargo compartments. Industry, pilot, and user groups have requested an exemption to allow for the shipment of bottled oxygen in class C cargo compartments which have fire detection and suppression systems. In a class C compartment, the fire would be detected and agent discharged to extinguish the fire. In the event of a suppressed but not fully extinguished fire, which would be the case if the origin was a deep-seated fire, the temperatures in the compartment could reach 400°F. A deep-seated fire typically involves class A materials such as paper, cardboard, or clothing that burns deep within the contents where it is difficult for an extinguishing agent to penetrate. In contrast, a surface-burning fire involves the combustion of materials more superficially and is much easier to extinguish. The major concern with the shipment of oxygen cylinders under this scenario is that the elevated temperatures could cause the cylinder pressure to increase, resulting in the opening of the pressure relief mechanism. If this occurs, the contents of oxygen could vent directly into the fire, causing a significant intensification of the fire and possibly overtaxing the suppression system.

Different types of pressure relief devices and cylinders are used for storing breathable oxygen. There are two types of rupturing relief valves, a frangible disc that will fail under excessive pressure (typically 2500 psi) and a thermal disc that will fail when the temperature exceeds 165°F or 225°F, depending on the type. There is also a spring-loaded relief valve that will slowly vent the contents of a pressurized cylinder in order to maintain pressure at or below 2000 psi, so that only a percentage of the oxygen would be vented if exposed to elevated temperatures. The rupture disc pressure relief device is the only type used on gaseous oxygen cylinders for crew and passenger breathing systems on commercial transport aircraft, so the research was limited to this type only. Ironically, the rupture disc type pressure relief devices pose a more serious concern in a fire environment because, with these relief devices, it is possible for the entire contents of the oxygen cylinder to be discharged at elevated temperatures.

## FURNACE TEST ARRANGEMENT

The primary focus of the furnace tests was to determine the oxygen cylinder temperature/ pressure required to induce bursting of the pressure relief disc. A parallel activity was also initiated to investigate the hazards associated with gaseous oxygen release from a cylinder during an aircraft cargo compartment fire. Since there are inherent dangers associated with the heating of pressurized oxygen cylinders, it was determined that all cargo fire tests would be conducted using a remotely placed oxygen cylinder. In order to determine the appropriate time and rate of oxygen release during the fire, a series of tests were first run in an industrial furnace to measure the pressure relief response of several different sized cylinders. For safety purposes, the cylinders were emptied of all gaseous oxygen then repressurized with gaseous nitrogen to 1800 psi.

A large, industrial-type high-temperature electric box furnace was used for testing. The furnace was heated by means of coiled electric resistance-type alloy elements that are supported in hard ceramic element holders. The furnace insulation consists of a primary layer of lightweight refractory insulating firebrick which is backed up with 2 inches of high-temperature mineral fiber board. The temperature control system includes two separate zones of heating elements, which are controlled independently with manual rheostat/bimetal percentage-type input controls. In addition, the overall furnace temperature is set by means of an automatic temperature control, which allowed ramping to 400°F in approximately 6 minutes. The internal dimensions of the furnace measured 37.5 by 26 by 25 inches (figure 1).

