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Pipe Overpack Container Fire Testing: Phase II-A

Hector Mendoza, Victor G. Figueroa, Walter Gill, Douglas J. Ammerman, and Scott Sanborn.

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Pipe Overpack Container Fire Testing Phase II-A

Hector Mendoza
Victor G. Figueroa
Structural and Thermal Analysis

Walter Gill
Fire Science and Technology

Douglas J. Ammerman
Scott Sanborn
Environmental Safety and Testing

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-MS0718

Abstract

The Pipe Overpack Container (POC) was developed at Rocky Flats to transport plutonium residues with higher levels of plutonium than standard transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP) for disposal. In 1996 Sandia National Laboratories (SNL) conducted a series of tests to determine the degree of protection POCs provided during storage accident events. One of these tests exposed four of the POCs to a 30-minute engulfing pool fire, resulting in one of the 7A drum overpacks generating sufficient internal pressure to pop off its lid and expose the top of the pipe container (PC) to the fire environment. The initial contents of the POCs were inert materials, which would not generate large internal pressure within the PC if heated. However, POCs are now being used to store combustible Transuranic (TRU) waste at Department of Energy (DOE) sites. At the request of DOE's Office of Environmental Management (EM) and National Nuclear Security Administration (NNSA), SNL started conducting a new series of fire tests in 2015 to examine whether PCs with combustibles would reach a temperature that would result in (1) decomposition of inner contents and (2) subsequent generation of sufficient gas to cause the PC to over-pressurize and release its inner content. In 2016, Phase II tests showed that POCs tested in a pool fire failed within 3 minutes of ignition with the POC lid ejecting. These POC lids were fitted with an all-metal (NUCFIL019DS) filter and revealed that this specific filter did not relieve sufficient pressure to prevent lid ejection. For the test phase discussed in this report, Phase II-A, the POCs are exposed to a 30-minute pool fire, with similar configurations to those tested in Phase II, except that the POC lids are fitted with a hybrid metal-polyethylene (UT9424S) filter instead. This report will: describe the various tests conducted in Phase II-A, present results from these tests, and discuss implications for the POCs based on the test results.

ACKNOWLEDGMENTS

The authors of this document would like to thank Mr. James O'Neil of NNSA and Dr. Robert C. Nelson of DOE EM for their close collaboration from the beginning of this test program. It was their motivation and knowledge of the facts surrounding this work which lead to funding and focus of this test program. Many thanks to Matthew Weber of NNSA as well for programmatic management of the program. We would also like to thank Pete Carson of Los Alamos National Laboratories who collaborated closely with Sandia National Laboratories in all aspects related to operation and staging of POC drums at Los Alamos National Laboratories. We would also like to thank L. Wes Chilton for assembling the test units; Richard B. Simpson, Jason Everett, Alvaro Cruz-Cabrera, and Michael Montoya for visible and IR video recording and editing; and Sylvia Gomez-Vasquez for running the tests. Other test support was provided by the ECI TTC crew.

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NOMENCLATURE

DAQ	Data Acquisition
DFT	Directional Flame Thermometer
DOE	Department of Energy
EM	Environmental Management
FLAME	Fire Laboratory for Accreditation of Models and Experiments
IR	Infrared
LANL	Los Alamos National Laboratories
MIDAS	Mobile Instrumentation and Data Acquisition System
MOD	Modifications
NNSA	National Nuclear Security Agency
NQA	Nuclear Quality Assurance
PC	Pipe Container
POC	Pipe Overpack Container
RFP	Rocky Flats Plant
SNL	Sandia National Laboratories
TRU	Transuranic
TC	Thermocouple
TTC	Thermal Test Complex
WIPP	Waste Isolation Pilot Plant

1. INTRODUCTION

The Pipe Overpack Container (POC) was developed at Rocky Flats to transport plutonium residues, which contain higher levels of plutonium than standard TRU waste, to the Waste Isolation Pilot Plant (WIPP) for disposal. The POCs consist of an inner Pipe Container (PC) surrounded by fiberboard (Celotex®) and plywood dunnage inside of a 7A drum (see Figure 1). The PC was designed to maintain separation of fissile material and to provide shielding from radiation. In 1996 Sandia National Laboratories (SNL) conducted a series of tests to determine the degree of protection POCs provide during storage accident events. These tests were conducted to support use of POCs by Rocky Flats Plant (RFP) to package and ship plutonium residues. The POCs used in these tests were fitted with the all-metal filter (NUCFIL019DS) on the drum lid as is currently being used on POCs at storage sites. One of these tests exposed four of the POCs to a 30-minute engulfing pool fire, resulting in one of the drums (fitted with the metal filter) generating sufficient internal pressure to pop off its lid and expose the top of the PC to the fire environment. The PC contents in this test were inert materials that would not generate significant pressures within the PC. Even if the O-rings and filter failed, only a small fraction of the radioactive material contained within the PC was predicted to be released. These test results were reported in 1997 for the RFP (Ammerman, Bobbe, Arviso, & Bronowski, 1997) and are also available in DOE STD-5506-2007 (DOE, 2007).

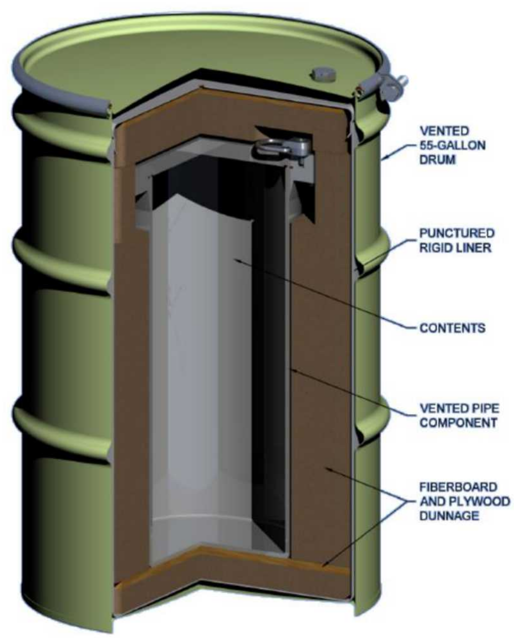


Figure 1. POC Assembly.

Further review of ongoing use of POCs showed that current generating facilities were utilizing the POC for storage of reactive salts and combustibles, and their further shipment to WIPP. The use of the POCs for combustibles was not considered an appropriate extension of the 1996 SNL tests, and the damage ratios (DRs) and aerosol release fractions (ARFs) could consequently be significantly different for this application and from what is quoted in DOE STD-5506.

The generating facilities, as well as WIPP, would like to be able to claim that some level of protection is provided by the POC for thermal assaults that could occur within DOE storage facilities. To gather information to support this claim, a storage drum test program headed by the DOE Office of Environmental Management (EM) and the National Nuclear Security Agency (NNSA) was established for the POCs with combustible contents. In 2015, SNL started conducting fire tests with POCs in support of the EM/NNSA test program.

Fire tests on POCs with combustible contents conducted by SNL in 2015 and 2016 demonstrated that, for a POC inside of a pool fire, pressure build-up inside the POC drum is sufficient to eject the drum lid and other components inside the POC within three minutes into the test. With no external intervention, the lid ejection ends up exposing the PC to high enough temperatures that would result in a DR ~ 1 and an ARF > 0. One solution to prevent the drum lid from ejecting is to change the current POC drum filters with an alternate filter design that could allow quick depressurization of the fully engulfing POC drum early in the fire. An alternate filter (UT9424S) with a hybrid metal-polyethylene design has been proposed as a replacement to the current all-metal lid filters (NUCFIL019DS) to prevent lid ejection on POC drums in a pool fire. This report describes the various tests conducted in Phase II-A of the EM/NNSA test program on POCs and 7A drums using a UT9424S filter on the drum lids to examine the performance of the drums in a pool fire with combustibles inside. Details of the test along with results of their implications are discussed as part of this report.

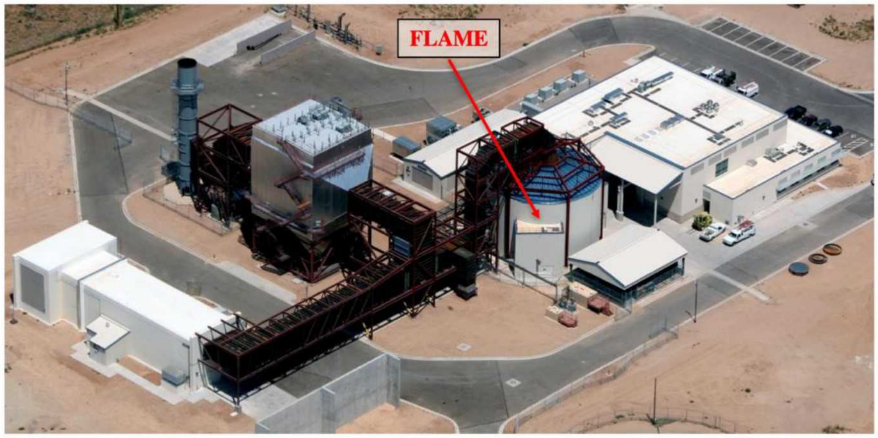
2. OVERVIEW OF FIRE TESTS

In the Phase II test series, POCs using an NUCFIL019DS drum lid filter were exposed to an engulfing pool fire but resulted in lid ejection. The primary goal of this test series, Phase II-A, was to determine the response of a POC using a UT9424S filter on the drum lid instead of the NUCFIL019DS filter currently being used on POCs at storage sites. Specifically, the overall goal of this test phase was to determine whether the use of a UT9424S filter would be sufficient to provide enough pressure relief from the pyrolysis gases produced inside a POC drum during a fire to prevent lid ejection when engulfed in a 30-minute pool fire.

