# Fire-Induced Pressure Response and Failure Characterization of PCV/SCV/3013 Containers – Phase 1

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# Fire-Induced Pressure Response and Failure Characterization of PCV/SCV/3013 Containers – Phase 1

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## Abstract

This report discusses the test series performed at Sandia National Laboratories (SNL) to test the response of Primary Containment Vessels (PCVs) under a hypothetical fire scenario. The PCV is the innermost container in a 9975 shipping package (NRC, 2014). This test series was the first of three phases aiming to characterize the PCV/SCV/3013 system, and it will be referred to as Phase 1. The purpose of these tests was to characterize the response of the PCV wall when filled with a bounding payload and exposed to an ASTM-E1529 (ASTM, 2014) standard fire environment. In particular, the goal was to test a working hypothesis for these PCVs: that, during a scenario where the PCV is exposed to an ASTM-E1529 standard fire environment, the accumulated internal pressure (resulting from the expansion of gases and vaporization of moisture/plastics during heat exposure) relieves through the O-ring segment of the PCV before PCV wall failure (rupture). Bounding internal and external conditions were purposefully established for this Phase 1 testing in order to maximize pressurization in the container. Specifically, this Phase 1 test series is designed to determine the worst case thermal stress conditions by exposing five SRNS PCVs with identical payloads to the severe ASTM-E1529 fire conditions in five different configurations with increasing potential to result in a release of the internal contents (i.e. failure). All five tests were successfully executed, and the failure modes were characterized for each test. This report discusses the details of the five tests performed in this phase, their outcomes, and their implications.

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## NOMENCLATURE

| | |
|---|---|
| ASTM | American Society of Testing and Materials |
| DAQ | Data Acquisition |
| MIDAS | Mobile Instrumentation and Data Acquisition System |
| PCV | Primary Containment Vessel |
| QA | Quality Assurance |
| SNL | Sandia National Laboratories |
| SRNL | Savannah River National Laboratory |
| SRNS | Savannah River Nuclear Solutions |
| TC | Thermocouple |
| TTC | Thermal Test Complex |

# 1. INTRODUCTION

In this test series, the response of Primary Containment Vessels (PCVs) was tested under a hypothetical fire scenario. The PCV is the innermost container in a 9975 shipping package (NRC, 2014). Six (6) PCVs were provided by Savannah River Nuclear Solutions, LLC (SRNS), where one of those units was used as a calibration test which is not discussed in this report; a sample image and diagram of these PCVs can be viewed in Figure 1. This test series was the first of three phases aiming to characterize the PCV/SCV/3013 system, and it will be referred to as Phase 1. The purpose of these tests was to characterize the response of the PCV wall when filled with a bounding payload and exposed to an ASTM-E1529 (ASTM, 2014) standard fire environment. In particular, the goal was to test a working hypothesis for these PCVs: that, during a scenario where the PCV is exposed to an ASTM-E1529 standard fire environment, the accumulated internal pressure (resulting from the expansion of gases and vaporization of moisture/plastics during heat exposure) relieves through the O-ring segment of the PCV before PCV wall failure (rupture). The hypothesis is tested in the PCV/SCV/3013 test series. This Phase 1 test series is designed to determine the worst case thermal stress conditions by exposing five SRNS PCVs with identical payloads to the severe ASTM-E1529 fire conditions in five different configurations with increasing potential to result in a release of the internal contents.

All work done for Phase 1 testing was performed under the SRS Quality Assurance Manual 1Q (SRNS, 2019) and the Sandia National Laboratories (SNL) Project Quality Plan (PQP) PCV/SCV/3013-PQP (Uncapher, 2018) to meet the requirements of ASME NQA-1 (ASME, 2008). Test personnel qualifications are documented in Appendix 6.4.

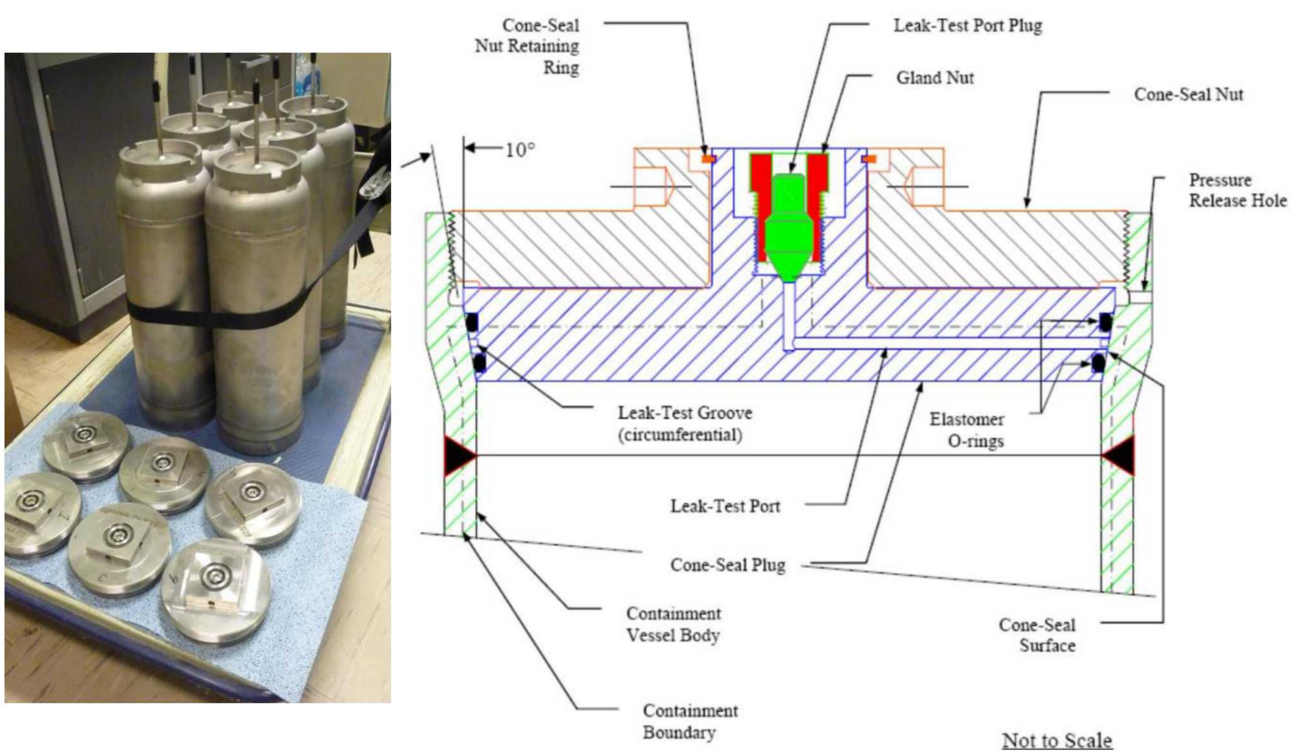


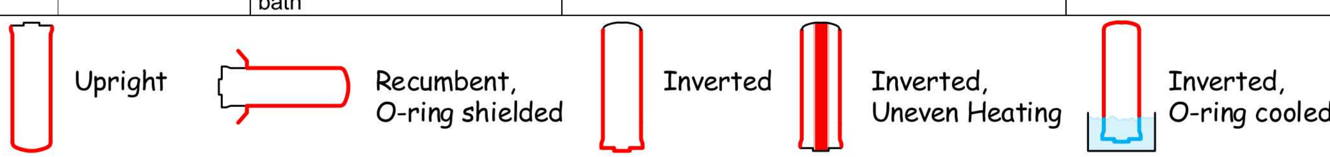

**Figure 1. PCV Units for Testing.**

## 1.1. Test Configurations

Originally, the five configurations presented in Table 1 were chosen as the Phase 1 configurations. These configurations were presented in the test plan for this test series, where Configuration 1-A was designed to be the baseline case since internal pressure generated throughout the test was expected to relieve through the O-ring segment of the PCV (Gill, 2018). The other four configurations were to test whether this pressure-relief mechanism could fail, either by (1) delaying the softening and decomposition of the O-rings during pressurization, or (2) by plugging the O-ring region with debris from the internal payload during pressurization. However, after seeing the outcome of the Configuration 1-B test, it was decided that Configuration 1-E would be re-designed since it had originally intended to be a more extreme case of Configuration 1-B. For the modified Configuration 1-E, the conditions were as outlined in Configuration 1-A, except that the orientation was set to be recumbent. Specific details of the configurations tested are described further in Section 2.

**Table 1. Original Test Configurations as Presented in the Test Plan.**

| Test | PCV Configuration | Heating | Discussion | Notes |
|---|---|---|---|---|
| 1-A | 1-A. New PCV, new O-ring, upright orientation | ASTM-E1529 flux and temperature profile imposed on the bottom and sides of an upright PCV. | Initial conditions established to match PCV with highest analyzed rupture (assumed) pressure. Added initial pressure with no heating to increase stress to container wall without stressing O-ring. Maximum lid torque applied to ensure smallest metal-to-metal clearances. | Pycnometric density of Pu oxide is 4.5 g/cc. 200 psi bounds all initial pressure calculated for KAC packages (max 150 psi). Internal pre-heating believed more impactive to O-ring than sidewall. |
| 1-B | 1-B. New PCV, new O-ring, recumbent orientation, O-ring area of sidewall shielded | ASTM-E1529 flux and temperature profile imposed on the bottom and sides of a recumbent PCV up to 2" from the O-ring. Sidewall within 2" of O-ring shielded. | Same as 1-A with variation of heating parameters established to further maximize container sidewall heating and minimize O-ring heating. Portion of PCV sidewall within 2" of O-ring shielded from direct radiant heating but allowed to radiate to ambient room. | Considered to represent post-seismic fire scenario of fallen recumbent PCV with bottom end hanging over the end of the table. |
| 1-C | 1-C. New PCV, new O-ring, inverted orientation. | ASTM-E1529 flux and temperature profile imposed on the lid and sides of an inverted PCV. | Same as 1-A with variation of container orientation (inverted to assess the effect of thread plugging) | Considered to represent post-seismic fire scenario of fallen inverted PCV. |
| 1-D | 1-D. New PCV, new O-ring, inverted orientation | ASTM-E1529 flux and temperature profile imposed to one side of the PCV long enough to heat the sidewall to a localized elevated temperature followed by full circumferential exposure for the remainder of the test. | Weaken the PCV wall with minimal seal heating and then increase the internal pressure of the vessel by heating more uniformly circumferentially while maintaining initial heat affected region hot. Lid on the floor would protect the lid from external heating. The 'floor' would also act as a heat sink, keeping the seal region cooler during the test (fire event). | Adjacent fire that grows to fully engulf the PCV at late times.<br>May be non-physical. |
| 1-E | 1-E. New PCV, new O-ring, inverted orientation | ASTM-E1529 flux and temperature profile imposed on the bottom and sides of an inverted PCV. Lid Area (O-ring) immersed in cooling bath | Same as Test 1-C with increased protection to lid area; physical protection of O-ring. | Most extreme thermal stresses<br>May be non-physical |



For the details of the configurations outlined in Table 1, it should be noted that while the tests were generally modeled to simulate real postulated thermal accident stresses, some aspects of the configurations would be considered unrealistic. These aspects included: use of a bounding payload configuration, use of a bounding engulfing pool fire heat-up profile, testing of inverted containers, and the use of insulation shields to focus thermal stress to specific locations on the PCV. The intent was to evaluate the stated hypothesis in a bounding manner that could be used to assess container response for any thermal stress condition in any DOE facility in the complex. Furthermore, another benefit of the chosen conditions is that it is typically easier to conduct future analytical modeling by reducing thermal stress conditions from those tested (interpolating), as opposed to modeling more severe thermal stresses (extrapolating) than those tested.