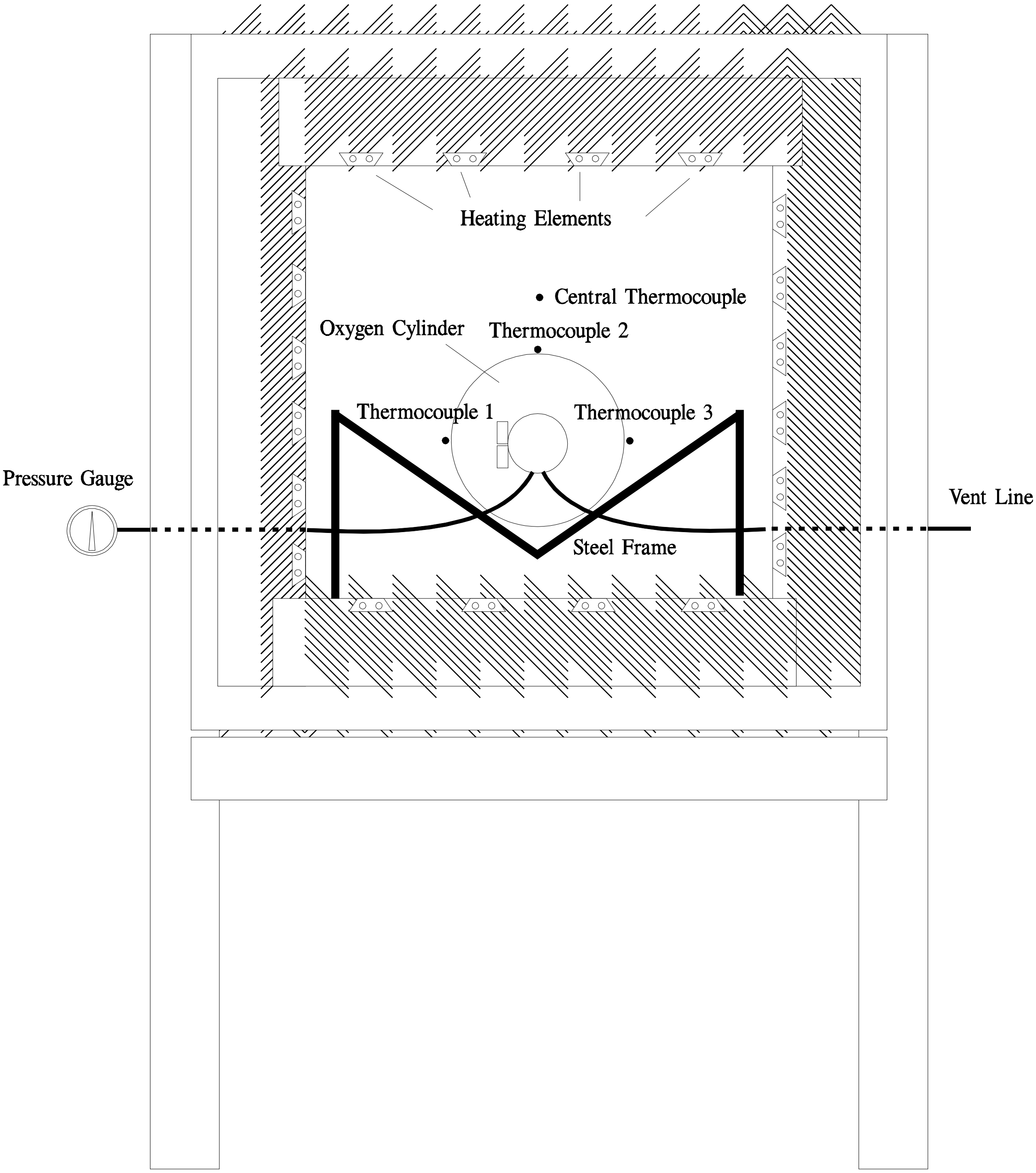

FIGURE 1. TEST FURNACE

During the tests, the cylinders were attached to a steel frame that fit snugly into the test furnace to prevent cylinder movement and subsequent damage to the furnace. The cylinder surface temperature was continuously monitored using three thermocouples attached directly to the cylinders. The furnace temperature was measured with a thermocouple located in the geometric center. A stainless steel line was run from the cylinder valve head, which connected to a pressure gauge, allowing the internal pressure of the cylinder to be measured continuously during the heating process. An additional line was connected to the valve pressure relief port for venting the pressurized gas external to the test furnace to reduce the likelihood of damage to the fragile interior surfaces.

## FURNACE TEST RESULTS

During the first furnace test, a 3HT-type 76.5-cubic-foot cylinder was placed in the test frame holder. The cylinder measured 7.25 inches in diameter by 29.75 inches in length, excluding valve assembly. After start of the test, the rupture disc activated at 9 minutes 53 seconds and required 33 seconds for the cylinder to fully evacuate. The temperature of the cylinder was 285°F, and the temperature inside the furnace was approximately 380°F at the time of release (figure 2). The cylinder internal pressure was approximately 2650 psi at the time of rupture disc activation. A second test was run under nearly identical conditions using a larger 115-cubic-foot cylinder that measured 9.00 inches by 29.56 inches. During this test, the rupture disc activated at 15 minutes 23 seconds and required 1 minute 12 seconds to fully empty. At the time of disc failure, the internal pressure was 2600 psi, and the cylinder surface temperature ranged between 300 and 320°F (figure 3). A final test was run using a small, 11 cubic-foot "walkaround" bottle that is typically used by flight attendants in the event of cabin depressurization. The cylinder was a type 3AA and measured 3.25 by 18.75 inches. A malfunction with the furnace temperature control resulted in a lengthy heating period; however, the rupture disc activated during temperature ramp-up at 17 minutes 12 seconds. The furnace temperature had reached between 350 and 370°F during release, at which point the cylinder surface temperature was between 300 and 325°F. The cylinder required only 5 seconds to fully discharge, and the pressure was observed to be approximately 2500 psi (figure 4). The average rate of release of nitrogen from the three cylinders was calculated to be approximately 2 $ft^3$/sec.