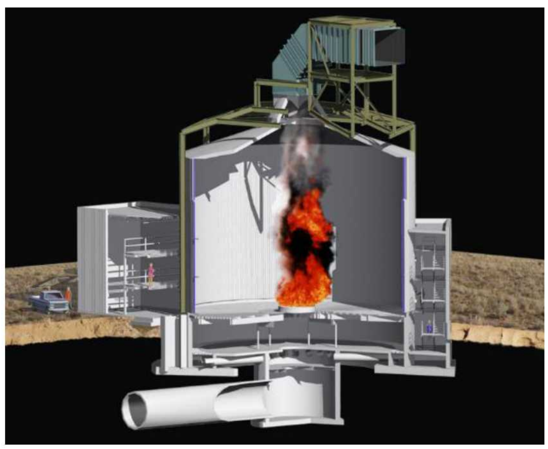
2.1. Test Facility

A total of four tests were performed at SNL as part of this test phase. All tests were conducted inside the Fire Laboratory for Accreditation of Models and Experiments (FLAME) test cell located in SNL's Thermal Test Complex (TTC), shown in Figure 2. FLAME is a vertical wind tunnel design for conducting pool fire tests under calm conditions. The test cell has an inner diameter of 18.3 m and is 12.2 m tall along its perimeter walls. The walls are made of steel channel sections and are filled with water to keep the perimeter of the facility cool. At the top of these walls, the ceiling slopes upwards (~18º) from the end of the walls to a height of 15 m over the center of the facility. A round hole 4.9 m in diameter at the top of the test cell transitions to a chimney duct, allowing fumes to escape the test cell.

Most of the test cell floor is made up of metal grid panels. At the center of the grid floor of the test cell is a fuel pan or gas burner. FLAME works with either a 3 m diameter gas burner (H2, CH4, etc.) or a liquid fuel pool (JP8, Jet-A, methanol, etc.). For this test, only the liquid fuel pool was used. Air channeled vertically through the grid floor, via a vent ring several feet below the floor and adjacent to the perimeter walls, allows air to be entrained naturally into the fire, as it would be in an outdoor fire.



(a)



(b)

Figure 2. (a) Location of FLAME within the TTC and (b) interior of the FLAME facility.

2.2. General Test Layout

Figure 3 shows the typical test layout for Tests #1 and #3 of this phase. Starting from the bottom up, the test layout consisted of: a 3 m circular fuel pan used to create the fuel pool, an empty 55-gallon drum with a hole on the lid to prevent pressure buildup, and a filled POC drum which is concentrically placed above the empty drum but on top of a table. The configuration for Tests #2 and #4 varied slightly from Tests #1 and #3, as shown in Figure 4. For Test #2, the setup of Tests #1 and #3 was used, but a 7A drum filled with typical combustibles was added on the grid floor outside of the fuel pan. Test #4 did not include any POCs and instead used a 7A drum filled with typical combustibles on top of the empty drum at the center of the pool. Furthermore, a 7A drum was also added on the grid floor outside of the fuel pan for Test #4.

In all tests, the 3 m circular fuel pan shown at the center was initially filled with Jet-A fuel. The pool was ignited with a torch that was started remotely. To maintain the drum of interest fully engulfed throughout the test, a remote refueling system intermittently added fuel to the pool in discrete amounts throughout the tests to maintain a steady pool depth. To limit the fire duration to 30 minutes, the pool has a drain system that dumped all remaining fuel at the end of the test, almost immediately terminating the fire at the point of dumping. Typical fuel consumption rate for these tests was about 0.3 kg/sec.

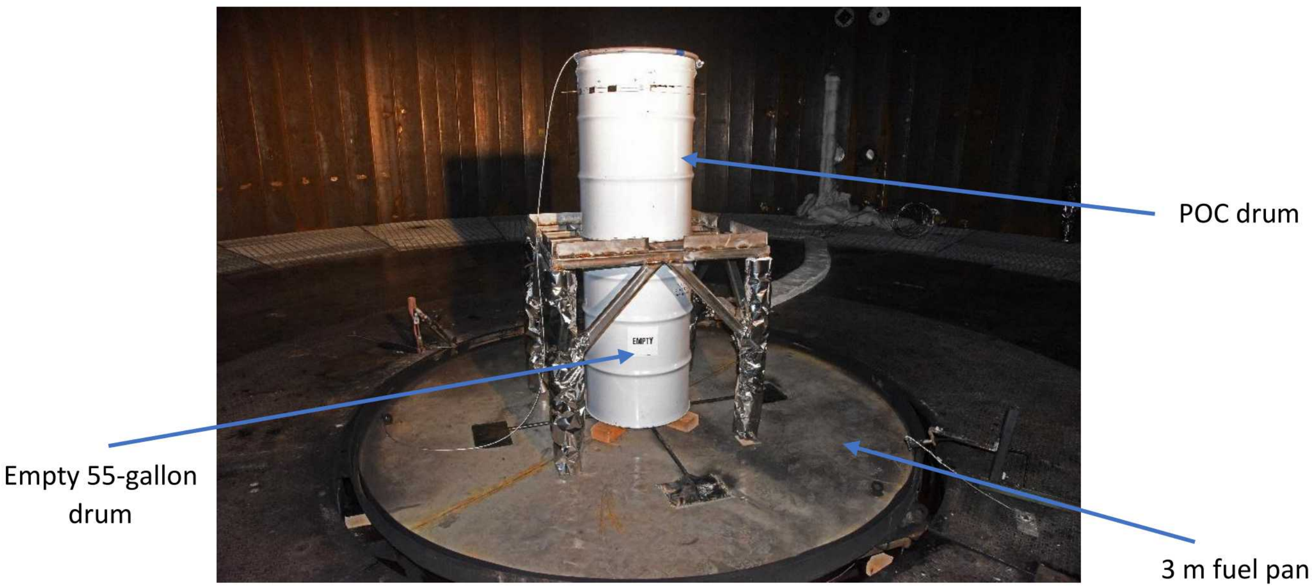


Figure 3. Typical fuel-pool/drum layout for Tests #1 and #3 inside of FLAME.

Figure 4. Typical fuel-pool/drum layout for Test #2 and Test #4 inside of FLAME.

While a variety of configurations exist for stacking POC drums, the vertical configurations shown in Figure 3 and Figure 4 are based on what is typically seen in storage facilities. These test configurations intended to mimic how drums are typically stacked on top of each other, in a drum-array arrangement within a single drum level, as shown by the storage arrangements exemplified in Figure 5. For drums at the center of the pool in all tests of this phase, only the top drum was loaded and instrumented. The reason for only loading and instrumenting the upper drum was because that drum would be the one to observe the highest flame temperatures in a typical storage fire should there be a fuel pool accumulated at the base of the bottom drum. This hotter region in the top drum occurs because pool fires typically consist of a relatively cold plume adjacent to the surface of the pool called the vapor dome which is caused by the evaporating fuel. Near the edge of the base of a quiescent pool fire, where the plume diameter is largest, air entrainment deep into the plume at this height is limited. Thus, combustion is efficient only near the edges of the fire where the air can effectively mix with fuel vapor. The lack of air inside the vapor dome prevents efficient combustion and thus results in a cooler region. Further up from the fuel pool, air entrains more readily further into the plume and therefore creating hotter regions deeper into the fire as a result of more efficient combustion. The height of the cold region is greatest at the center of the fuel pool and decreases towards the edge of the pool. Thus, the shape of the cooler region resembles a dome. Objects submerged within this vapor dome, as is the bottom drum in all test configurations of this phase, experience lower heat fluxes than other objects outside of this region within the fire. Consequently, drums stacked one meter above the fuel pool observe the most conservative conditions, which is why the upper drums are selected as the test subjects (Gritzo, Nicolette, Murray, & Moya, 1995).

(a)

(b)

Figure 5. Examples of drums in typical storage configuration. (a) is at LANL, (b) is at Savannah River Site (SRS).

The lower, empty drum placed in the tests was to better simulate the configurations commonly used in storage facilities. For the same reasons of trying to create the most conservative conditions a POC can experience in a test facility during a pool fire, there were no drums immediately adjacent to any of the test drums as shown in the arrays of the storage facility example in Figure 5. However, for Tests #2 and #4, aside from having the drums in the center of the pool fire, a second drum was tested in the vicinity of but outside the pool. The distance for the second drum in Test #2 was chosen so that the drum would receive approximately 45 kW/m^2 of the radiant heat flux from the fire. Similarly, the distance for the second drum in Test #4 was chosen so that it would receive approximately 35 kW/m^2. Lastly, these peripheral drums were oriented to where the UT9424S lid filter was facing the fire.

3. SUMMARY OF FIRE TESTS

As stated above, in Phase II, a POC using a NUCFIL019DS lid filter and exposed to a pool fire resulted in lid ejection within 3 minutes. The goal of Phase II-A was to test whether the use of a UT9424S filter (instead of a NUCFIL019DS filter) is sufficient enough to relieve pressure buildup to prevent lid ejection on a POC or 7A drum when engulfed in a 30-minute pool fire. The first three tests in this phase utilized the UT9424S filter on POC drums, while the fourth test utilized the filter on two 7A drums. Table 1 below summarizes all four tests performed in this phase and organizes them based on: test number, drum type, drum contents, radial location of test subject relative to the center of the pool, and the corresponding pool fire heat flux imposed on the test drum. To monitor the conditions during each test, pressure and temperature were recorded at various locations. Specifically, Test #3 and #4 did not collect temperature data, but Test #1 and #2 used SNL quality assurance processes to collect quality temperature measurements. Pressure data was collected for Test #1 and #2 using a pressure port on the POC drum, while data loggers inside the POC and inside the PC were used for Test #3. Lastly, as part of SNL quality assurance processes, all drums were weighed before and after each test to determine mass loss. For Test #4, no pressure or temperature instrumentation was used and only pre/post-test masses were recorded. The details of the test setup are further described in the subsections below.