Lastly, during testing, the configuration nomenclature used in the Test Plan (and shown in Table 1) was modified for easier reference (Gill, 2018). Rather than using the alpha-numeric nomenclature, the new nomenclature was modified to be purely numeric. Table 2 shows the mapping of the "Test Plan" (old) nomenclature to the "New" nomenclature. The "New" nomenclature will be used in this document from this point forward.

**Table 2. Mapping of configuration nomenclature from test plan to test results.**

| Test Plan nomenclature | New nomenclature |
|---|---|
| Configuration 1-A | Configuration 1 |
| Configuration 1-B | Configuration 2 |
| Configuration 1-C | Configuration 3 |
| Configuration 1-D | Configuration 4 |
| Configuration 1-E | Configuration 5 |

# 2. TEST SETUPS

All tests were performed at SNL's Thermal Test Complex (TTC). For all five configurations tested as part of this test series, each PCV was filled with an identical payload. The instrumentation used was also identical, where Type-K thermocouples (TCs) were used to measure temperature at various points on the test units, and Gefran KN2-series high temperature pressure sensors were used to measure the pressures inside the PCVs. All configurations employed the same type of heater assembly to produce the heat flux necessary to attain the ASTM-E1529 fire environment. These heater assemblies consisted of silicon carbide heater rods (used as the heat source) that concentrically radiated onto a shroud which then radiated a uniform heat flux onto the PCV assembly. In all setups, the shroud used was the same dimensions with an outer diameter of seven inches and a wall thickness of 0.063 inches. The main distinction between the different setups was the orientation of the PCVs. Details of the setups are provided in the subsections below.

## 2.1. PCV Modification

Six PCVs were obtained by SRS and modified in the F-Area Fabrication Shop, in accordance with SRS design drawing SRNL-MPCV-002, which is included as Attachment A in the modification work package (SRNS, 2017). The PCVs were modified by drilling a hole in the center of the bottom of the vessel and welding a ¼" high pressure nipple for subsequent attachment of pressure sensors at SNL. The vessels were then subjected to helium leak tests commensurate with original PCV fabrication requirements (Neikirk, 2018) and subsequently shipped to SNL.

## 2.2. Payload

Each tested PCV was filled with an identical payload. Various evaluations were conducted by Savannah River National Laboratory (SRNL) to determine the adequate surrogate contents to properly resemble plutonium oxide inside a PCV. Aluminum oxide (alumina) was chosen as the surrogate material because it has a similar pycnometric density (3.97 g/cc) to plutonium oxide (4.8 g/cc) and is available as a high purity powder (99.5 % alumina) with a particle density distribution also similar to plutonium oxide. While the alumina was not evaluated for specific thermal/pressure response, it is non-reactive at elevated temperatures and has a high melting point (2,072 °C). Water was added by dropper to attain a 3 % moisture content by weight. Alumina spheres (pycnometric density 3.87 g/cc) were selected in these tests for adjustment of container volume that is normally displaced by various convenience cans and spacers that may be present in the actual PCV. The alumina spheres added to attain the desired free volume in the PCV are less dense than the metal convenience cans their volume replaces but at the same time provide an increased surface area to permit enhanced convective flows within the matrix. This arrangement was expected to enhance heat transfer into the container contents and would therefore result in more conservative pressurization of the PCV. The evaluation done by SRNL also studied the amount of plastic necessary to properly resemble the plastic content used for bagging convenience containers normally placed inside a PCV. The value chosen for the amount of plastic content in the Phase 1 series represents the amount of polyethylene that would generate the same amount of gas as that evaluated. Further details of the payload evaluations conducted by SRNL can be found in the Appendix, Section 6.1. Figure 2 shows an example of the payload used inside the PCVs for this test series. The payload packages were prepared at SRNL (Eldridge & Scoggin, 2018) and subsequently shipped to Sandia National Laboratories in mylar containment bags to ensure constant environmental conditions were maintained within the payload prior to test assembly at SNL.

Packaging instructions directed that only the mylar bag should be removed and discarded during assembly. However, the outer layer of polyethylene bagging was also removed in error during payload packaging (see Figure 2(c)). This resulted in a reduction of payload plastic mass and an increase in calculated PCV free volume from that specified in both the Test Plan (Gill, 2018) and the Payload Packaging Report (Eldridge & Scoggin, 2018). This was verified later to have been done for all five test packages. Table 3 presents a summary of the weight loss for each package. The average weight loss for all five payloads (28.31g) is included in the payload initial condition summary, Table 6.


(a) (b) (c)

**Figure 2. Payload for PCVs: (a) Isolated Payload; (b) Payload Inserted in PCV; and (c) Payload with Mylar Shipping Bag and Outer Payload Bag Removed.**

**Table 3. Outer Plastic Bag Weight Loss.**

| Config. | Payload # 000577-001- | Pre-Test Payload Weight | | | | Difference | |
|---|---|---|---|---|---|---|---|
| | | As-Constructed* | | As-Assembled** | | Outer Bag Weight | |
| | | (g) | (lb) | (lbs) | (g) | (lbs) | (g) |
| 1 | PL08 | 4694.50 | 10.35 | 10.29 | 4667.47 | 0.06 | 27.03 |
| 2 | PL05 | 4665.70 | 10.29 | 10.22 | 4635.71 | 0.07 | 29.99 |
| 3 | PL07 | 4672.30 | 10.30 | 10.24 | 4644.79 | 0.06 | 27.51 |
| 4 | PL06 | 4673.80 | 10.30 | 10.23 | 4640.25 | 0.07 | 33.55 |
| 5 | PL03 | 4672.80 | 10.30 | 10.25 | 4649.32 | 0.05 | 23.48 |
| | | | | | average: | 0.06 | 28.31 |

* Ref. (Eldridge & Scoggin, 2018), Table 3-3

** From Field Measurements

A snorkel plate assembly (shown in Figure 3), consisting of a flat circular plate with a small diameter tube attached, was constructed by SNL and inserted in the bottom of the PCV during assembly of the test package. Its purpose was to minimize the potential for plugging of the pressure tap. Its mass and volume displacement were not included in the payload calculations (Eldridge & Scoggin, 2018), it is however included in the Payload Initial Condition Summary, Table 6.

### 2.3. Instrumentation

For each test, Type-K thermocouples (TCs) were used to monitor the temperature at three equidistant angular positions around the PCV and about mid-height of the PCV. The 0° position was defined by the location where the pressure relief hole[1] was on the PCV (see Figure 1), and the 120° and 240° positions were measured clockwise from the 0° point. For the recumbent configurations (Configurations 2 and 5), the 0° position was always set to point up (perpendicular to ground surface), and for the rest of the configurations the position was arbitrary. On the interior of the shroud, four Type-K thermocouples were used to measure and allow modulation of the electrical power supplied to the silicon carbide rods, thus controlling the thermal environment. The angular positions on the shroud were aligned with the positions on the PCV. Figure 3 below demonstrates the thermocouple instrumentation on the PCVs and shrouds. A total of four thermocouples were installed on the PCV, with two thermocouples positioned on the 0° position about 1 inch apart (as was done on the shroud). The same configuration was applied to the shroud. Of the eight thermocouples installed, four thermocouples were monitored and recorded by the MIDAS system as NQA-1 data output and four thermocouples were monitored in the Control Room in support of heater rod power adjustments needed to attain the specified ASTM-E1529 temperature/flux profile. The four thermocouples monitored and recorded by the MIDAS system were, in all cases except two, the mid-height PCV thermocouples at 0°, 120°, and 240° positions and the shroud thermocouple at the 0° position. The exception to this was on Configuration 1 and

[1] The pressure relief hole is designed to relieve internal pressure from the PCV during opening while there is still thread engagement between the body and the lid. This prevents possible operator injury caused by pressurized ejection of the lid.

Configuration 4, and details of these exceptions are described in Sections 2.4.1 and 2.4.4, respectively.