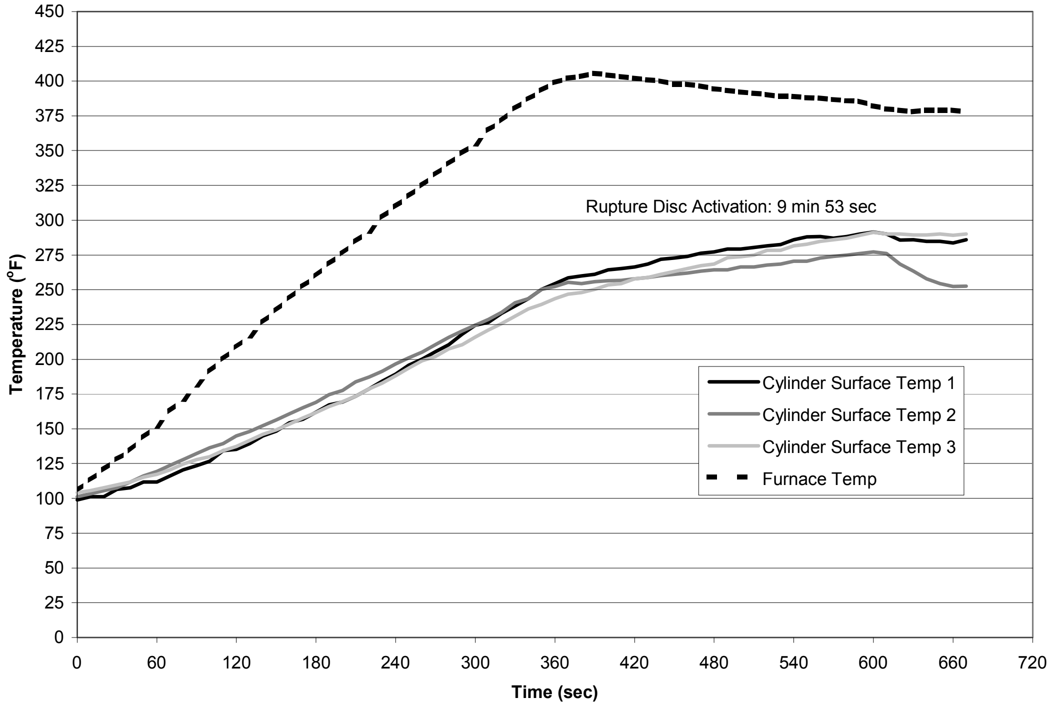

FIGURE 2.  FURNACE TEST RESULTS USING 76.5-CUBIC-FOOT CYLINDER

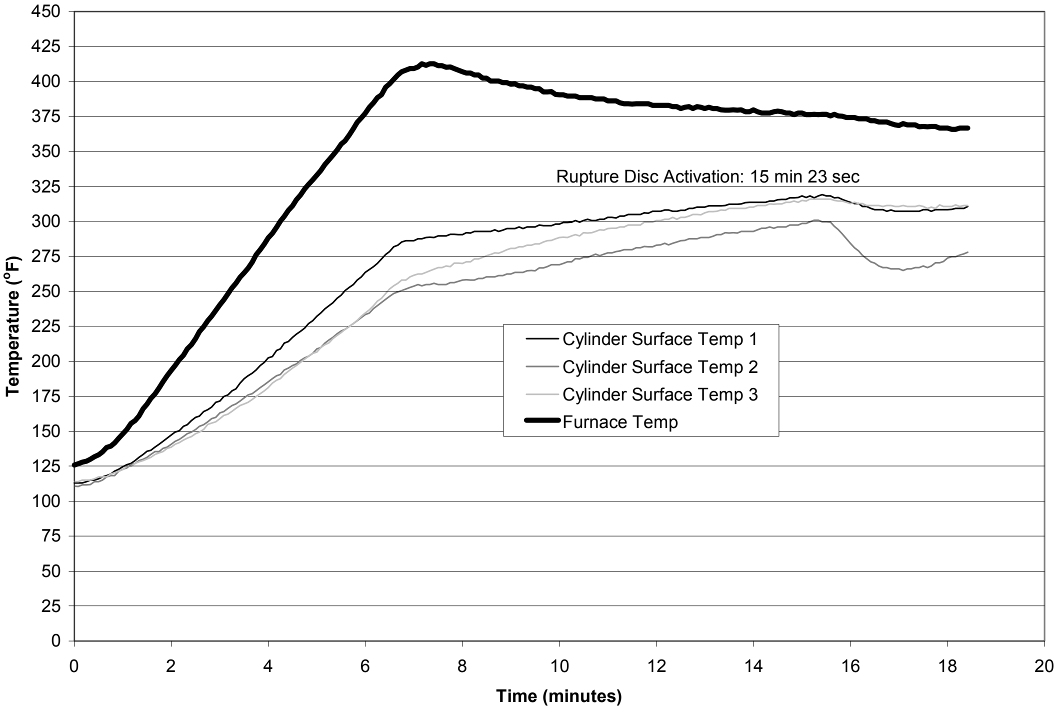

FIGURE 3.  FURNACE TEST RESULTS USING 115-CUBIC-FOOT CYLINDER

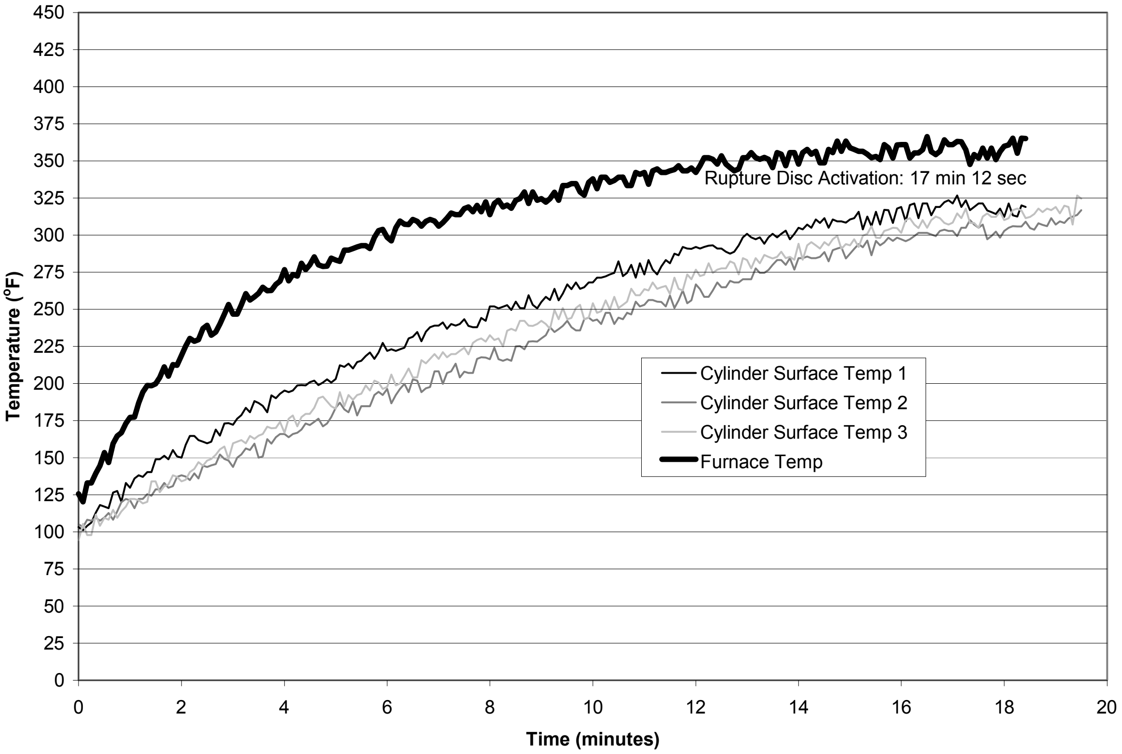

FIGURE 4. FURNACE TEST RESULTS USING 11-CUBIC-FOOT CYLINDER

## TESTING OF ATA SPECIFICATION 300, CATEGORY I OVERPACKS

The furnace tests on unprotected oxygen cylinders demonstrated that a fairly insignificant amount of heat was capable of initiating a rupture disc activation. Additional tests were conducted to evaluate the insulative properties of several currently available overpacks meeting ATA Specification 300, Category I. The most common overpacks are manufactured from plywood laminated with ABS plastic. Other designs include rotationally molded polyethylene, aluminum, fiberglass, and injection-molded plastic. The test overpacks were designed to house the 76.5-cubic-foot cylinder (9 inches by 30 inches). Because some of the overpacks could not be designed properly to provide adequate wall thickness and still remain small enough to fit inside the test furnace, the testing was limited to three particular overpacks: Bill Thomas Associates (BTA), Viking Packing Specialists, and Anvil. During the tests, the overpacks with stored oxygen cylinder were subjected to the identical 400°F environment as the tests performed on the unprotected cylinders. Small access holes were drilled into each overpack and fitted with compression-type bulkhead fittings to allow for the passage of the three thermocouple wires used to monitor the cylinder surface temperature.