Table 1. Summary of Tests

Test #	Type	Contents: 55-gallon drum/PC	Radial Location (m)	Heat Flux (kW/m^2)
1	POC	Standard/cheesecloth	0	80
	POC	Standard/cheesecloth	0	80
2	7A #2	Typical combustibles	2	45
3	POC	Standard/cheesecloth	0	80
	7A #1	Typical combustibles	0	80
4	7A #3	Typical combustibles	2.5	35

3.1. POC and 7A Dum Contents

In all tests, the POCs and 7A drums were loaded with typical combustibles used in each respective drum. For POCs, “typical” implied cellulose and plastic materials, which is the most prevalent content inside POCs based on TA-55 inventory. Pete Carson, a POC-inventory/POC-content SME from TA-55 in Los Alamos National Laboratories, further specified “typical” loading conditions for the PC as having a plastic bag-out-bag filled with cheesecloth, which is what is used for the PCs in this test phase. Figure 6 shows an example of one of the PCs with the filled bag-out-bag laying on top, just before placing it inside the PC. For the 7A drums, contents were of mixed items that consisted of approximately 50% cellulose and 50% plastics by volume. The mixed items were selected based on what can typically go in these types of drums, and Figure 7 shows an example of the contents used in the 7A drums for Test #4.

Figure 6 . POC with filled bag-out-bag.

Figure 7. Typical contents of 7A drums.

3.2. Drum Closure

Previous fire testing demonstrated the importance of correct drum-closure procedures, therefore, staff from LANL and WIPP monitored the procedure for tightening the drum lid rings for these tests. The specifications required a 55 ft-lb torque on the lock ring bolt (plus the tool uncertainty, which was ± 2.5 ft-lbs for the tool used in these tests) when a 5 mm lock ring gap was attained. To prevent damage to the lock ring and bolt when trying to achieve the 5mm gap as the lock ring was tightened, the lock ring was hammered with a mallet around the drum ring several times throughout the tightening process allowing the lid gasket to adjust. Figure 8 shows how calipers were used to ensure the 5 mm gap on the lock ring, and Figure 9 shows how the lock ring bolt was torqued to 57.5 ft-lbs once the 5 mm gap was attained. This procedure was followed on all POC and 7A drums.

Figure 8. Measurement of lock ring gap.

Figure 9. Lock ring torque.

3.3. POC Lid Filter

As mentioned at the beginning of this report, previous tests have shown that, when engulfed in a pool fire, the current all-metal filter used on POC drum lids results in lid ejection due to the pressure buildup resulting from pyrolysis gases generated inside the POC. This is undesirable. The UT9424S drum lid filter, shown in Figure 10, has been proposed as a viable POC lid filter alternative given that it is based upon the UT9424 filter that is already approved for use in TRU waste drums at storage sites. Of particular interest for this test phase, the UT9424S filter further has design features that allow it to relieve gas pressure that can build inside the drum during a fire accident. The bolt-like housing of this filter has a unique design in that it is attached to a plastic bushing which gets bolted to the drum lid. The expectation is that the melting of this plastic bushing early on in a pool fire test would allow a sufficient outflow of gases from inside the drum to prevent lid ejection. Therefore, the focus of this study was to investigate the performance of a POC in a 30-minute pool fire using this UT9424S POC drum lid filter.

Figure 10. UT9424S drum lid filter.

3.4. Pressure Instrumentation

The POC drums for Test #1 and Test #2 were instrumented with a pressure port as shown in Figure 11. The pressure port was connected to a remote pressure transducer (Endevco® 8530B-200) using a Conax® connector and ¼ inch stainless steel (SS) tubing attached to the bottom of the POC drum. The reason the pressure transducer was located remotely inside FLAME, away from the fire, was to prevent any drift (i.e., bias) that could be caused by exposure to the high temperature of the fire. To further prevent pressure drift resulting from temperature changes in the transducer's piezoresistive circuit, an aluminum block was used as a heat sink to maintain the temperature of the pressure transducer relatively constant. The aluminum block had one through-hole to fit the ¼" drum input pressure line on one side, and the 8530B-200 transducer on the opposite side. A second hole perpendicular and connected to the through hole just described was used to fit a ¼" tube that went to an OM-CP-PR140 data logger.

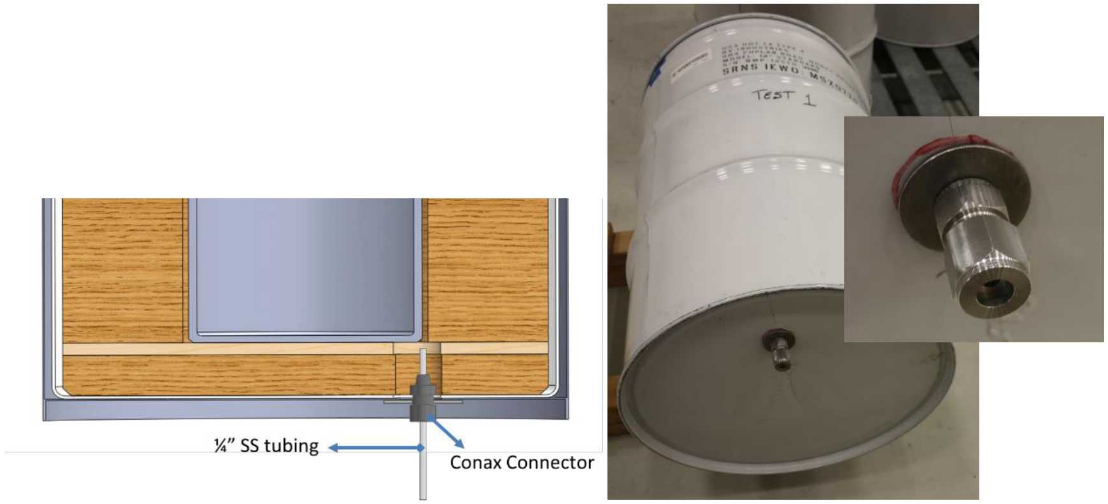


Figure 11. Lower portion of POC showing location of pressure port on the POC drum.

For Test #2, wireless data loggers were initially set to measure the pressure inside the POC. However, the wireless data loggers require a pre-programmed date and time before enclosing them in the drum. Due to a change in the test date and time after the POC had already been assembled with the data loggers, the data logger information was rendered useless. Nonetheless, pressure data was still obtained from the pressure transducer for Test #2.

For Test #3, the pressure port was covered and unused. In this test, however, wireless data loggers were successfully used to measure the pressure inside the POC. A total of two data loggers were used inside the POC; one inside the PC, and one outside the PC. As shown in Figure 12, the data logger outside the PC was inserted in a cutout made to the Celotex® cylinder surrounding the PC. The depth of this insertion was minimized (based on the results of the previous tests) to not affect the results of this test. The second pressure data logger was secured to the bag-out-bag inside the PC as shown in Figure 13.

For Test #4, no pressure data was recorded for either of the 7A drums.

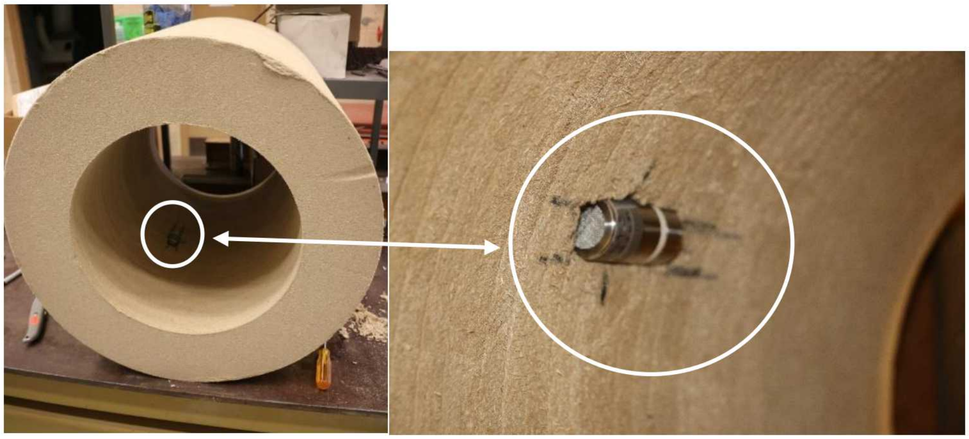


Figure 12. Pressure data logger installed outside the PC in Celotex® cylinder for Test #3.