As part of the initial conditions for each configuration, the vessel was pressurized to 200 psi using nitrogen. A Gefran KN2-series high temperature pressure sensor was used to ensure this pressure was reached when initially pressurizing, and the same sensor was also used to actively monitor pressure fluctuations during the test. Figure 4 shows a fully instrumented setup where the pressure sensor on the pressure manifold is highlighted. The Gefran pressure sensor output data was converted, within the MIDAS software to report measured pressure in psia as presented in the

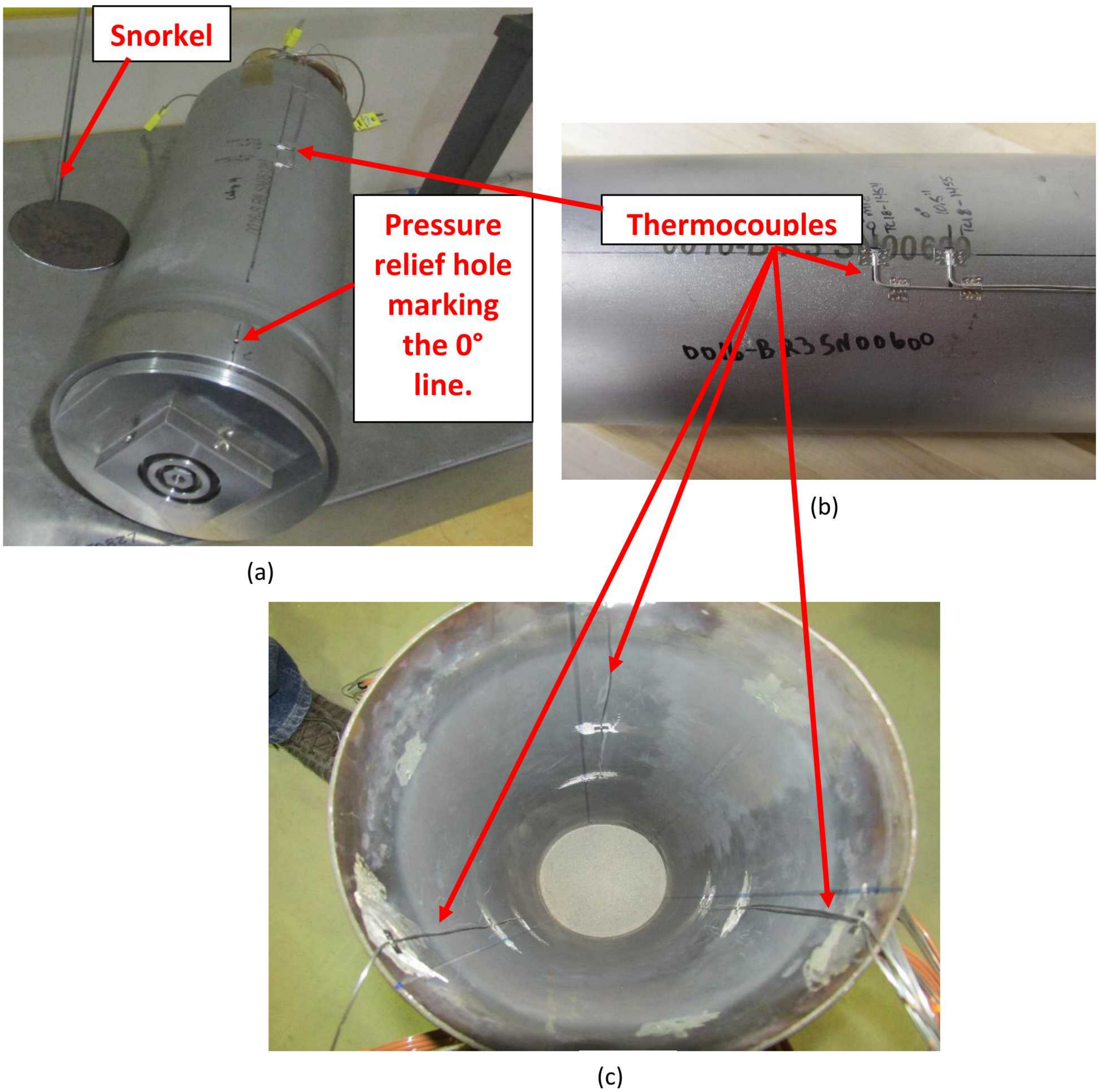



**Figure 3. TC Instrumentation. (a) shows the pressure relief hole denoting the 0° line, (b) shows a sample of TC placement on the PCV, and (c) shows TC placement in the shroud.**

pressure output curves for each test in Section 3. The data for the pressure conversion from volts to psi is documented in the Quality Assurance (QA) package provided by SNL under the pressure sensor calibration section. In this documentation, it is noted how the sensors were calibrated at approximately 23 °C. However, during testing, the manifolds where the pressure sensors were mounted were maintained at 200 °C. Section 6.3 in the Appendix shows how the pressure drift due to temperature changes was approximately 17 psi.

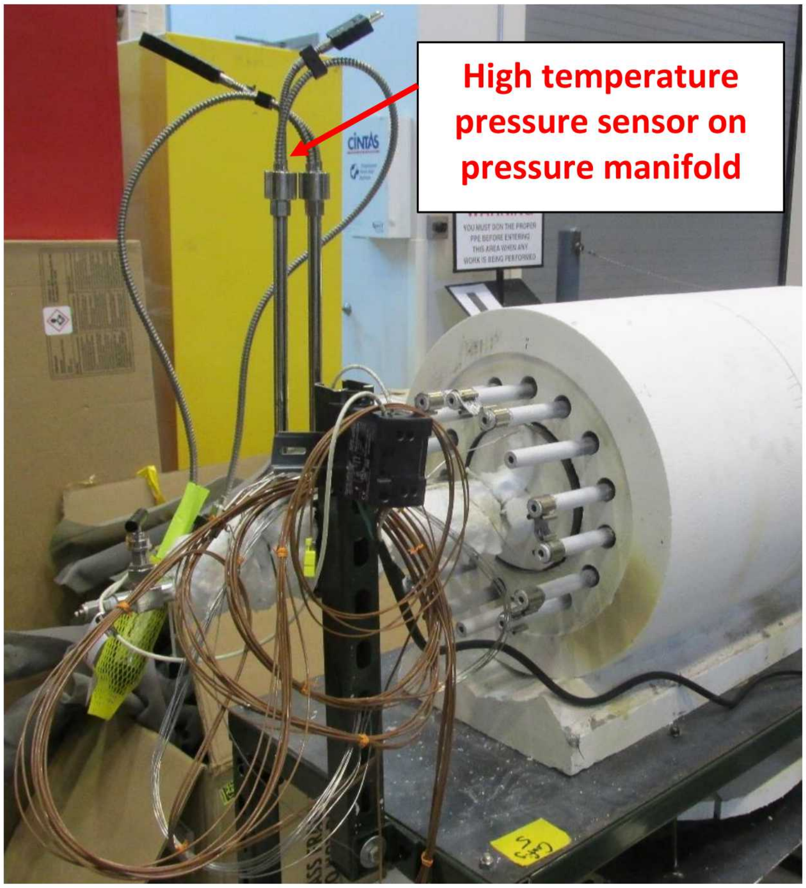


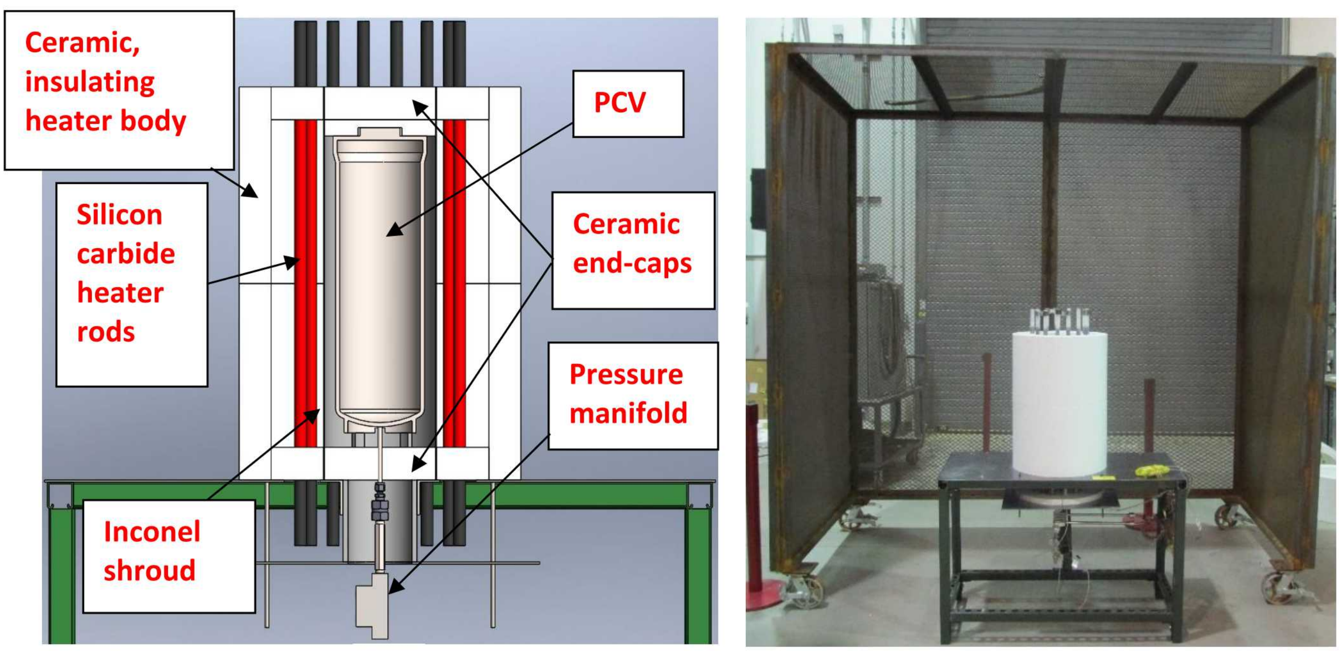

**Figure 4. Example of Full instrumentation showing TCs and Pressure Manifold.**

## 2.4. Configurations

While each configuration had its unique characteristics, they were all variations of the baseline configuration, Configuration 1. As noted previously, the primary goal of Phase 1 testing was to determine if the PCV could rupture in extreme thermal stress conditions prior to loss of the polymer O-rings and venting past the PCV lid. The five configurations were meant to simulate real or bounding fire scenarios; the unique characteristics of all five configurations are discussed in the subsections below.

### 2.4.1. Configuration 1

Figure 5 shows a schematic of the test setup for Configuration 1 along with an image of the actual test unit. A portable wire mesh cage, part of which is shown in Figure 5(b), was provided as a means to protect other equipment in the room. Configuration 1 aimed to model an engulfing fire for a PCV in an upright position where the top of the PCV is exposed to the cooler, top portion of the fire. In such a fire, the heat flux to the container top would normally be significantly lower than the heat flux to the container sides (which receive direct flame exposure). To properly simulate this scenario, the heater rods extended approximately 3/4 inches on both ends of the PCV, but the top of the head-end of the PCV was protected as shown in the schematic in Figure 5(a). In the schematic, where some of the major components of the test setup are also highlighted, the PCV is in an upright position, concentrically situated inside the heater assembly. As previously mentioned, the heater assembly is composed of silicon carbide heater rods with the insulating ceramic heater body, and the assembly is shown in both images of Figure 5. To ensure uniform radiant heat on the PCV during testing, an Inconel shroud was placed between the silicon carbide heater rods and the PCV. To attain the ASTM-E1529 standard fire environment, the interior of the heater was insulated from heat exchange with the environment using the ceramic end-caps shown. Lastly, the pressure manifold discussed in the prior subsection was located at the bottom of the assembly for this configuration. To better visualize the location of the shroud within the actual heater assembly, Figure 6 highlights the shroud and exterior components of the assembly.