## OVERPACK TEST EXECUTION

During the first test, an empty 76.5-cubic-foot oxygen cylinder was placed inside the Viking overpack, and the three thermocouples were attached to the cylinder surface. The overpack exterior was constructed of 0.1875-inch-thick polyethylene thermoplastic. Polyethylene foam was glued to the interior side of the overpack for impact resistance (figure 5). Within 10 minutes of the start of the test, the furnace temperature rose to 350°F (figure 6). At approximately 60 minutes, the cylinder surface temperatures were observed to be below the point of rupture disc activation, ranging from 230°F to 280°F. However, significant quantities of smoke began to emerge from the test furnace vents, causing the test to be terminated at 69 minutes. The maximum surface temperature was 300°F. Posttest examination revealed the entire overpack had melted and formed a plastic coating around the cylinder, with excess material puddled at the floor of the test furnace.

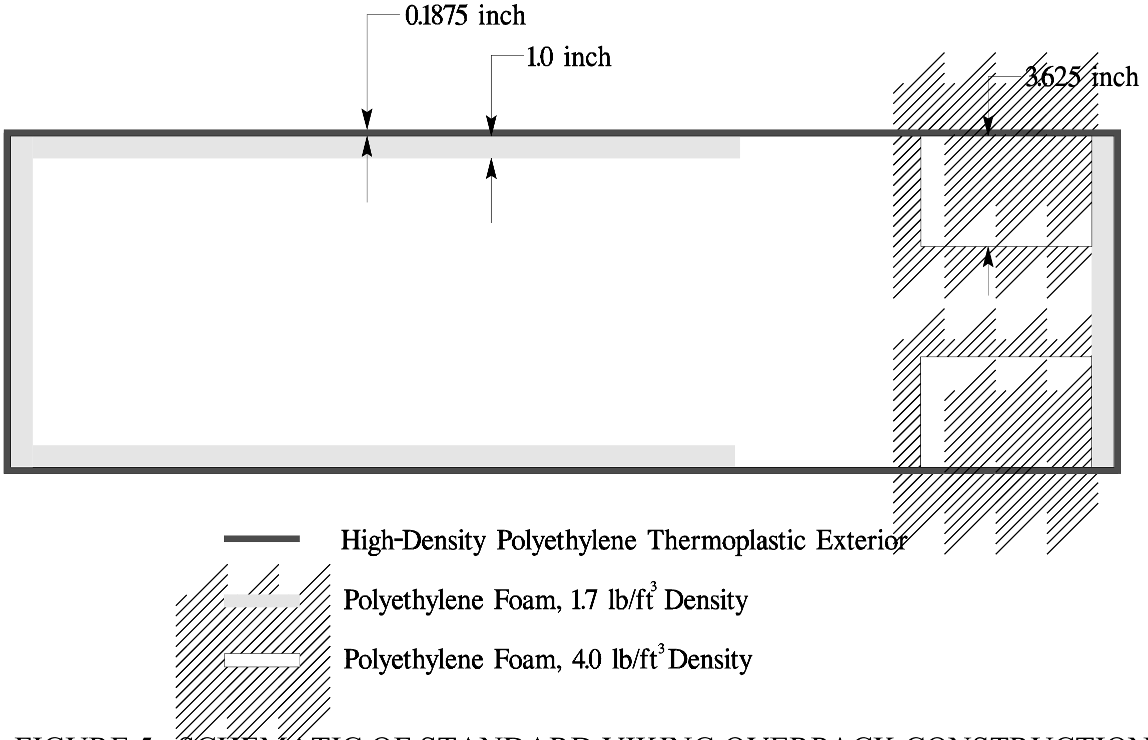

FIGURE 5. SCHEMATIC OF STANDARD VIKING OVERPACK CONSTRUCTION

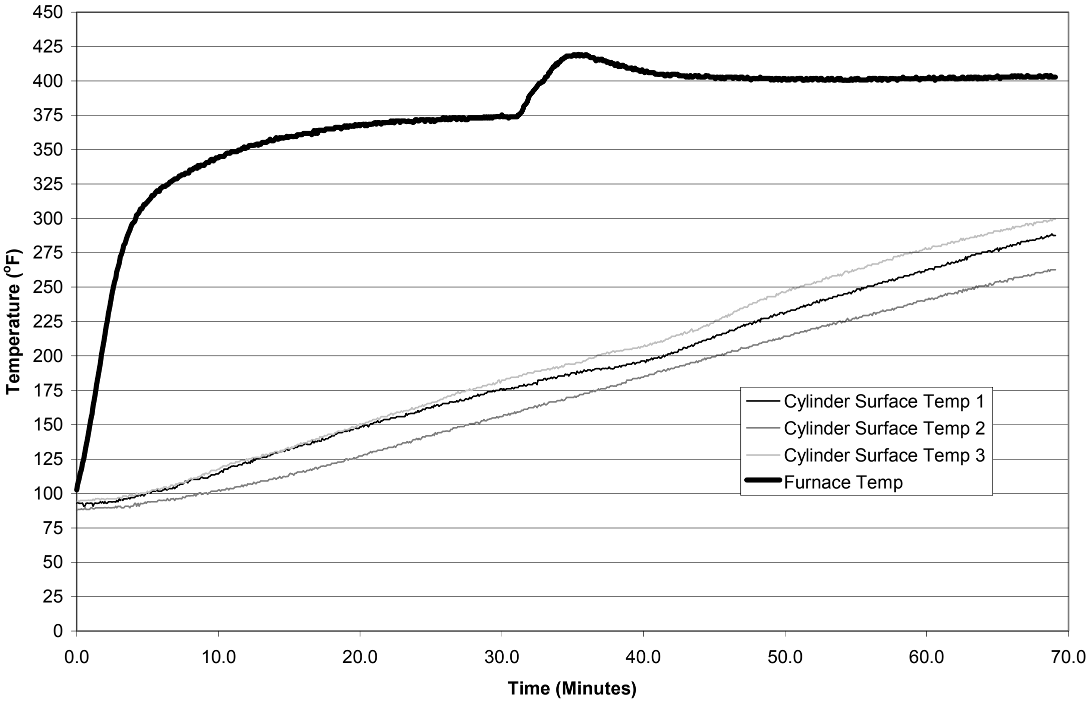

FIGURE 6. FURNACE TEST RESULTS USING 76.5-CUBIC-FOOT CYLINDER INSIDE STANDARD VIKING OVERPACK

Subsequent tests were conducted on ATA Specification 300 overpacks in which the 76.5-cubic-foot cylinder was charged with nitrogen. A line piped from the relief valve through a bulkhead fitting in the overpack to a furnace access hole allowed pressure venting external to the test furnace. Cylinder pressure was monitored continuously through an additional line from the valve to an externally mounted pressure gauge. Due to a problem with the nitrogen charging system, the cylinder could only be charged to 1500 psi and not the full 1800 psi normally achieved. Although the cylinder was not fully charged, the tests were conducted with thermocouples attached to the surface of the cylinder to monitor its temperature. This would provide an accurate estimate of when the pressure relief mechanism would normally activate if the cylinder was initially fully charged to 1800 psi.