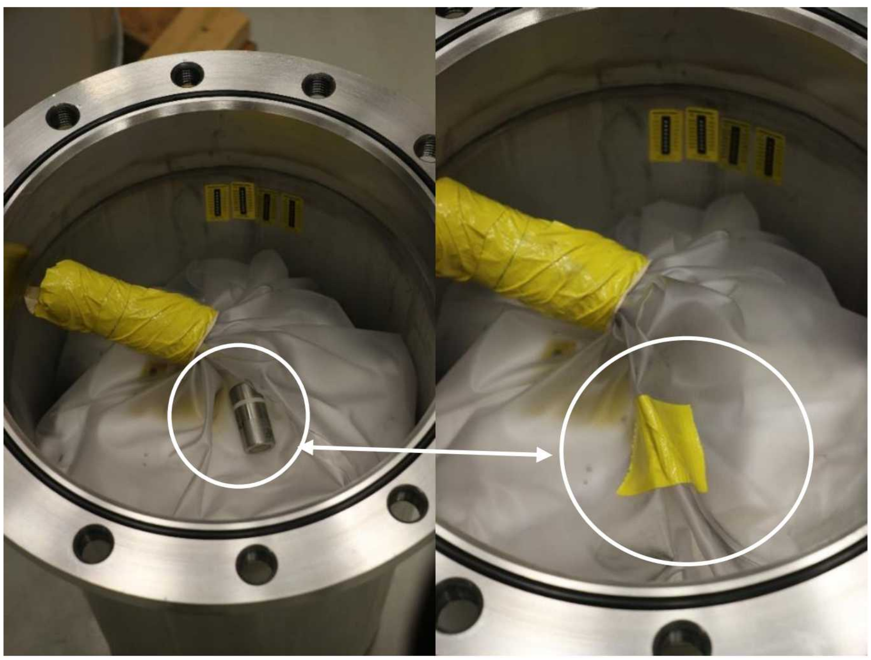


Figure 13. Pressure data loggers secured inside PC for Test #3.

3.5. Temperature Instrumentation

Real time temperature data on the interior of the POC was not recorded. Instead, only peak temperatures inside the PC were monitored using Omega® irreversible temperature labels. Figure 14 shows how temperature labels TL-E-105, TL-E-170, TL-E-250, TL-E-330, TL-E-410 were used as a set to record any peak temperature reached between 77 °C and 260 °C.

The temperature label sets were used in a total of seven locations of interest:

1. On the underside and center of the PC lid.
2. On the side wall of the PC, approximately 2-inches from the bottom.
3. On the side wall of the PC, approximately 10-inches from the bottom.
4. On the side wall of the PC, approximately 20-inches from the bottom.
5. On the inside and bottom of the bag-out-bag.
6. On the inside and top of the bag-out-bag combustibles.
7. On the inside and mid-section of the bag-out-bag.

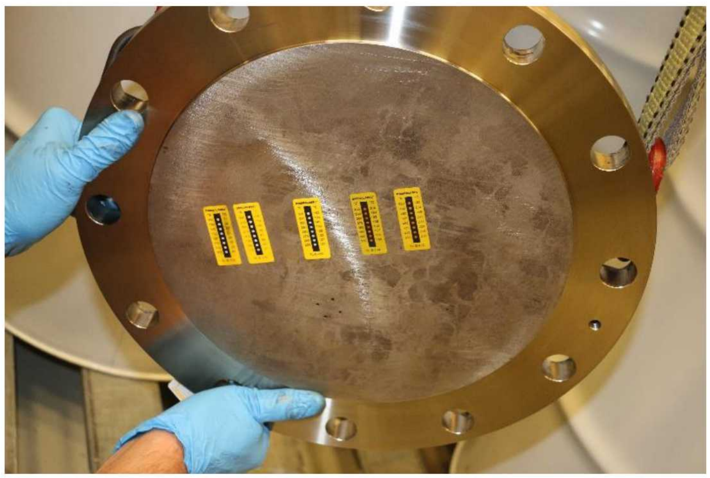


Figure 14. Example of temperature label set used on underside of PC lid.

For Tests #1 and #2, real time temperature data was obtained using mineral insulated 1/16" type K thermocouples at six different locations on the exterior of the POC:

1. On the UT9424S filter on the POC lid.
2. At 90° intervals around the perimeter of the drum, 4 inches away from the drum wall, and at a height of 27.5 inches measured from the base of the drum. The drum seam was used to mark the 0° point to identify all four angular locations as shown in Figure 15.
3. On the bottom drum lid, at the same radius as the filter location on that lid.

For Tests #3 and #4, no temperature data was recorded.

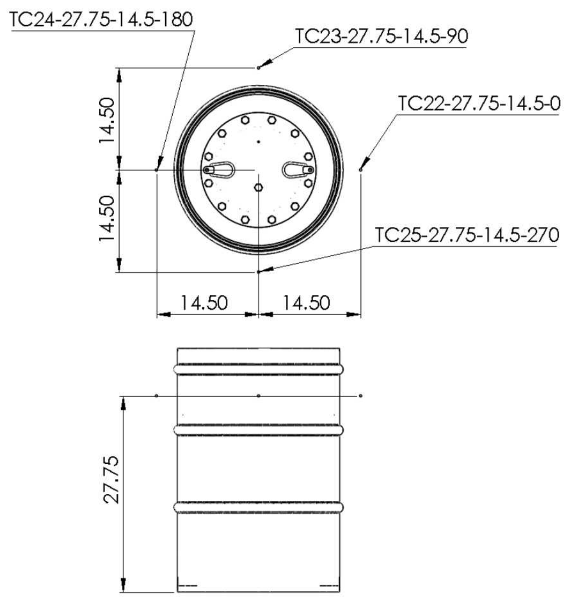


Figure 15. Location of thermocouples outside the POC drums.

3.6. Video

The entire duration of the test was recorded on real-time digital video from two orthogonal directions, while the engulfed package was filmed with mid-wave (MWIR) and long-wave (LWIR) infrared cameras. Figure 16 below illustrates the location of these cameras.

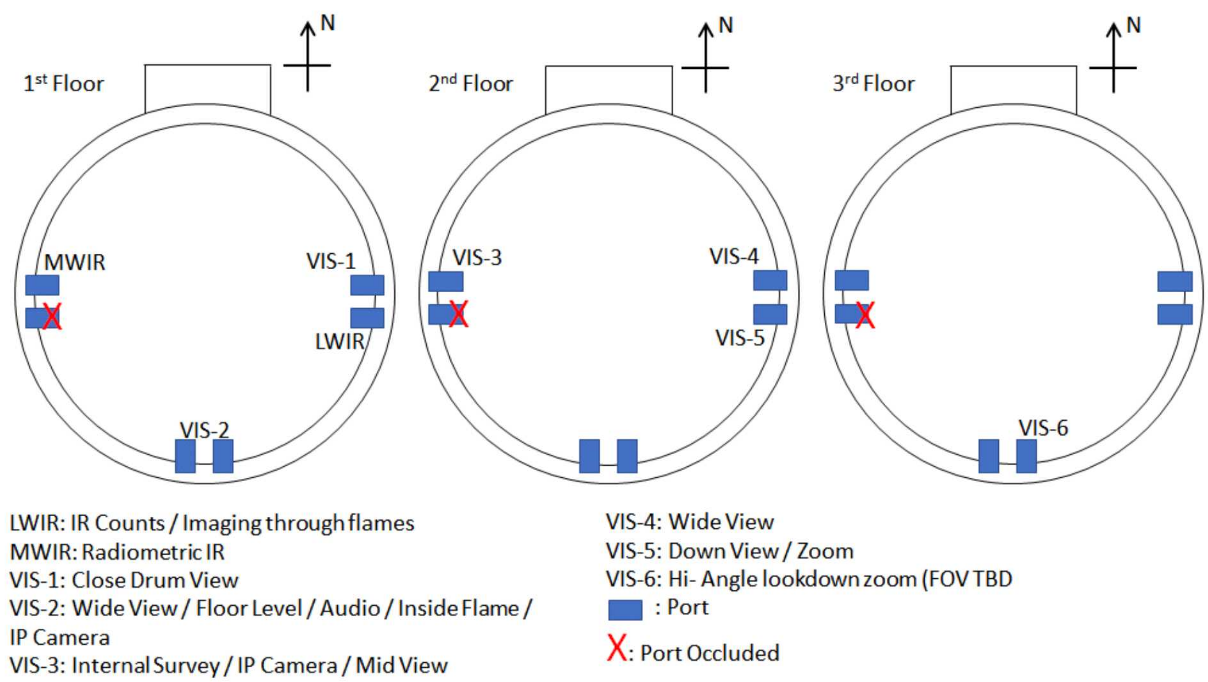


Figure 16. Camera locations.

4. TEST RESULTS

Table 2 summarizes the results of the tests in this phase. Overall, the results of Tests #1 - #3 were a success. Specifically, early on in the test, the plastic bushing of the UT9424S filter melted allowing the filter to pop off, thereby creating a vent to relieve pyrolysis gases from inside the drum. The pressure inside the drums consequently remained low enough to prevent lid ejection for the three tests involving POCs and therefore resulted in a success. In Table 2, any mass loss recorded as 0% indicates that, if there was any mass loss, it was too insignificant to be recorded by the 0.5 kg precision of the scales used. Since the 7A drums had no PC, "NA" was marked for the PC mass loss percentage, but all mass loss contributed to the "Payload Mass Loss" whereas only the PC contents contributed to the "Payload Mass Loss" for POCs. For Tests #1 - #3, the PC mass loss percentage in Table 2 is based on the weight of the bag-out-bag. The PC in Test #1 was the only PC to experience mass loss, but it was minimal and an explanation for that is provided in section 4.1. For the POC mass loss, the percentage is based on the total weight of the POC including the internal contents but excluding the weight of additional components such as instrumentation, insulation, and fittings. One of the main observations from this table is that mass loss was approximately the same for all POCs, roughly around 14%. The 7A drums placed outside the pool in Tests #2 and #4 saw minimal mass loss, where the closer and hotter location of the 7A drum in Test #2 directly explains the higher mass loss when compared to the negligible mass loss experienced by the 7A drum in Test #4. The details and implications of the results for each test are discussed in the sections below.