(a                                        (b

**Figure 5. Baseline Test Configuration. Configuration 1, where (a) is a cross-sectional schematic of PCV inside the test unit, and (b) is an external view of the test unit.**

As mentioned above, an incorrect thermocouple connection was made with Configuration 1 during testing[2]. Instead of three PCV thermocouples and one shroud thermocouple being monitored and recorded in the MIDAS system, all four PCV thermocouples were connected to MIDAS and all four shroud thermocouples were connected to the Control Room. As a result, the shroud thermocouple data for Configuration 1 was not handled through an NQA-1 compliant system[2].

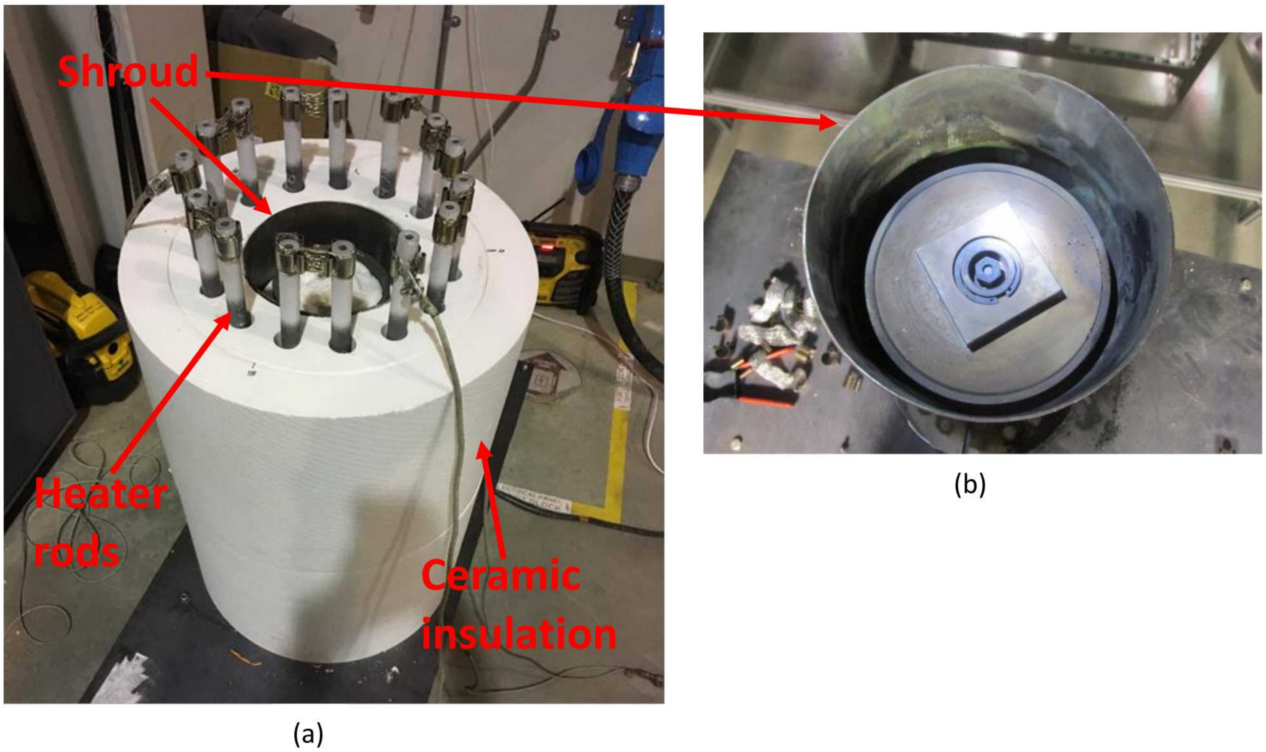



**Figure 6. Components of Test Assembly: (a) is the full heater and PCV assembly, and (b) shows the shroud with PCV inside.**

### 2.4.2. Configuration 2

Configuration 2 aimed to model a post-seismic fire scenario of a fallen/recumbent PCV with the bottom-end hanging over the end of a table it would sit on. It would also model a scenario where the bottom portion of the PCV rolls into a pool fire with the PCV's head end remaining outside the pool. This scenario would result in a fully engulfed bottom end of the PCV while the O-ring region (head-end) of the PCV would be shielded from the fire by the table. Therefore, the setup for Configuration 2 was similar to Configuration 1 with a few differences. The uniform heating boundary condition applied to Configuration 1 was applied to this configuration, but instead of placing the PCV in an upright orientation, the entire heater assembly was placed in a recumbent position as shown in Figure 7. Furthermore, as highlighted in this figure, a two-inch thick heater insulation barrier was placed at the head-end of the PCV to properly replicate the condition of the O-ring region being shielded from the fire. This insulation barrier intended to provide a

2 SRNS was notified at the time of testing and is aware of the non-NQA-1 shroud temperature measurements.

conservative boundary condition as it prevented the head-end from being exposed to the imposed heat flux, and it further allowed any heat conducted towards the head-end to be cooled through convective and radiative heat exchange with the ambient.

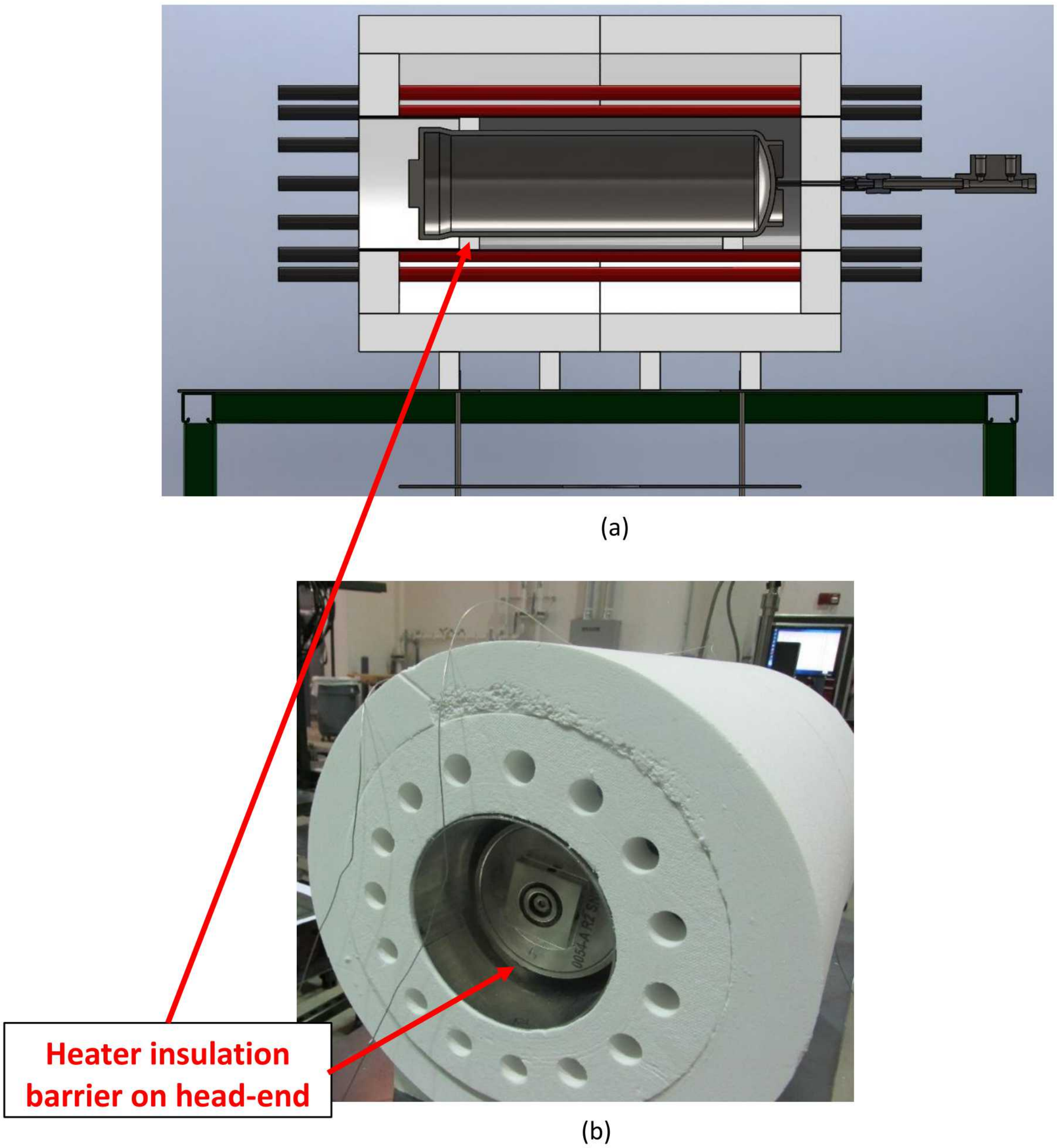
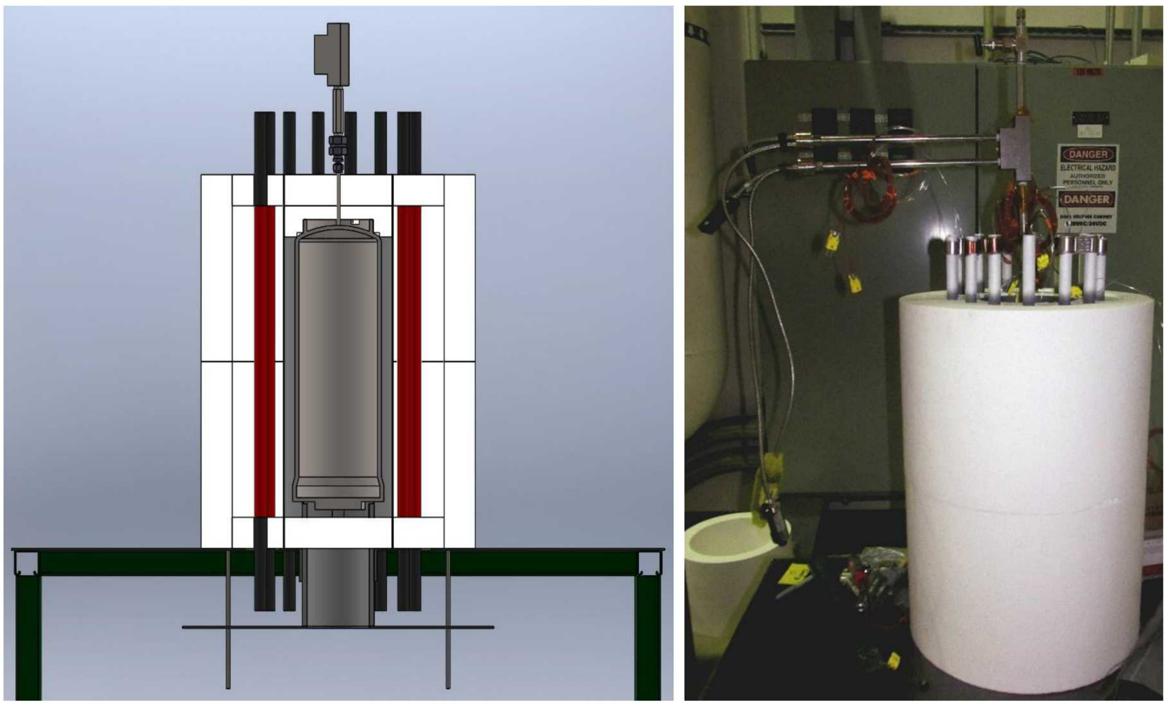