During the second test, the charged cylinder was loaded into the overpack supplied by Bill Thomas Associates (manufactured by A&J Manufacturing Company). This overpack was constructed of plywood laminated with fiberglass matting impregnated with epoxy resin. On the interior of the overpack, urethane foam was glued to the inner sidewalls to provide the required impact protection. A plywood brace was also mounted near one end to support the neck of the cylinder, and a 2-inch-thick layer of polyethylene foam was glued to the other end (figure 7). After placing the cylinder/overpack on several bricks inside the test furnace, the unit was ramped to 400°F (figure 8). After 60 minutes, the cylinder surface temperature had reached 300°F, the temperature at which the relief disc typically fails (due to the slightly lower pressure inside the bottle at the start of the test, the pressure was below the level needed to activate the burst disc at this temperature). The test was terminated, and the overpack was inspected. The inspection revealed slight delamination of the fiberglass exterior surface, as the heat began to break down the epoxy resin. The interior of the overpack revealed no damage to the urethane foam; however, the polyethylene foam used in the end had completely melted.

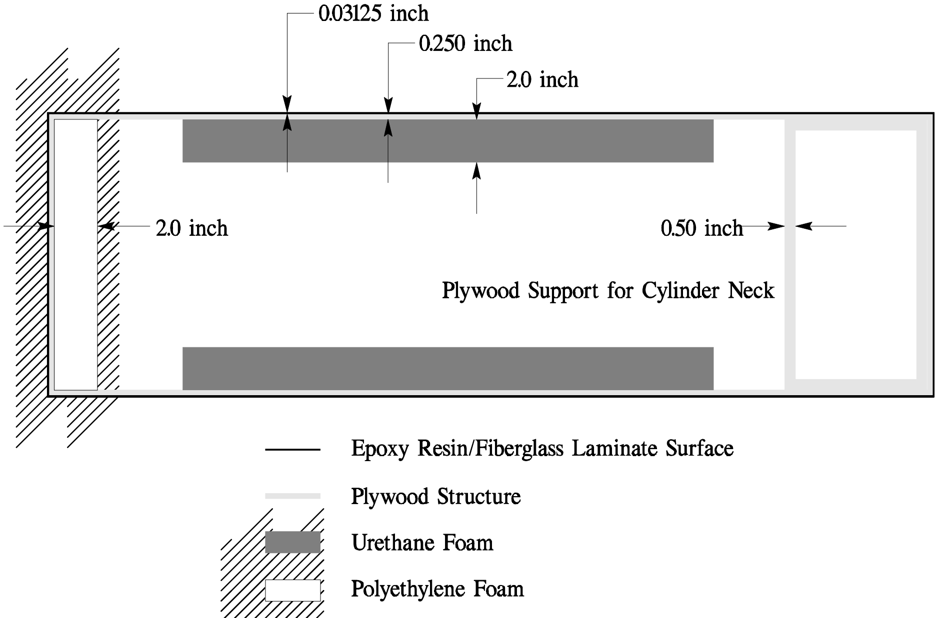

FIGURE 7. SCHEMATIC OF BILL THOMAS ASSOCIATES OVERPACK CONSTRUCTION

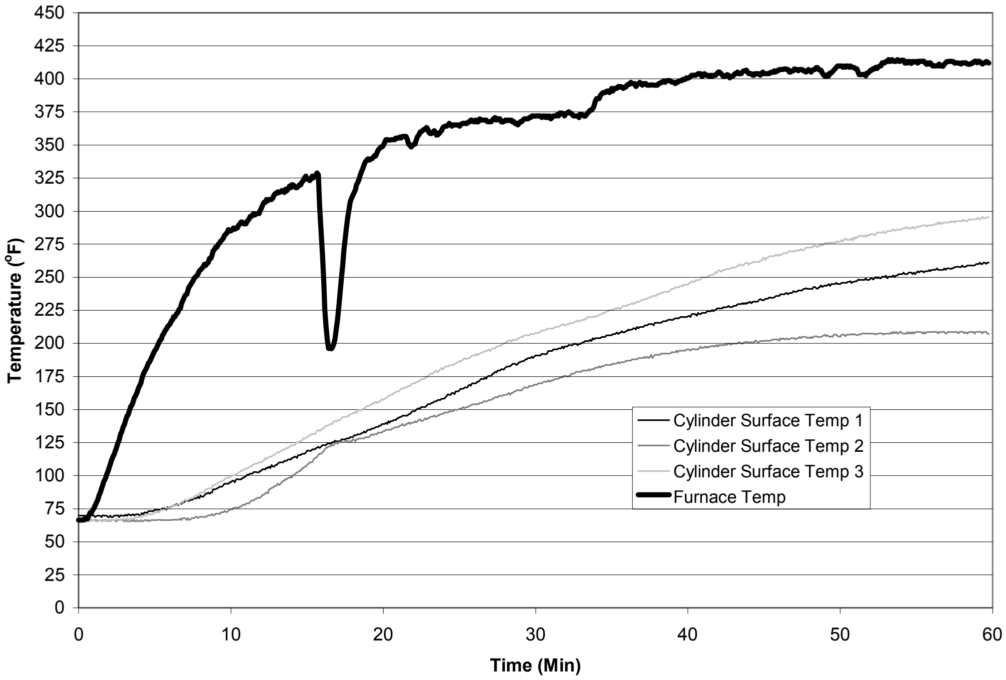

FIGURE 8. FURNACE TEST RESULTS USING 76.5-CUBIC-FOOT CYLINDER INSIDE BTA OVERPACK

During the next test, the charged cylinder was loaded into the Anvil overpack. This unit resembled the BTA overpack in that it utilized plywood construction faced with a thermoplastic (figure 9). Approximately 1-inch-thick urethane foam was glued to the interior side of the plywood. Upon test initiation, the furnace temperature approached 400°F in approximately 15 minutes (figure 10). During the test, the temperature of the cylinder surface reached a maximum of 300°F at 90 minutes, at which point the test was terminated. A posttest inspection revealed melting of the exterior thermoplastic surface, exposing the plywood structure in several areas. In addition, the glue used to adhere the urethane foam to the plywood interior surface had melted into a black oily substance, allowing the foam to become displaced in several areas, especially the upper surface.