Table 2. Results Summary

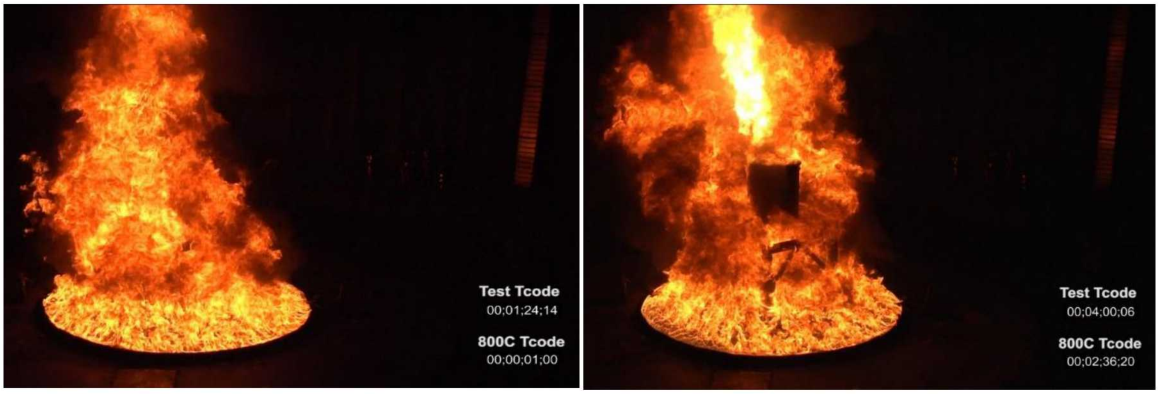
Test #	Type	Drum Lid Ejection?	Total POC/Drum Mass Loss %	PC Mass Loss %	Payload Mass Loss
1	POC	No	13.8%	0.7%	0.7%
2	POC	No	14.8%	0.0%	0.0%
	7A #2	No	2.1%	NA	2.1%
3	POC	No	14.3%	0.0%	0.0%
4	7A #1	No	0.0%	NA	0.0%
	7A #3	No	27.3%	NA	27.3%

4.1. Test #1

The outcome of the first test determined how the remaining tests would be performed. Due to the uncertainty of what could happen in the test, a tether was attached to the lid of the POC drum on Test #1, as shown in Figure 17. In case the POC drum lid ejected with a large force, this tether was attached to prevent the lid from flying out and damaging the FLAME facility. However, the success of this test rendered the tether unnecessary for subsequent tests.

Figure 17. Tether attachment on lid of POC drum in Test #1.

For Test #1 and all subsequent tests, the fire was considered fully engulfed when the thermocouples around the top drum reached 800 °C. Figure 18 below exemplifies the POC in the fully engulfed pool fire before and after the filter ejection. In Figure 18(a), the fire is shown just as it becomes fully engulfed but with the lid filter still in place. Once the filter popped off, approximately two minutes after reaching fully engulfed conditions, two notable phenomena were observed: (1) liquified polyethylene was ejected from the POC drum due to the melted interior drum liner, as shown in Figure 19, and (2) a flame jet resulting from the pyrolyzed gases being ejected as the pool fire burned, as shown in Figure 18(b). The spilling of the liquified polyethylene persisted for about 15 seconds after it started, which was at approximately two minutes and 30 seconds after reaching fully engulfed fire conditions. The jet created from the pyrolysis gases persisted throughout the test and stopped about two minutes after the 30-minute marker, the point at which the fuel supply had recessed to extinguish the pool fire.



(a) (b)

Figure 18. POC under fully engulfed fire conditions: (a) Before filter ejection and (b) after filter ejection.

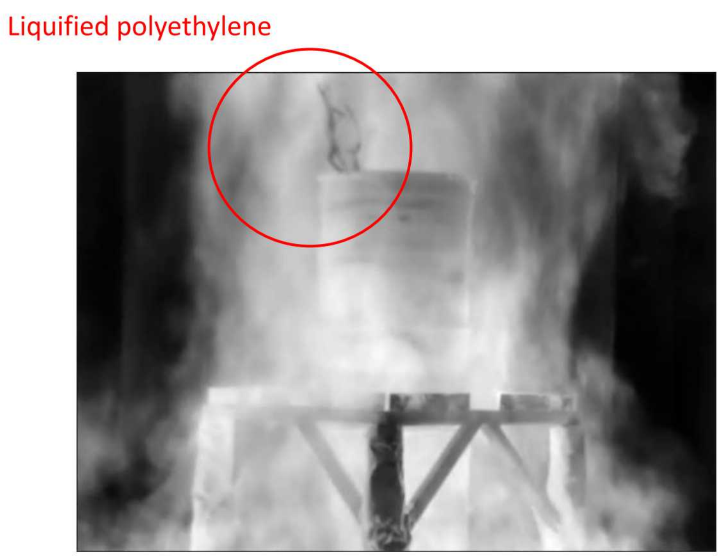


Figure 19. IR image of POC under fully engulfed fire conditions after filter ejection.

The remains of this test were allowed to cool overnight, and Figure 20 below shows the conditions of these remains. In this figure, it is apparent that there was no lid ejection. Therefore, attachment of a tether became unnecessary for subsequent tests performed under the same conditions. However, even though there was no lid ejection, there was still significant bulging of the lid in this test resulting from the pressure buildup caused by the pyrolysis gases. The bulging of the lid along with the ejected filter are captured in Figure 21, where it can be seen how the peak of the bulge reached just over two inches above the edge of the lock ring. When comparing the tested filter with a new one, Figure 22 shows how the plastic bushing around the tested filter indeed melted during the fire, thus allowing the filter to eject from the POC lid. However, it is noted that the bushing probably finished melting off after the filter ejection.

(a) (b)

Figure 20. Remains of Test #1. (a) Full setup and (b) POC only.

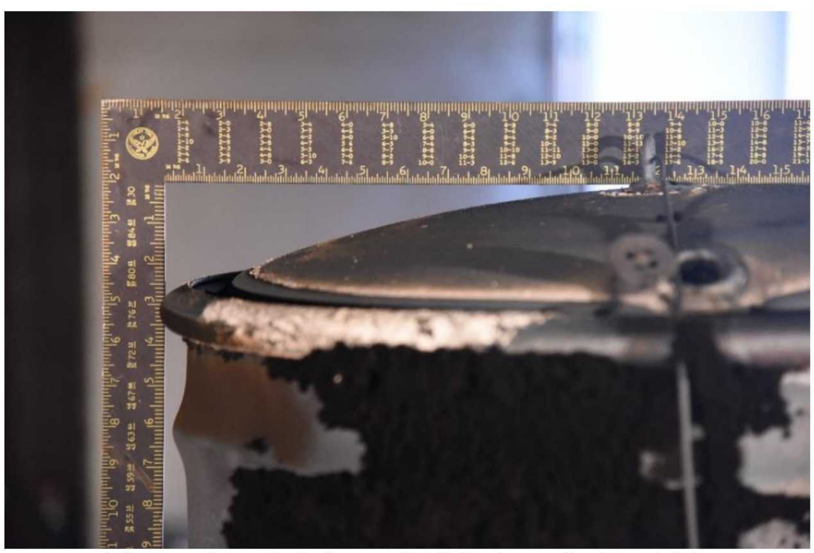


Figure 21. Bulging of POC drum in Test #1.

Figure 22. Comparison of new filter vs tested filter from Test #1.

In Figure 23, it can be seen how the internal contents of the POC were affected and how the Celotex® burned about two inches inward in the radial direction. When removing the PC, it is also noticeable how there was additional charring near the pressure port on the Celotex® inside the POC. In the close-up view of Figure 24, the residue on both the Celotex® and the PC near the pressure port are highlighted. This residue was not analyzed but is probably due to a local hot spot resulting as a consequence of the hole created on the Celotex® to install the pressure port. Specifically, the void created for the pressure port could have also created enough space to allow melted polyethylene to rise to these spots, thus leaving this tar-like substance as the melted polyethylene cooled. In addition to the residue on the PC and Celotex, Figure 25 shows how the bag-out-bag also partially melted near this same spot as it reached a temperature of 160 °C near that region, which directly caused the 0.7% mass loss noted in Table 2 for the PC. However, after inspecting other temperature labels within the PC but away from the alleged hotspot, no other label showed such a high temperature was reached. Instead, these other temperature labels located at a similar height (but 180° away from as the hotspot inside the PC) only showed 82 °C as the highest temperature reached. Based on these observations and conjectures from Test #1, it was concluded that insulation should be placed around the pressure port to substitute for the missing Celotex® in subsequent tests. Therefore, insulation was placed in the pressure port voids of Tests #2 and #3.

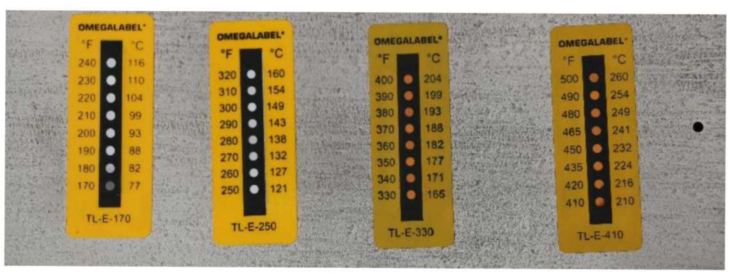
Figure 23. Internal conditions of POC from Test #1 after test completion when Celotex® top is removed.

0

(a) (b)

Figure 24. Residue near the pressure port on (a) the PC and on (b) Celotex®.

Figure 25. Bag-out-bag after completion of Test #1.



(a)

(b)

Figure 26. Temperature labels on (a) interior of PC lid and (b) inside the PC along its wall (note that in both images only the bottom dot on the left-most label has changed color, indicating a peak temperature below 82 °C).