**Figure 7. Heater and PCV Setup for Configuration 2. Head-end is exposed to ambient and guarded from heating section by the insulation barrier shown. (a) shows a cross-sectional schematic, and (b) is an image from actual test prior to installing heater rods.**

### 2.4.3. Configuration 3

Similar to Configuration 2, Configuration 3 intended to mimic a hypothetical post-seismic fire scenario of a fallen PCV, but rather than assuming that the PCV would result in a recumbent position, the PCV was assumed to result in an inverted orientation. Therefore, this configuration varied from the baseline in that the PCV was placed in an inverted orientation (head-end down, pressure manifold up). While this condition may not be expected, it was chosen to be able to evaluate all scenarios. Similar to the baseline, the uniform heating boundary condition applied to Configuration 1 was also applied to this configuration. The inverted orientation can be noticed in Figure 8, which shows a schematic and an image of the actual setup.



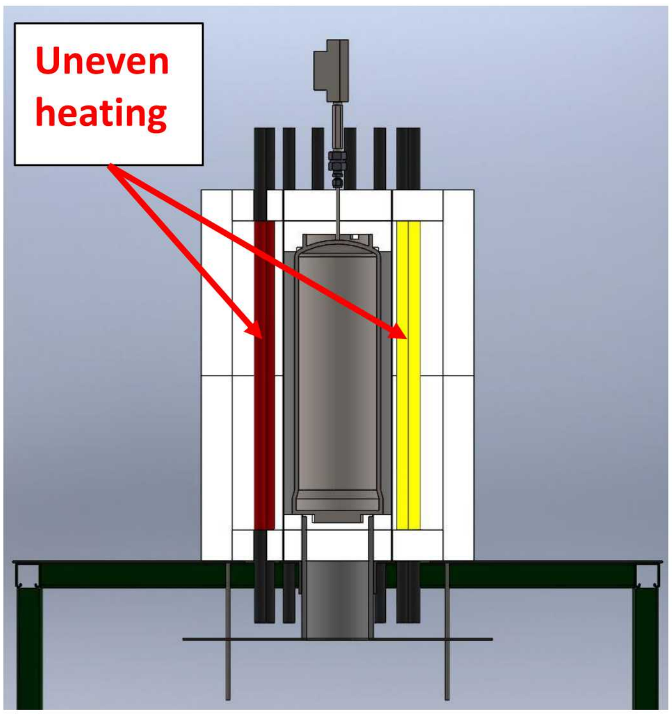

(a) (b)

**Figure 8. Heater and PCV Setup for Configuration 3, Where PCV is Inverted. (a) shows cross-sectional schematic, and (b) shows actual setup.**

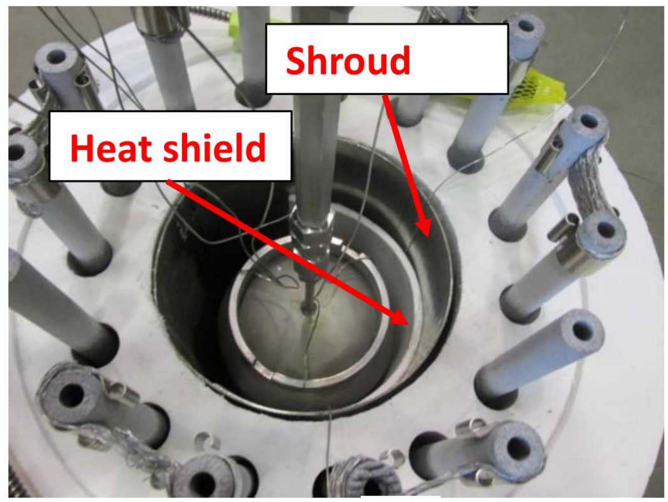
### 2.4.4. Configuration 4

Configuration 4 intended to simulate a post-seismic scenario of a fallen and inverted PCV where an adjacent fire does not fully engulf the PCV. This configuration was thus similar to Configuration 3 in that the PCV orientation was inverted, however, the heating boundary condition was applied non-uniformly in an attempt to capture the physics of a partially engulfed PCV. Figure 9 depicts the setup and boundary conditions of Configuration 4. The uneven heating was applied by using the same heater setup as in prior configurations, but a heat shield was placed on 240° (2/3) of the perimeter in between the shroud and the vessel, as shown in Figure 9(b). The heat shield was placed to cover the area between the angles of 60° and 300° on the perimeter of the shroud, resulting in 60° of non-shielded area on either side of the 0° reference point.

For this configuration, three thermocouples were incorrectly connected to MIDAS. Instead of connecting the shroud thermocouple at 0° to the MIDAS input, the shroud at 120° was connected. Secondly, instead of connecting the PCV TC at 120°, the secondary thermocouple at 0° was connected. Thirdly, instead of connecting the PCV at 240°, the PCV at 120° was connected. As a result, the shroud thermocouple data at 0° and the PCV thermocouple data at 240° was not handled through an NQA-1 compliant system, similar to the shroud temperature for Configuration 1.




(a)




(b)

**Figure 9. Heater and PCV Setup for Configuration 4. (a) is a cross-sectional schematic of Configuration 4, showing the uneven heating boundary condition, and (b) is a top view of the actual setup.**

### 2.4.5. Configuration 5

Configuration 5 was similar to Configuration 2, but Configuration 5 intended to simulate a post-seismic scenario where the entire PCV is fully engulfed by a fire (as opposed to the partial engulfment boundary condition set in Configuration 2). Therefore, this setup was similar to the baseline with a uniform heat flux boundary condition but with the test unit placed in a recumbent position. Different from Configuration 2, however, the head-end of the PCV was not insulated from the heater radiation and was instead exposed to the heat flux over the full length of the PCV. The insulation placed at the ends of the heater was to prevent heat losses to the ambient, as was done with Configuration 2. Figure 10 depicts the setup and boundary conditions for Configuration 5.

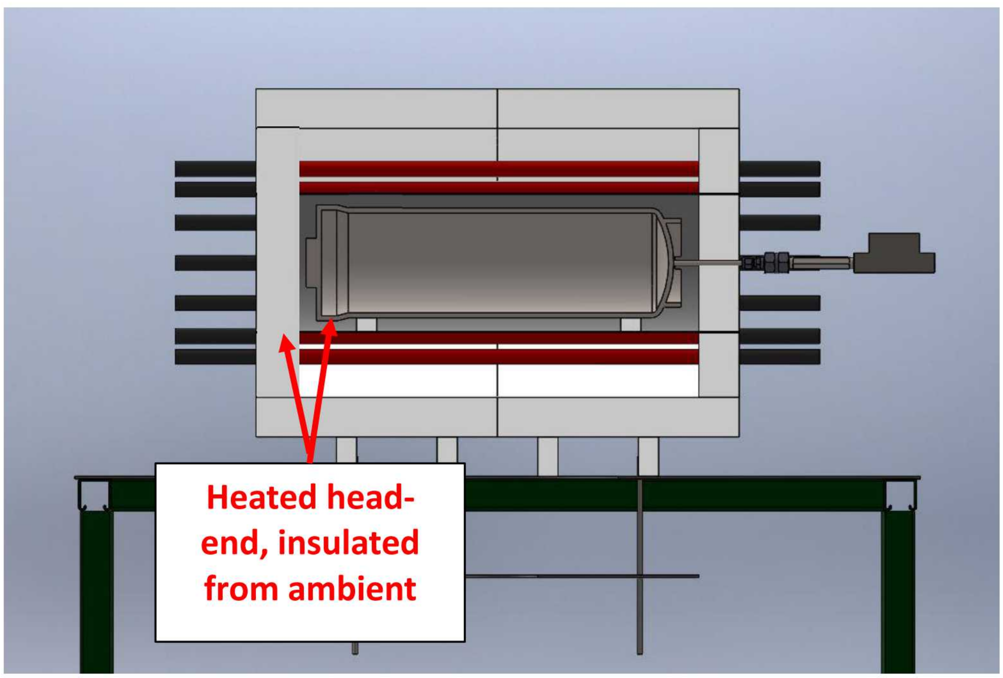



**Figure 10. Cross-Sectional Schematic of Configuration 5, showing how the head-end was heated and insulated from ambient.**

## 2.5. Test Protocol – Event Timing

Due to the non-linear behavior of the silicon carbide heater rods when subjected to high electrical current at early times, one cannot assume the electrical "power on" event will serve as a fiducial mark for all subsequent events. Instead it was elected to use the attainment of the 1.0 $kW/m^2$ flux level by the shroud (90°C) as a meaningful starting mark. This mark was set post test, and as such, all measurement data in this report is normalized from that point. Data recorded from the power-on event is retained in the QA record data for the test series.

# 3. RESULTS

The five configurations mentioned in Section 2.4 were tested as outlined, and the results of each test are presented in the subsections below. For the incident heat flux, ASTM-E1529 specifies an imposed heat flux of 158 kW/m2 to be reached within 5 minutes of the initial testing point (ASTM, 2014). The flux imposed by the heaters on the PCV wall is difficult, if not impossible, to measure using equipment that wouldn't alter the way the PCV would react under heating. Instead of using equipment within the test setup to measure the imposed heat flux on the PCV, the flux was calculated using the temperature measured on the shroud. Based on the design of the enclosed ceramic heater assemblies, the theory for radiation within a cavity could be used and the heat flux on the PCV could thus be calculated with the Stefan-Boltzmann Law using the shroud temperature ($q = \sigma T^4$, where $\sigma$ is the Stefan-Boltzmann constant), where the surface behaves like a black body. Section 6.2 in the Appendix describes a calorimeter analysis performed that confirms this type of approach taken to calculate the incident heat flux on the PCV using the shroud temperature.