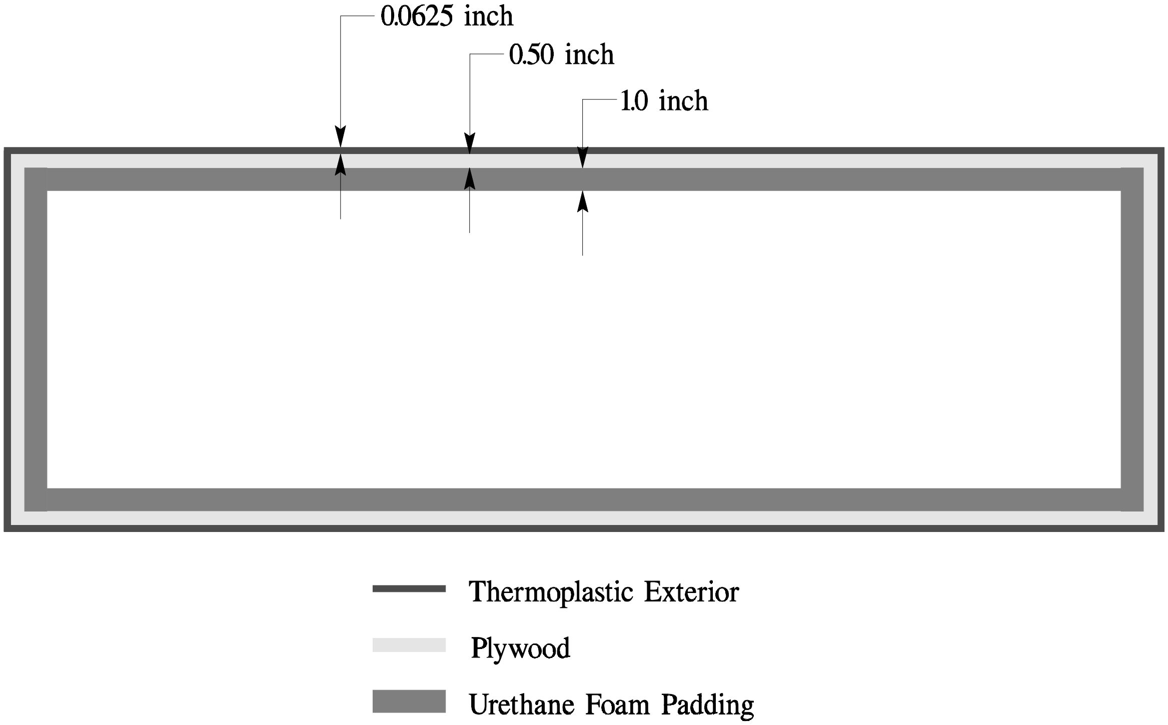

FIGURE 9. SCHEMATIC OF ANVIL OVERPACK CONSTRUCTION

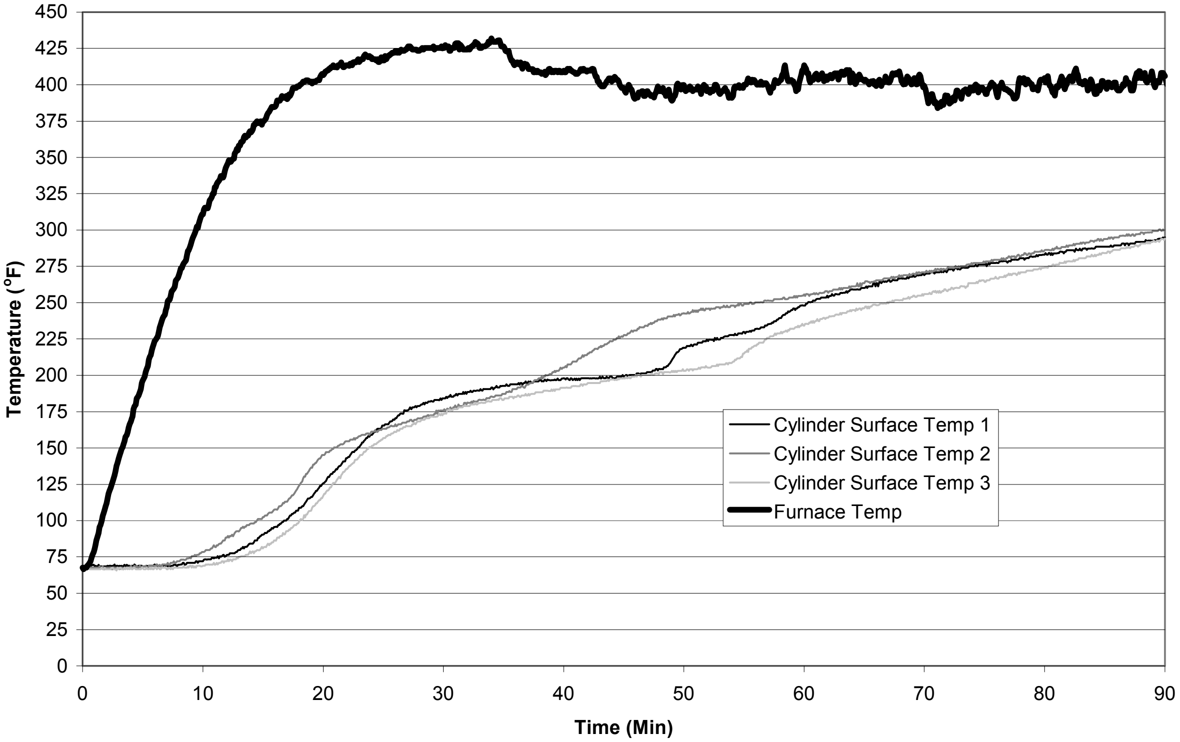

FIGURE 10. FURNACE TEST RESULTS USING 76.5-CUBIC-FOOT CYLINDER INSIDE ANVIL OVERPACK

In an effort to evaluate the potential increase in thermal protection offered by a modified system, additional tests were performed on overpacks specifically designed for this purpose. The overpacks were manufactured by Viking and contained an array of materials aimed at insulating a cylinder placed inside. During the first test, the empty 76.5-cubic-foot oxygen cylinder was placed in the overpack which was placed on several stacked bricks inside the furnace. A bulkhead compression fitting mounted to the overpack allowed for the passage of thermocouple wires for the purpose of measuring the cylinder surface temperature. The overpack exterior consisted of a heat-resistant thermoplastic known as Kydex. A 1-inch-thick fiberglass batt material was sandwiched between the exterior layer of Kydex and an additional layer of Kydex of the same thickness (figure 11). A layer of polyethylene foam was glued to the internal layer of Kydex to provide impact resistance. After test initiation, the furnace temperature reached 400°F in 10 minutes. The test was allowed to progress for approximately 60 minutes, at which point large quantities of smoke began to appear from the test furnace vents. The temperature of the cylinder surface never exceeded 90°F during the test (figure 12). A posttest inspection revealed the source of the smoke was from the two ends of the overpack which had come in contact with the furnace heating elements. The heated thermoplastic lost some of its structural integrity, allowing the ends to sag and eventually come in contact with the furnace surface. In addition, the latch mounts had pulled away from the overpack due to the rivets pulling through the heat-softened thermoplastic exterior, exposing the fiberglass insulation. The interior of the overpack was undamaged.