4.2. Test #2 and Test #3

Tests #2 and #3 had outcomes similar to that of Test #1 with a few differences. As mentioned previously, due to the fact that the fire conditions and configuration were the same for Tests #2 and #3 as in Test #1, the tether shown in Figure 17 was not installed on the POC drum lid for these other two POC tests. Secondly, as shown in Figure 27, the void space around the pressure port was filled with insulation in an effort to mitigate the effects seen in Test #1 near that void space by minimizing the direct heat transfer from the fire to that region of the PC.

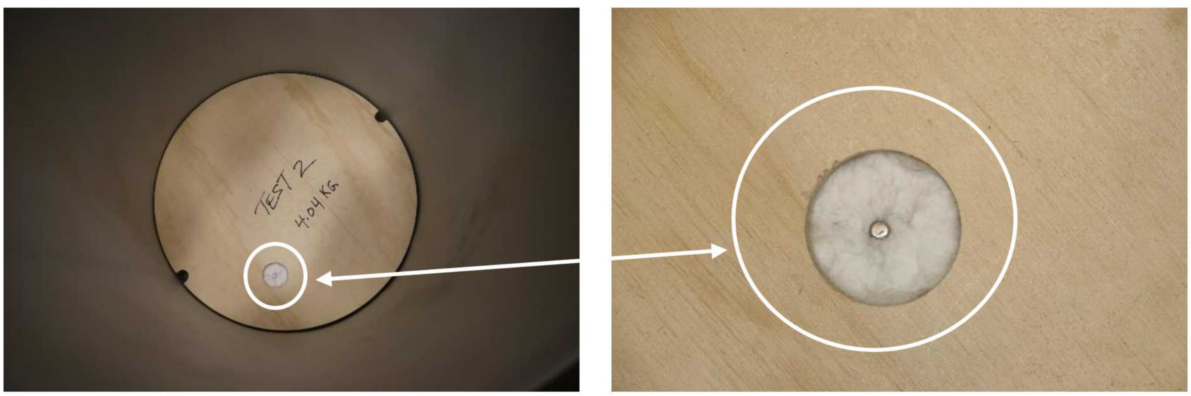


Figure 27. Pressure port void filled with insulation.

As occurred in Test #1, the UT9424S filter ejected early on in both tests preventing a buildup of a pressure large enough to cause lid ejection. Both, Tests #2 and #3, maintained their lids. During the fire, a notable difference with Test #1 was that the liquified polyethylene shown in Figure 19 was not observed in either Test #2 or Test #3. This difference may be attributed to the insulation placed in the pressure port void, which was expected to reduce the heat transfer to the PC during the fire. These results of Test #2 and Test #3 are a more realistic expectation since the insulation used to fill the hole better mimics the case when the hole in the Celotex® for the pressure port is never made in the first place. Inspection of the internal contents of the POC after the fire further revealed that the temperatures experienced by the PC and the bag-out-bag were lower than observed in Test #1. Specifically, temperature labels placed near the pressure port on the outside of the PC showed that the hottest point experienced during the fire was about 82 °C. This lower temperature prevented any degradation of the bag-out-bag for either of these two tests, which explains why negligible mass loss was observed for the PC of either of these tests as noted in Table 2. The temperature labels placed on the bag-out-bag showed that the hottest point experienced by the bag-out-bag was about 71 °C, which was significantly lower than the 160 °C seen in Test #1. Lastly, the POC drum lids from both tests only bulged about half as much as the lid from Test #1.

This lower bulge supports the theory that more heat was experienced by the internal components of Test #1 due to the uninsulated void space created around the pressure port.

For the 7A drum used in Test #2, the response of the drum was different than that of the POC drums. While ejection of the UT9424S filter did occur, a flame jet was not observed on this drum as had been observed on the POCs of Tests #1 - #3. This variation in response was attributed to the distance between the 7A drum and the center of the pool fire. Specifically, the distance between the drum and the center of the pool reduced the heat flux imposed on the drum to 45 kW/m^2, which in turn resulted in a reduction in mass loss (only 2.1% mass loss was recorded for this drum) and pyrolyzed gases. Therefore, the reduced heat flux combined with the reduction in pyrolyzed gases explains the lack of a flame jet on the 7A exposed in Test #2.

4.3. Test #4

Test #4 did not involve any POCs. Instead, as mentioned in section 3.1 above, the 7A drums were filled with mixed items that comprised approximately 50% cellulose and 50% plastics by volume. However, the same UT9424S filter was used on the drum lids as was used in the POC drum lids. For the 7A drum fully engulfed at the center of the fire, the UT9424S filter ejected from the drum lid early on in the test, which in turn allowed a pressure relief and prevented lid ejection, similar to the POC drums used in Tests #1 - #3. Once the filter was ejected from this drum, pyrolysis gases emitted through the filter orifice resulted in a flame jet above the drum, similar to Tests #1 - #3. The pyrolysis reactions of the internal contents in this drum ended up causing the 27.3% mass loss shown in Table 2. For the drum placed at 35 kW/m^2, while the UT9424S filter did eject, no flame jet was observed and negligible mass loss was experienced by this drum. Figure 28 shows how the remains of the two 7A drums in this test varied, where the drum in the center of the pool shows significant degradation when compared to the drum placed outside the pool. In contrast with Tests #1 - #3, no temperature or pressure instrumentation was installed on or in either of the 7A drums.

(a) (b)

Figure 28. Remains of 7A drums for Test #4. (a) drum placed at the 35 kW/m^2 distance, and (b) drum placed in center of pool fire.

5. DISCUSSION OF COLLECTED DATA

5.1. Test #1 Temperatures and Pressures

In Figure 29, the temperature evolution of the six main thermocouples used for Test #1 are shown. The four thermocouples with angular labels are the ones on the POC drum wall used to measure the flame temperature around the POC which were described earlier in Figure 15. The other two thermocouples were on the filter and bottom drum lid. According to the thermocouples around the POC drum wall, Figure 29 shows how the flame temperature around the POC had some slight variation from one thermocouple to the other. It is speculated that this is a direct result of two phenomena: (1) The flame's natural tendency to lean towards one side as seen in Figure 18(a), and (2) when the filter popped off, the pyrolysis gases exiting the POC drum created a flame jet that potentially changed the fire dynamics and could have further provided additional localized heat near that region, as was shown in Figure 18(b). Nonetheless, the four thermocouples showed comparable temperatures around the POC lid, and they all reached the fully engulfed zoned (marked by a temperature of 800 °C) within 90 seconds of ignition. The thermocouple on the filter reached its peak temperature after the end of the fire when the jet of pyrolysis gases has more oxygen available to sustain combustion and the region of combustion lowers to near the drum lid surface. For the bottom drum, Figure 29 shows how it experienced a slower response time with lower temperatures and smoother profile. The slower response time and cooler temperatures are a result of the vapor dome described in section 2.2. This temperature response on the lower drum directly supports the argument that the top drum is within the hottest region of the pool fire and is therefore in a more conservative location for the test. Even for this cooler drum, the temperature at the filter location rises above the melting temperature of the plastic filter bushing within about 100 seconds from the time the fire becomes fully engulfing. This indicates that this drum filter will also be ejected well before there is sufficient build-up of pressure within a bottom drum to eject its lid.

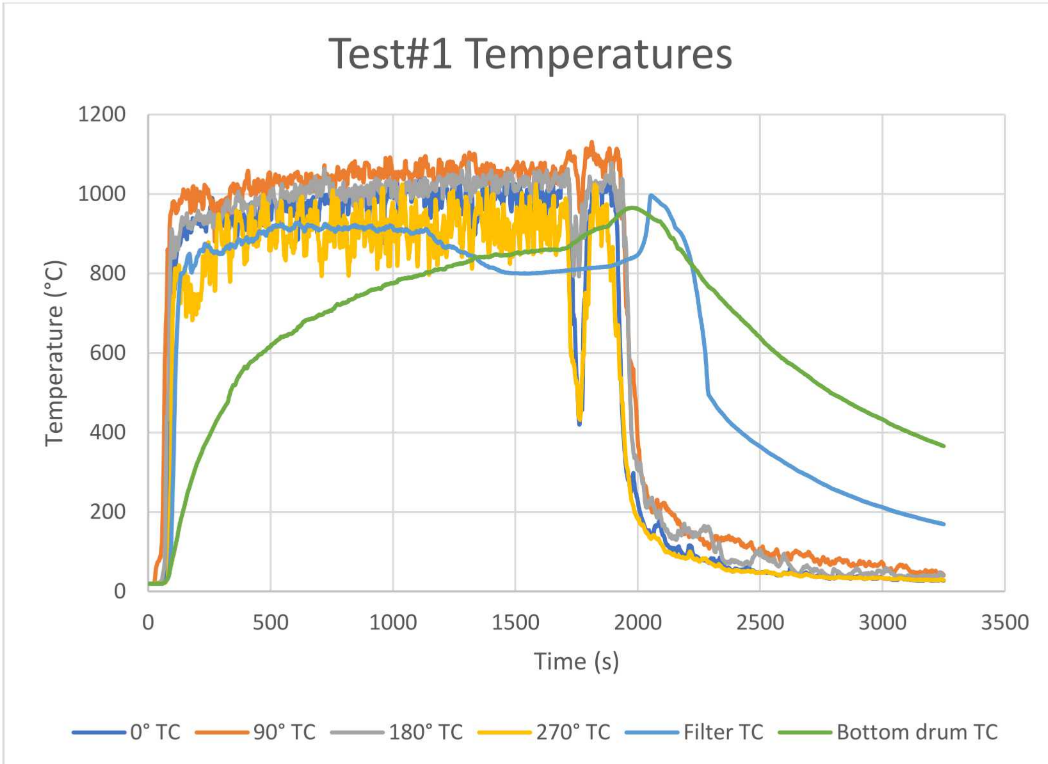


Figure 29. Test #1 measured temperatures.