For configurations that resulted in a ruptured vessel during testing, the power to the heaters was removed at the time of rupture. For configurations that only resulted in breached O-rings, after the pressure inside the vessel was expelled due to the breached O-rings, the incident heat flux was imposed for an additional 20-30 minutes to investigate whether some degree of re-pressurization of the PCVs would occur. Figure 11 below shows examples of these two types of heat flux profiles imposed, where configurations 2 and 3 experienced a rupture, and configurations 1 and 5 only experienced a release through the O-rings. ASTM-E1529 specifies that the test setup should provide a cold wall heat flux of 158 kW/m$^2$ ± 8 kW/m$^2$ on all exposed surfaces of the test specimen within the first 5 minutes of test exposure and should be maintained for the duration of the test. By defining the beginning of each test as the point where the shroud is imposing a 1 kW heat flux, the fluxes for each configuration are compared against the ASTM standard to show that the criterion was met when assuming a linear rise to 158 kW/m$^2$ within 5 minutes for the standard. A profile for Configuration 4 was not provided because the shroud was purposely heated non-uniformly, but a similar power input to the heaters was provided as in the other four configurations.

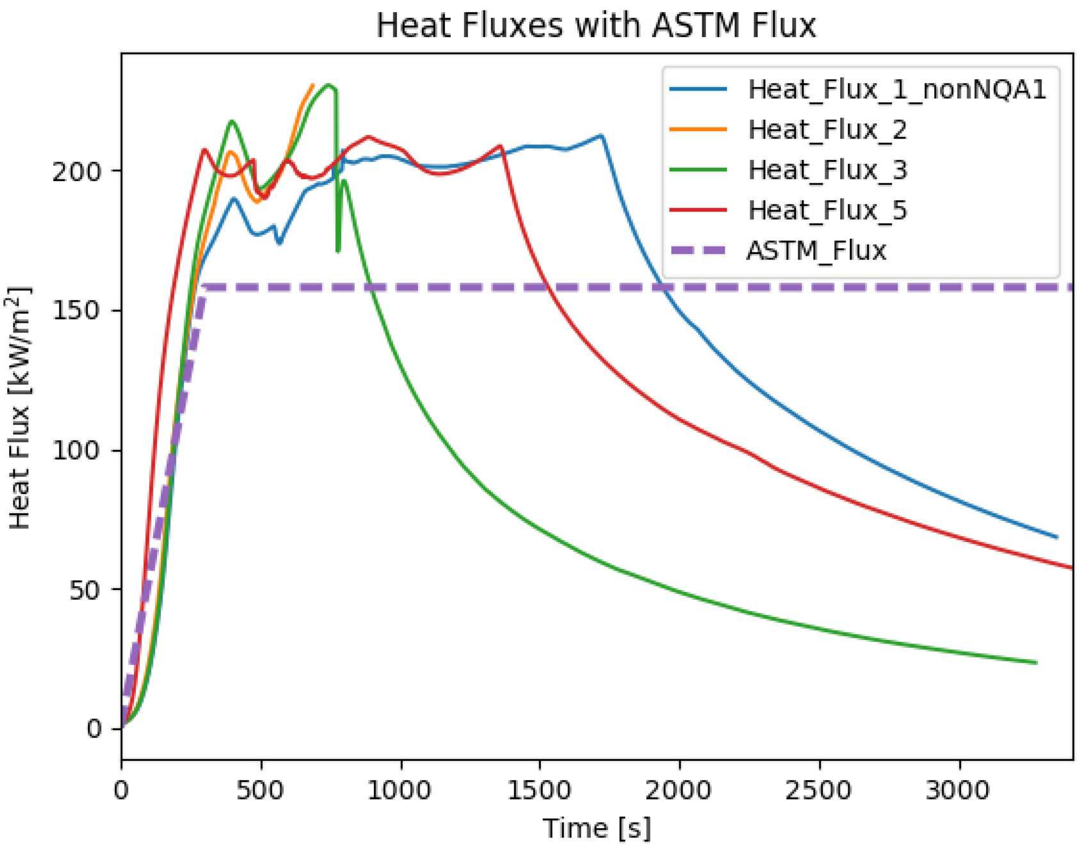



**Figure 11. Configuration Heat Flux Profiles Based on Mid-Height Cold Side Shroud Temperatures as compared to ASTM-E1529 standard.**

ASTM-E1529 also specifies that "the temperature of the environment that generates the heat flux shall be at least 815 °C after the first 3 minutes of the test and shall be between 1010 °C-1180 °C at all times after the first 5 minutes of the test". Figure 12 shows how these conditions were met by showing the shroud temperatures, where the change in slope (highlighted by the two blue x's) marks the 815 °C and 1010 °C temperatures at 3 and 5 minutes, respectively. The vertical axis was set to show a maximum of 1180 °C in order to show that the profiles fully satisfied ASTM-E1529.

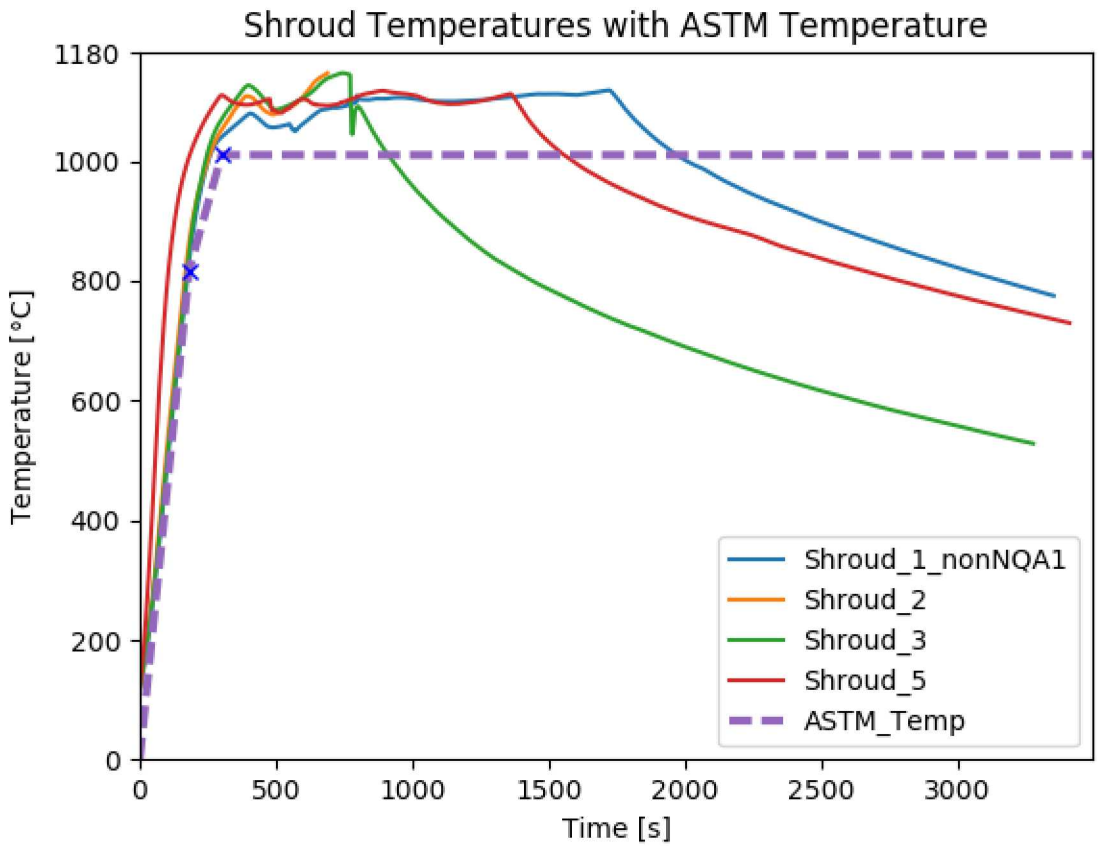



**Figure 12. Configuration Temperature Profiles as compared to ASTM-E1529 standard.**

Each configuration tested produced a different outcome as captured by the post-test images and the recorded temperature and pressure data. All pressure and temperature data were recorded using SNL's Mobile Instrumentation and Data Acquisition System (MIDAS), where the MIDAS global clock was used to synchronize the two types of data for each test. For each configuration, images of the remains are shown along with plots of the temperature and pressure profiles in the discussions below. For each of the temperature and pressure plots, the legends were set to where the three thermocouples on the PCV were denoted by the suffix "P" and the three digits in the label corresponded to the angle at which they were placed on the PCV. As mentioned in Section 2.3, the angles were measured clockwise from the 0° point, which was marked by the pressure relief hole on the head-end. The thermocouples on the shroud are denoted by the suffix "S" in the plots, and the angles were set to match the angles on the PCV. Discussions for each configuration are presented below. In these discussions, it should be noted that, while pressure profiles are provided until the end of each test to visualize behavior, SNL does not guarantee accuracy of the pressure magnitude after peak pressures are reached due to drift arising from the sensors being exposed to temperatures outside their calibrated range.

### 3.1. Configuration 1

Configuration 1 was the baseline for this test series. The heating boundary condition applied to Configuration 1 was expected to cause enough softening of the O-rings to allow pressure relief via the pressure relief hole and prevent vessel rupture. Figure 13 shows how this did indeed happen and how Configuration 1 did not result in a ruptured vessel. Inspection of the pressure and temperature evolution of the configuration plotted in Figure 14 shows how the temperature rise around the PCV is immediately followed by the pressure rise inside the PCV. The pressure measurement shows how the PCV never experienced pressures above 500 psia. When examining the temperature profiles, the rise in temperature around the PCV was symmetrical, directly demonstrating that heating was symmetrical around this test unit. As noted in Section 2.3, a shroud temperature was not recorded through the MIDAS system. For the purposes of this report, a non NQA-1 shroud temperature is shown, which shows how the imposed heat was retained for approximately 20 minutes after seal failure.