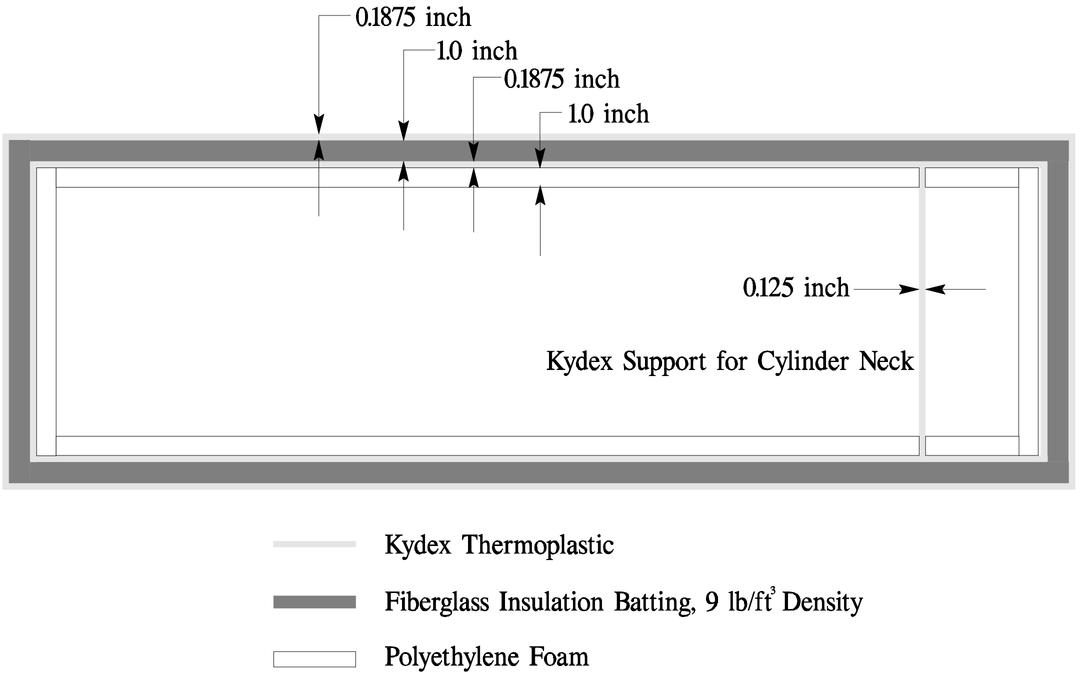

FIGURE 11. MODIFIED VIKING OVERPACK USING FIBERGLASS BATT INSULATION

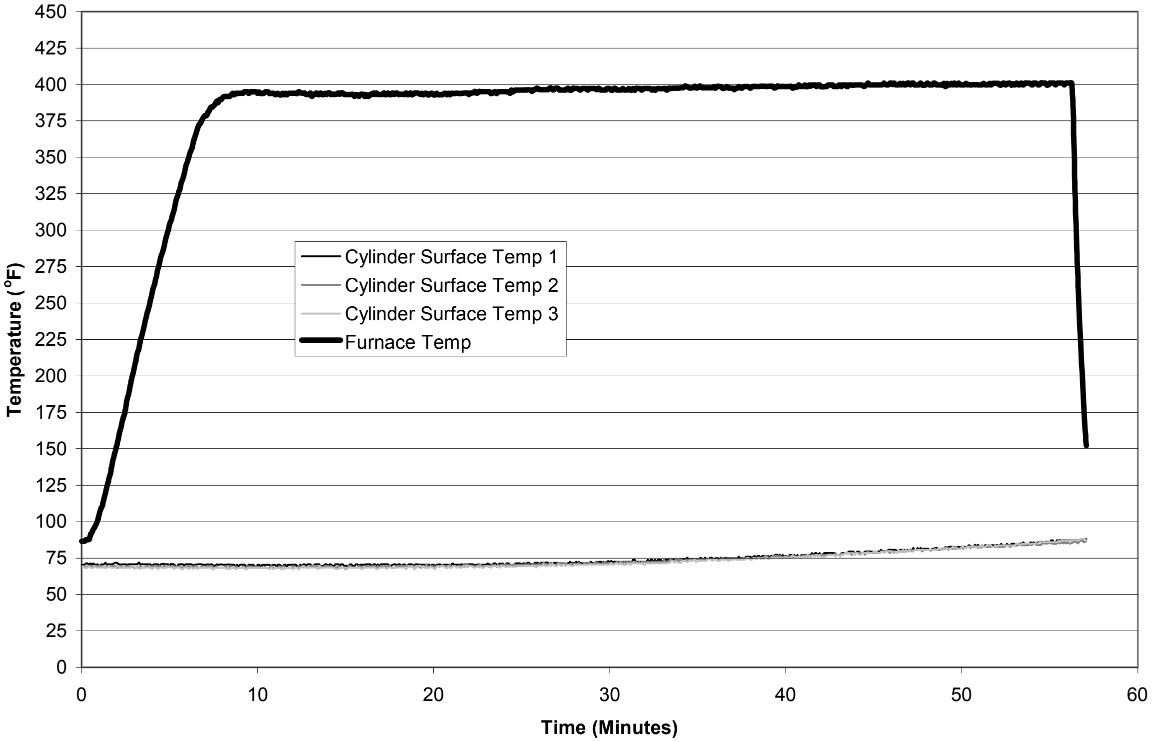

FIGURE 12. FURNACE TEST RESULTS USING 76.5-CUBIC-FOOT CYLINDER INSIDE FIBERGLASS INSULATION VIKING OVERPACK

A subsequent test was performed on an upgraded version of the thermally protected overpack. The new design utilized an aluminum-faced rigid insulating foam in place of the fiberglass batting (figure 13). External and internal layers of Kydex surrounded the rigid foam. After loading the charged cylinder into the new-design overpack, the furnace was activated and the temperature approached 400°F in approximately 15 minutes. During the test, the temperature of the cylinder surface reached a maximum of 210°F at 90 minutes, at which point the test was terminated. A posttest inspection revealed the external layer of Kydex had melted and burned in several locations, exposing the aluminum foil face of the rigid foam insulation panel which had remained intact. The inner layer of Kydex was slightly warped but had not changed color. Although the cylinder surface temperatures were kept relatively low, the cylinder and valve assembly had become slightly discolored as a result of combustion of the Kydex and possibly the rigid foam panel. Due to a malfunction with the data acquisition, the temperature versus time data obtained during the test could not be retrieved. However, these data were observed during the test and indicated a gradual increase of the cylinder surface temperature up to a maximum of 210°F at 90 minutes.

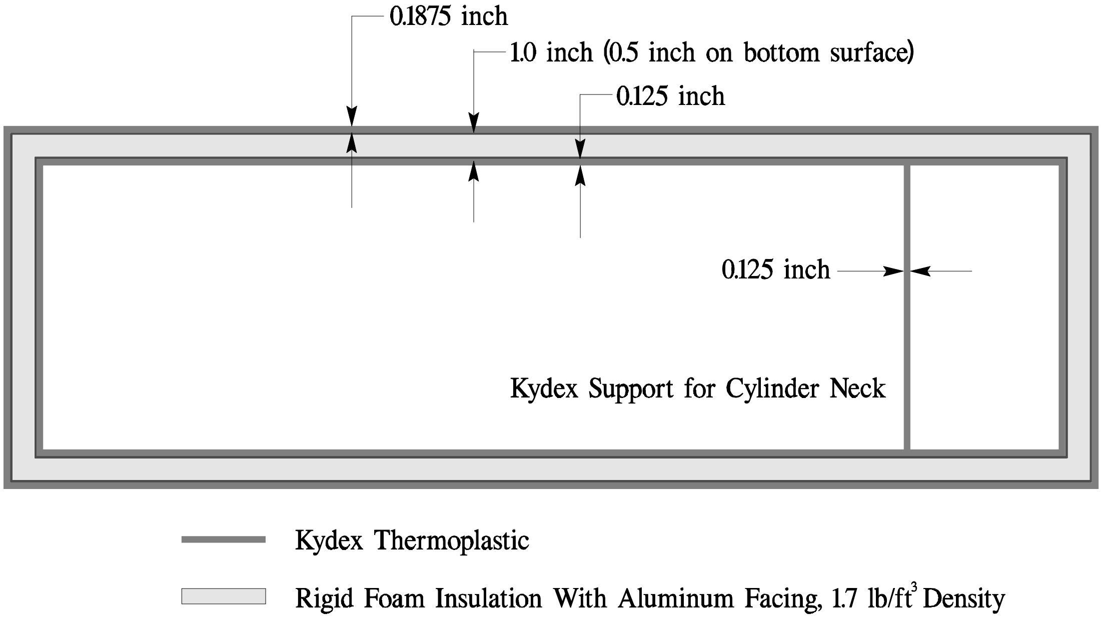

FIGURE 13. MODIFIED VIKING OVERPACK USING RIGID FOAM INSULATION

## CONCLUSIONS

Past research has shown that temperatures can reach 400°F during suppression and control of fires in class C cargo compartments, which are equipped with detection and suppression systems. During initial furnace tests, it was revealed that a fairly insignificant amount of heat (300°F cylinder surface temperature) was capable of causing rupture disc activation in various sized unprotected oxygen cylinders. Upon rupture disc activation, the entire contents of the cylinder will discharge in short duration. Further tests conducted on currently available overpacks have shown that a significant delay in the activation of cylinder relief discs is possible. Two overpack designs provided between 60 and 90 minutes of protection. An overpack designed specifically for thermal protection was capable of maintaining very low cylinder temperatures (less than 100°F) for 60 minutes, suggesting extended periods of cylinder protection are achievable.

Oxygen cylinder overpacks designed for thermal protection could prevent the overpressurization of cylinders during a suppressed cargo fire and the potential increase in fire hazards associated with the release of oxygen. A new standard for overpack materials should reflect extended periods of elevated temperatures typical of a suppressed class C compartment fire. In addition, the overpack materials should be capable of withstanding open flames for a short duration, which could result when a cargo fire originates, prior to fire detection and activation of the suppression system.