The pressure measured inside the drum with the pressure port instrumentation for this test is shown in Figure 30. From this plot, it is not easy to distinguish exactly what is occurring based on the pressure profile alone. However, it is noticeable that, early on in the test a little after 2 minutes from ignition, the drum lost pressure due to the ejection of the POC filter. It is speculated that the system subsequently continues to build pressure as the polyethylene liner thermally decomposes. The pressure drop starting near 250 seconds is attributed to the transition of polyethylene pyrolysis gases to Celotex® pyrolysis gases being generated as the fire heated the POC from the outside in. Lastly, it is also speculated that other random peaks throughout the pressure profile could have resulted from the pressure port having become temporarily obstructed for brief periods of time throughout the burn.

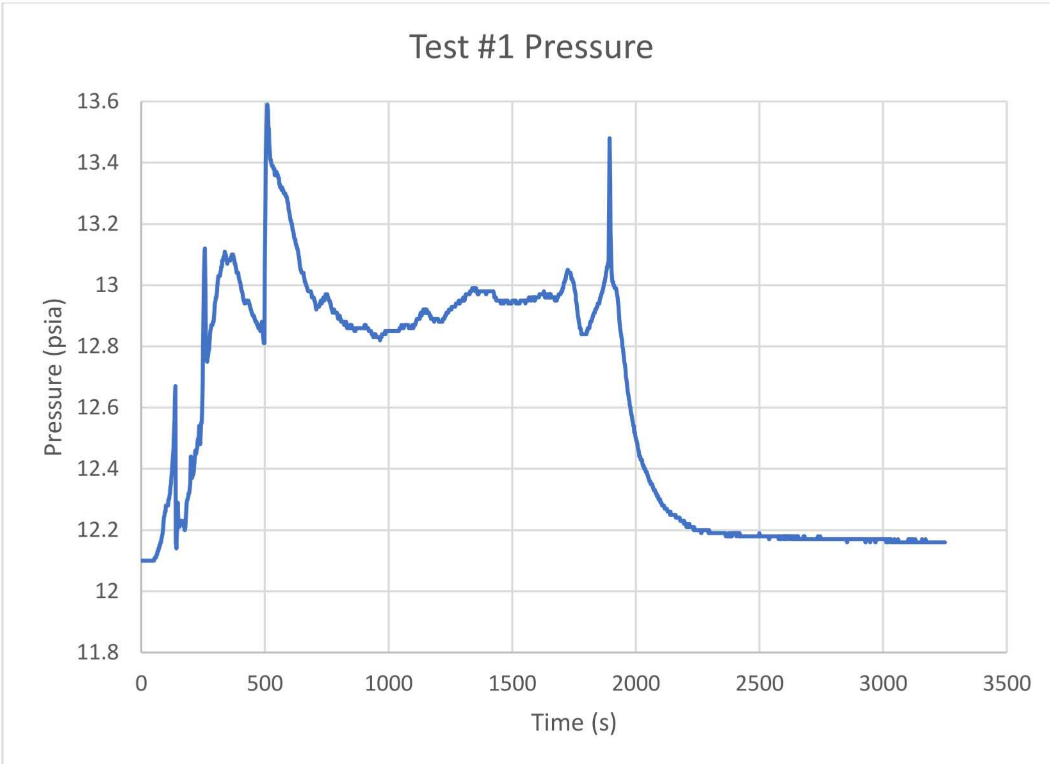


Figure 30. Test #1 measured POC pressure.

5.2. Test #2 Temperatures and Pressures

The instrumentation for Test #2 was very similar to Test #1. In Test #2, the only difference was that the temperature of the bottom drum was not measured. The temperature results for Test #2 were very comparable to those of Test #1, and Figure 31 shows how similar patterns were observed throughout the test. Specifically, all four thermocouples around the POC reached the fully engulfed 800 °C temperature within 90 seconds and sustained temperatures above that for the 30-minute duration of the fire. The slight variations from one thermocouple to another were also observed in Test #2 as was observed in Test #1 as caused by the leaning of the fire.

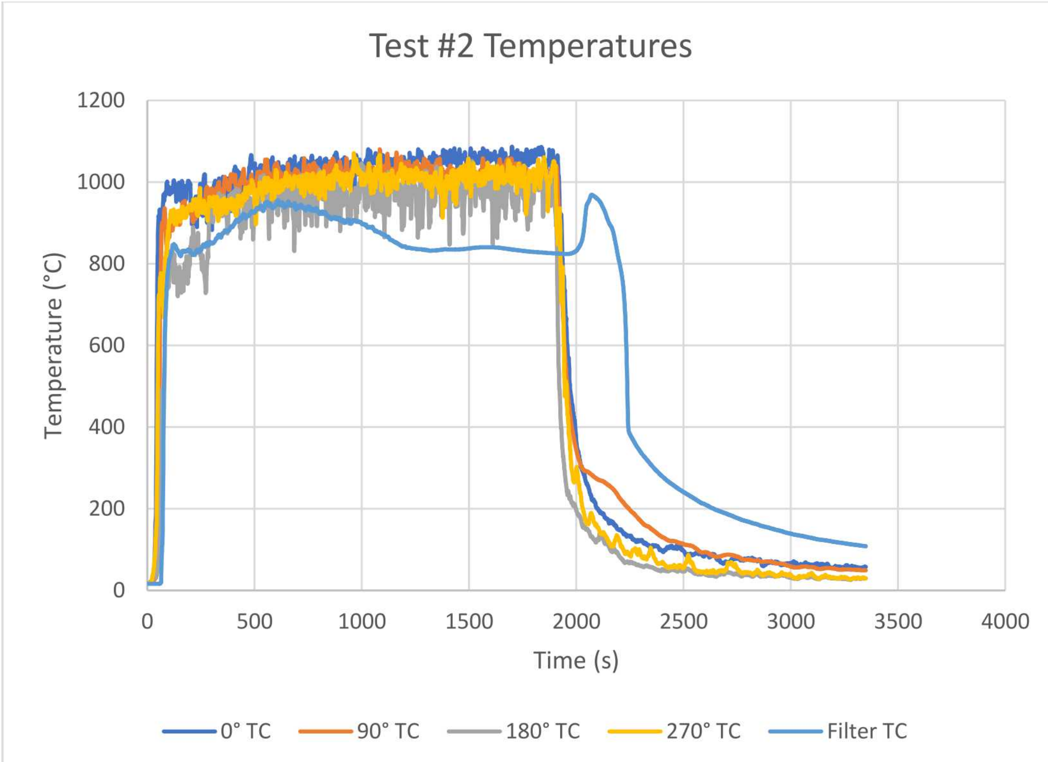


Figure 31. Test #2 measured temperatures.

In Figure 32, the pressure profile observed in the POC drum of Test #2 is shown. This profile has some variations when compared to that of Test #1. The overall differences are attributed to the pressure port temporarily being obstructed for brief periods throughout the burn resulting in random pressure buildups. However, the first pressure-drop observed at the beginning of the burn occurs in both tests at similar times (within two minutes from the beginning of the test). For both tests, even though the profile for Test #1 indicates that it saw slightly higher pressures, the pressure stayed relatively low (below 14 psia) throughout the entire period of both tests. Considering that the atmospheric pressure at the test location is approximately 12.2 psi, the pressure results indicate that neither drum ever experienced more than 2 psi of pressure buildup. Lastly, both pressure profiles also show a significant decline in pressure right after the 30-minute marker for the end of the test, as would be expected due to the fuel being recessed from the pool.

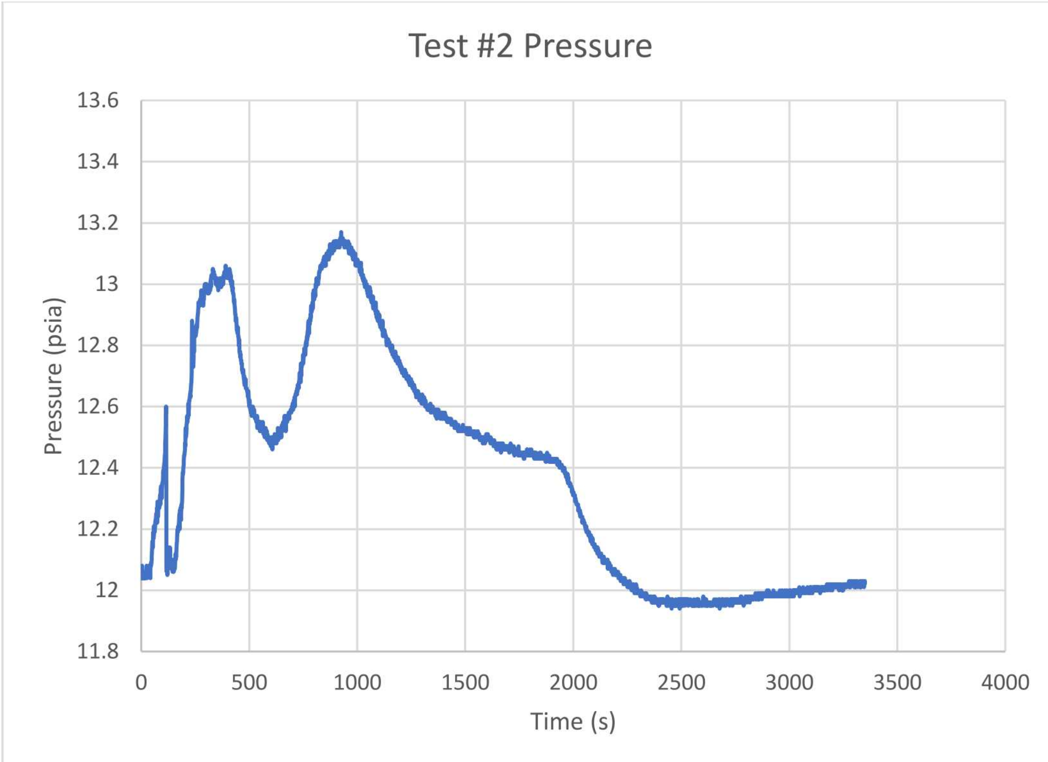


Figure 32. Test #2 measured POC pressure.