A review of the test data indicates this container released as expected, by failure of the inner and outer O-rings and release of gas/particulate via the pressure relief hole located at the head end of the container (note the discoloration at the pressure relief hole location in Figure 13). The pressure inside the PCV initially reached approximately 438 psia at about 726 seconds into the test. At this point, the PCV relieved pressure over a period of about 13 seconds (initially at about 5 psi/sec then slowing to around 1 psi/sec) down to about 412 psia. At 739 seconds, the PCV began to re-pressurize until at 808 seconds (471 psia), the final pressure release occurred, at a rate of approximately 140 psi/sec. The peak (of three) radially spaced mid-height thermocouple readings at these three points was 655 °C at 726 seconds, 672 °C at 739 seconds, and 763 °C at 808 seconds. There is insufficient information to conclude what caused the re-pressurization after the initial pressure drop. However, the data indicates that all temperature readings were increasing over this time in accordance with the specified ASTM E1529 temperature/flux profile, thereby negating consideration of attributing the cause to variations in heater rod input by the Control Room Operator. Clearly, O-ring degradation at 726 seconds permitted leakage from the PCV. There is some conjecture that the softened O-rings plugged the leak to permit the PCV to again hold pressure for another 69 seconds, at which point O-ring degradation was sufficient to result in complete depressurization of the PCV. Nonetheless, it's clear that the PCV in Configuration 1 reached a peak pressure of 471 psia at 808 seconds into the PCV

It is noted that this phenomenon occurred very early and to a much less significant degree in Configuration 5. It did not occur on the other Phase 1 tests. While the data from the other tests shows there were pressure perturbations at the time of release, none resulted in re-pressurization of the PCV; these perturbations are attributed to other phenomena as discussed in those test results.

Thermocouple measurements at the 0° position were noticeably cooler (~100 °C) than measurements at the 120° and 240° positions. A similar response is noted in other configurations. Data from recumbent Configurations 2 and 5 shows the 0° thermocouples reached temperatures higher than the other thermocouples in each test. It is concluded that where the oval-shaped payload package was in direct contact with the inside of the circular PCV, the oxide mass provided a heat sink to maintain cooler sidewall temperatures at those locations. Although, the orientation of the payloads within the PCV was not recorded, the recumbent configurations were both oriented with the 0° pressure relief hole pointed up. There would be no direct contact of the payload with the interior of the PCV at the 0° thermocouple location (i.e., less heat sink) and therefore, a higher temperature. The same can be concluded for the area around the O-rings. The PCV lid at that location is a solid piece of stainless steel except for the small leak test groove and leak test port (see Figure 1). The additional mass of the lid, in strong contact with the PCV outer wall, would provide a direct path for heat transmission away from the outer wall into the solid lid. Although no temperature measurements were taken at the O-rings, the lack of O-ring decomposition prior to the times specified above clearly indicates that the head end region of the PCV stayed cooler than the mid-height location of the thermocouples. That is, the O-rings were still intact beyond the point where the thermocouples (attached mid-height on the PCV) reached the O-ring decomposition temperature of 475-525 °C (Laurinat, 2017). Because incident thermal flux was evenly distributed by the Inconel shroud, the only mechanism for this axial temperature gradient would be the extra thermal mass in the head end region as compared to regions with no payload mass. PCV wall temperatures in the areas with payload mass (bottom portion of PCV in Configuration 1) would be expected to be even lower than the upper head end wall temperatures. This is additionally supported by the PCV response in later test configurations as discussed in those sections of this report.

Finally, it is noted that the shroud temperatures dropped slightly at both times of pressure drop, then increased. Even though Configuration 1 shroud temperature measurements are not NQA-1 verifiable, the measurements are considered accurate as the phenomena (temporary shroud temperature drop at pressure release) is present in other test configurations. It is determined that the immediate temperature drop is due to the relatively cooler PCV internal gas impinging on the shroud and flowing around the shroud thermocouple positions during release. This only lasts until either the gas is fully expelled, or the gas ignites (see Figure 13).

Additional post-test analysis, including comparison of pre-test post-test weights, indicate that Configuration 1 mass decreased by 254 g. There was no detailed post-test analysis of container contents. So, there is no determination of the amount of plastic, water, and powder released from the container. Instead, an upper bound estimate of powder mass lost (assuming no loss of plastic or water from the container) and a lower bound estimate of powder mass lost (assuming all of the plastic and water were vaporized, or otherwise released in the container failure, before any powder could get out) is calculated. In the worst case (upper bound), all 254 g lost would be powder. This represents 19% of the powder in the payload, or mass loss fraction of 0.19. In the best case, all 254 g lost would be plastic and water. The amount of powder released would be 0.0. It is noted here that neither the upper, nor lower bound cases are physically realistic. The actual amount of powder lost would be somewhere in between these two cases and would skew toward the best case because moisture vaporization and pyrolysis of plastic were needed to cause the pressurization experienced. This evaluation is conducted for each configuration, except Configuration 2 (see Section 3.2) and is summarized for all tests in Table 5.