5.3. Tests #3 and #4 Temperatures and Pressures

For Test #3, there were no temperature measurements, and no pressure measurements were performed using the pressure port either. Instead, pressure measurements were taken inside the drum and inside the PC using remote data loggers as described in section 3.4. The results for the measured pressures are shown in Figure 33 and Figure 34 for pressure inside the drum and inside the PC, respectively. As seen in the measurements from Tests #1 and #2 when using the pressure port on the drum, the first drop in pressure occurred within the first 2 minutes for the drum in Test #3 (at approximately 80 seconds). Furthermore, it was observed that, for Tests #1, #2, and #3, the drum pressure reached at the point just before this first pressure drop is about 12.6 ± 0.1 psia. This agreement throughout the three different tests, combined with the observations in the videos corresponding to the tests, reaffirms that this first sudden drop in pressure is in fact attributed to the UT9424S drum lid filter ejecting. As discussed for Test #1, the subsequent peak occurring near 180 seconds is speculated to be a result of the production of polyethylene pyrolysis gases followed by a transition to Celotex® pyrolysis gases. In Figure 33, around 500 seconds into the test, it is seen how the pressure stabilized as the pyrolysis gases were suspected to be produced mainly from the Celotex® inside the drum. The last pressure drop observed, just before 2000 seconds, results from the pool fire being extinguished at the 30-minute mark. For the pressure observed inside the PC, Figure 34 shows how, in general, it exhibited similar behavior to that shown for the POC drum in Figure 33. The PC pressure profile, however, is much smoother. This smoother profile observed inside the PC was attributed to the fact that many of the random pressure fluctuations experienced by the drum were attenuated by the PC. For Test #4, as mentioned in sections 3.4 and 3.5, temperature and pressure data were not recorded.

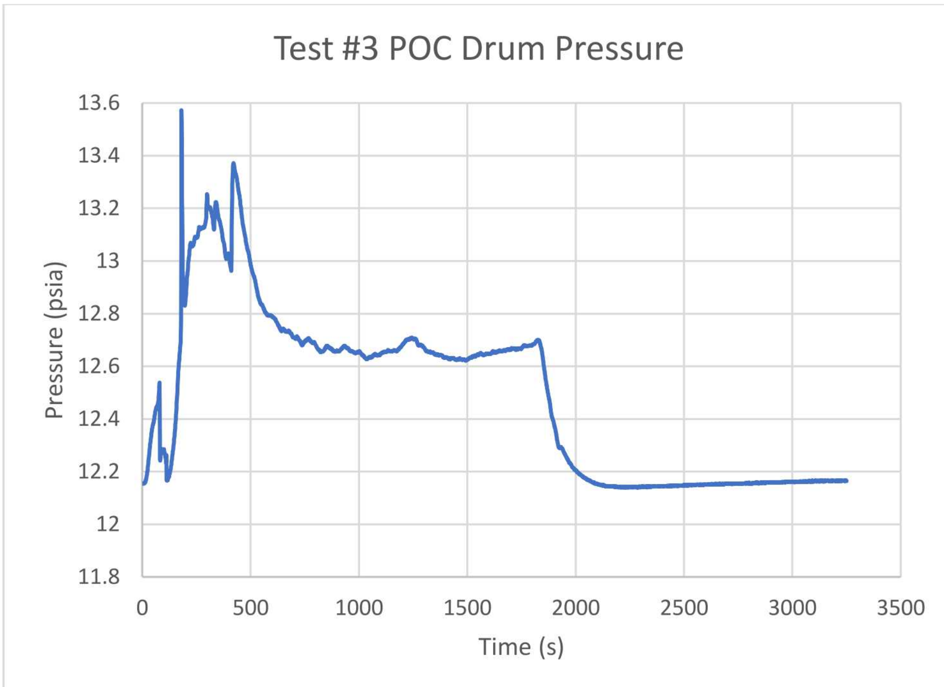


Figure 33. Test #3 POC drum pressure measured using data loggers.

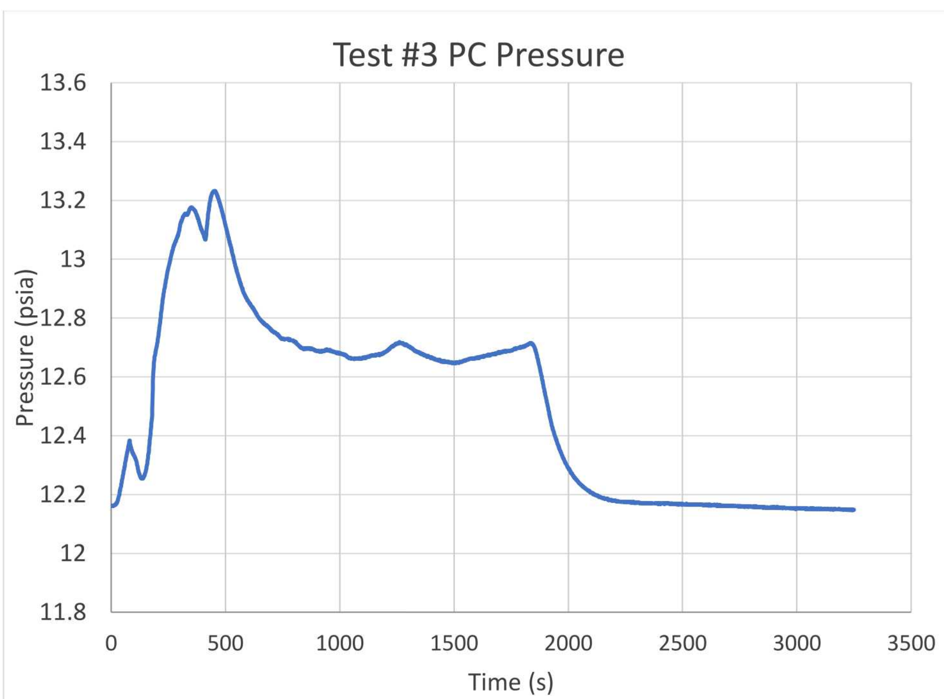


Figure 34. Test #3 PC pressure measured using data loggers.

6. CONCLUSIONS

This report described the various pool fire tests conducted at SNL in Phase II-A as part of the DOE EM and NNSA storage drum test program that was established for POCs under the loading conditions typically being employed at current DOE storage sites for combustible TRU waste. In addition to POCs, 7A storage drums filled with combustibles were also included in some of the tests. The goal of this test series was to examine the response of POCs equipped with a UT9424S drum lid filter while exposed to a 30-minute pool fire. Secondarily, the behavior of 7A drums filled with typical combustibles and with the same UT9424S filter on the drum lid was studied as well. This report presented results from these tests and discussed their implications for the POC and 7A drums tested under set conditions.

Four tests were performed in total for this test phase. The first three tests tested a POC engulfed in a pool fire, and the fourth tested 7A drums filled with combustibles in and near a pool fire. For the POC tests, results included: (1) Peak temperature measurements inside the PC, (2) temperature measurements around the exterior of the POC, (3) pressure measurements inside the POC drum, (4) pressure measurements inside the PC, (5) total POC mass loss measurements, and (6) qualitative data that showed the state of the POC components after the fire. For the 7A drums, results included total mass loss measurements as well as qualitative data that showed the state of the 7A components after the fire.

Based on the data collected, for a POC equipped with a UT9424S lid filter and exposed to the hottest region of a 30-minute pool fire, the lid filter ejects within 2 minutes of ignition. The filter ejection allows sufficient pressure relief from the POC drum to prevent lid ejection. During the fire, the POCs lost approximately 14% of their mass on average, mainly in the form of pyrolyzed polyethylene and Celotex® surrounding the PC. Test #4 revealed that a 7A drum filled with approximately 50% plastic and 50% cellulose (by volume) also maintained its lid as the filter ejected under the same fire configuration as the POC tests. Furthermore, Test #4 revealed that a 7A drum placed at a distance corresponding to 35 kW/m^2 of heat also ejects the UT9424S filter on the drum lid and allows enough pressure relief from the drum to prevent lid ejection. However, some burning and charring was observed in the contents of the 7A tests. The most conservative case, where the 7A drum of interest was stacked on top of an empty drum in the middle of a pool fire, resulted in 27% mass loss. The 7A drum placed at 35 kW/m^2 experienced negligible mass loss.

While this test series showed that ejection of the alternate metal-polyethylene filter (UT9424S) proved to relieve enough pressure to prevent lid ejection of the POCs when exposed to a 30-minute pool fire, the setup used in this test series isolated a POC drum at the hottest region in a fire with a vented, empty drum beneath it. During the fire, the tests showed that a flame jet results from pyrolyzed gases exiting the filter orifice on the POC drum lid. This flame jet created uncertainty on the outcome of POCs exposed to a fire in a real storage site setup, where POCs are stacked on top of one another. As a result, the outcomes of this test series suggest that testing stacked POC drums that represent actual storage site configurations is recommended.

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