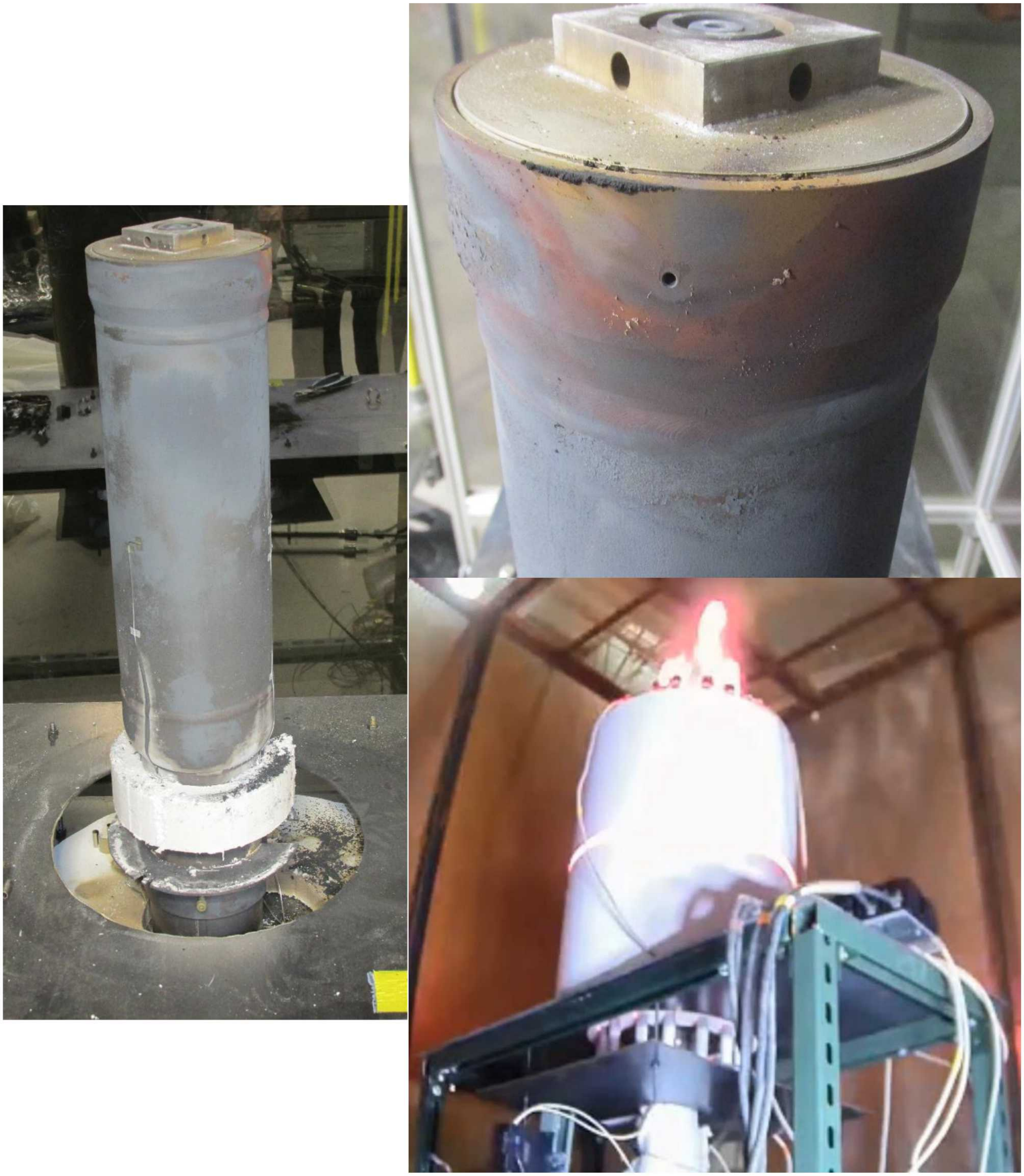


**Figure 13. Configuration 1 Post-test PCV and Video Image Showing Flames During Test.**

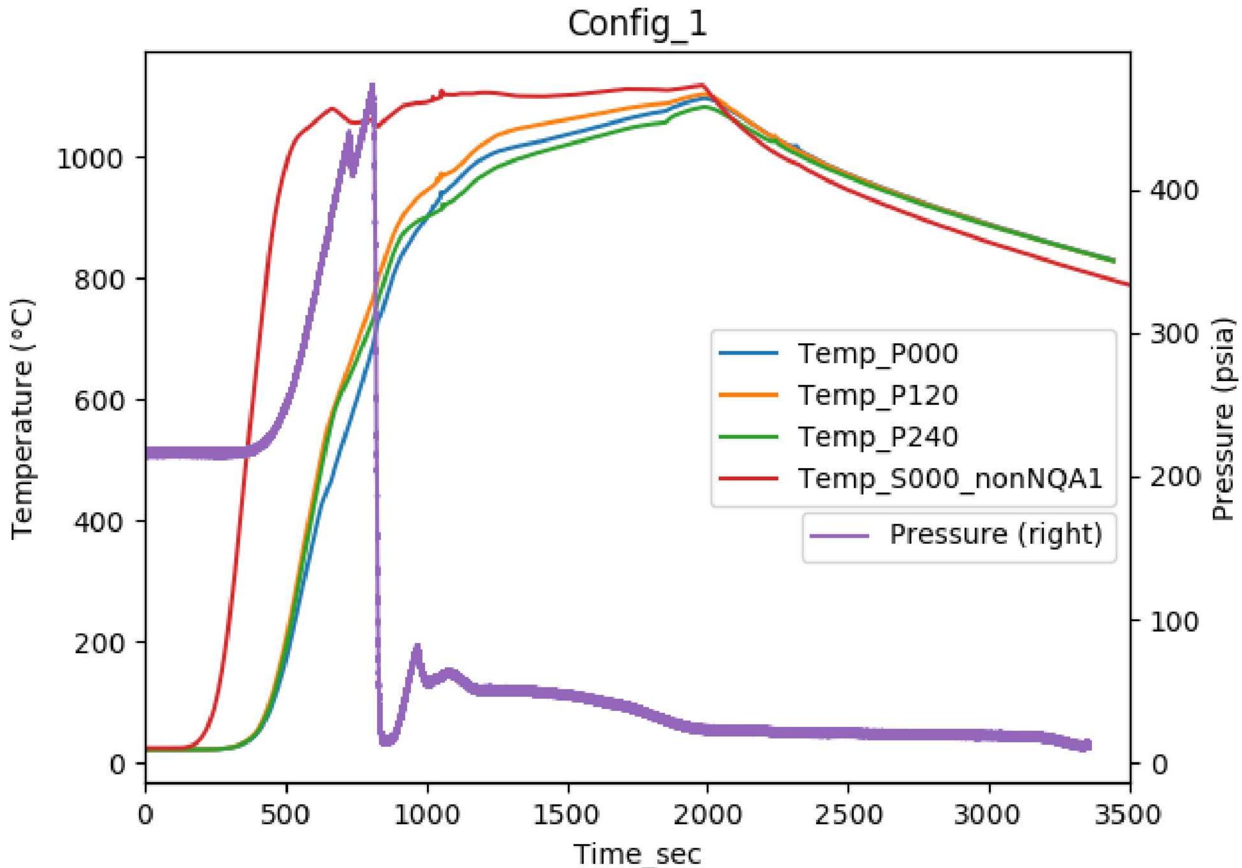



**Figure 14. Temperature and Pressure Profiles for Configuration 1.**

## 3.2. Configuration 2

The heat flux imposed on Configuration 2 was set to have a similar profile as that imposed on Configuration 1 as defined by the ASTM-E1529 standard. As mentioned in Section 2.4.2, the main differences on the boundary conditions of Configuration 2 was that a ring of insulation was covering an area two inches long around the perimeter of the PVC on the head-end, and the PCV was in a recumbent position. The insulating ring prevented the O-ring region from receiving direct, radiative heat exposure and allowed the head-end to be open to the ambient. The open section of Configuration 2 further allowed any heat conducted into the O-ring region from the rest of the PCV to radiate into the ambient room as well as receive further cooling through convection with the ambient air. The recumbent position of Configuration 2 conservatively permitted full length heating of the PCV sidewall over a portion of its circumference as compared to partial length heating of the sidewall over its full circumference (as might occur in an actual fire scenario). By comparison, Configuration 2 permitted the greater surface area for heating without a heat sink. Further details of the setup for this configuration were discussed in Section 2.4.2.

Figure 15 shows the remains of the Configuration 2 PCV, which shows how the configuration resulted in a catastrophically ruptured vessel. The remains indicate that the cooler O-ring region prevented degradation of the O-rings for Configuration 2 when compared to Configuration 1.

Figure 16 shows how the pressure steadily rose after experiencing the initial temperature increase on the PCV thermocouples. The fact that the figure also shows the steep and consistent temperature gradient of the PCV wall during the test further suggests that O-ring degradation seems to have been prevented for this configuration. Figure 16 further shows how the peak pressure observed by Configuration 2 was approximately 1,100 psia. At this peak pressure, the pressure instantly dropped, indicating that this was the point of vessel rupture. This point of rupture is also indicated by the simultaneous loss in temperature data which resulted from the thermocouples detaching during the rupture. Consequently, since this configuration resulted in a ruptured vessel, it serves as a condition in which the hypothesis mentioned in the introduction fails.

No post-test measurements were conducted for Configuration 2. It is clear from Figure 15 that a large portion of all parts of the payload, and the snorkel plate were ejected from the container.

**Figure 15. Post-test PCV for Configuration 2.**

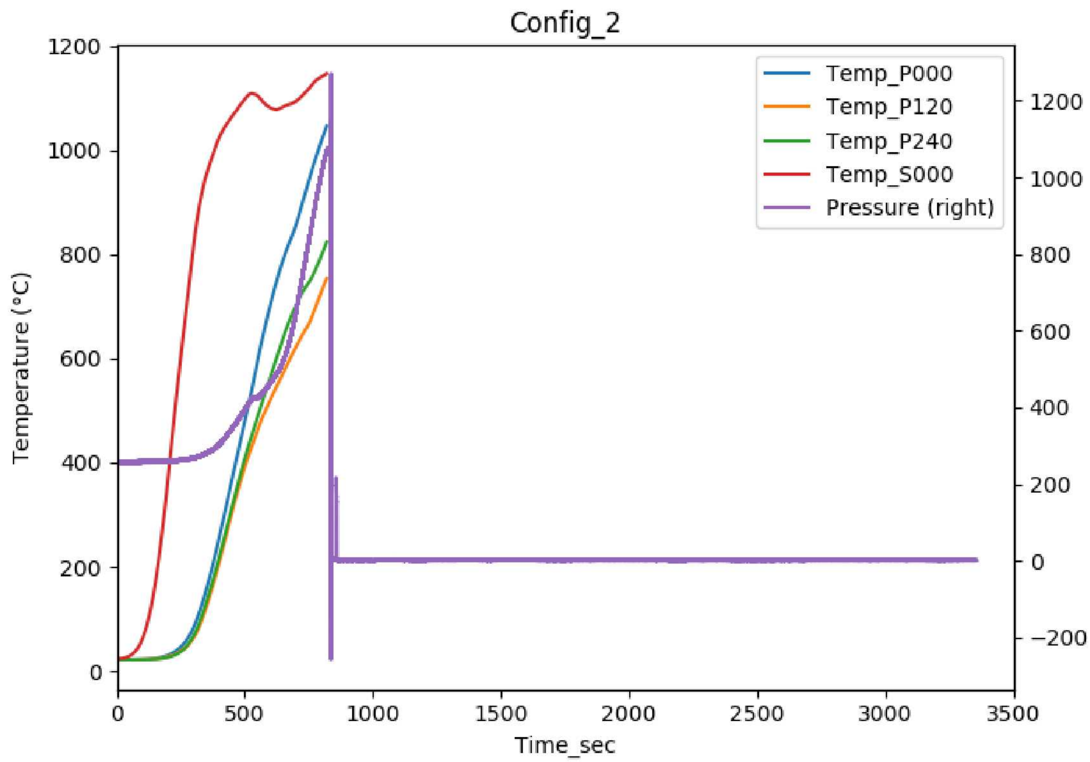



**Figure 16. Temperature and Pressure for Configuration 2.**

### 3.3. Configuration 3

Configuration 3 varied from Configuration 1 in that the PCV was inverted to represent a hypothetical post-seismic fire scenario of a fallen and inverted PCV. However, as previously stated, the heat flux imposed on this configuration followed a similar profile to Configuration 1. Further details of the setup for this configuration were discussed in Section 2.4.3.

In Figure 17, it can be seen how the tested PCV for Configuration 3 bulged to the point of failure, resulting in a ¾ inch longitudinal fracture. This fracture location would suggest that, since the PCV was inverted, the internal contents served as a heat sink and helped obstruct heat transmission to the O-ring region inside the PCV. The swelling observed in Figure 17 was also large enough to cause the PCV to expand out to the shroud and deform it. The swelling was not radially uniform, but it did swell around the entire circumference of the PCV. As a result of that contact, it is uncertain whether the shroud prevented the PCV from expanding further to create a larger opening than the ¾ inch fracture observed. Similar to the test for Configuration 2, Figure 18 shows how the pressure inside the PCV steadily increased as the temperature rose until reaching a peak pressure of approximately 780 psia. While it is not fully known, perturbations in the pressure profile were initially speculated to be caused by heater rod power adjustments made by the Control Room Operator. A pressure drop of about 10 psi occurs very early (at about 6 minutes) in the heat-up process. The pressure drop only lasts for 2 seconds. The mid-height sidewall (on the PCV) temperatures at this point are slightly above the O-ring degradation temperatures cited above. However, given the mass of oxide between the thermocouple location and the O-rings, it is highly unlikely that O-ring degradation is involved in this very short-lived pressure dip as it was for a similar pressure perturbation in Configuration 1. Another perturbation occurs at about 580 seconds into the test, where the PCV internal pressure increases by less than 1 psi over a period of about 15 seconds. Since PCV sidewall temperatures are in the range of 570°C at this point, it is very unlikely that the container is swelling. Another possibility, though also unlikely, would be degradation of the inner O-ring. If this occurred, it would very slightly increase the PCV free volume to include the leak port volume. However, the mid-height temperatures are just barely above the O-ring degradation temperatures, and the heat sink around the O-rings would most likely prevent significant heat-up of the O-ring at the bottom of the test assembly. The peak PCV pressure occurs at 782.4 psia, 904 seconds into the test. The highest mid-height sidewall temperature at this time is about 986°C. This condition is immediately preceded by a slight levelling, or rollover, of the pressure curve over the previous 3-5 second timeframe which is postulated to be caused by PCV swelling which results in expansion of the PCV internal volume. The swelling is indicative of the stainless-steel side wall reaching its yield strength in the area of the PCV void space (above the payload). The pressure rollover is followed by an immediate pressure drop of about 730 psi, indicating the vessel wall is breached. At this point of vessel failure, it is presumed that the fracture observed in Figure 17(c) allowed immediate pressure relief. This pressure relief is believed to create a brief and local convection current that caused the shroud temperature to drop as seen in Figure 18. The immediate shroud temperature increase after this is likely due to ignition of released decomposition gases with substantial flaming from both ends of the test assembly (Figure 21). The subsequent, steady temperature decline corresponds to the point where, unlike Configuration 1, the imposed heat was removed; i.e., at the point of vessel rupture.

Post test weights of Configuration 3 indicate the exact same weight loss as Configuration 1 (254 g). the upper and lower bound powder mass loss fraction is 0.19 and 0.0, also identical to Configuration 1. It is suspected that the deformation of the shroud caused by swelling of the PCV resulted in direct contact between the two at the point of the longitudinal tear in the PCV. The direct contact likely impeded, or restricted, the release of material from the container and reduced the amount of powder that was lost in the release.

(a) (b) (c)

**Figure 17. Post-test PCV for Configuration 3. (a) shows the shroud bulging, (b) is a full view of the PCV, and (c) zooms in on the fracture experienced by the PCV.**

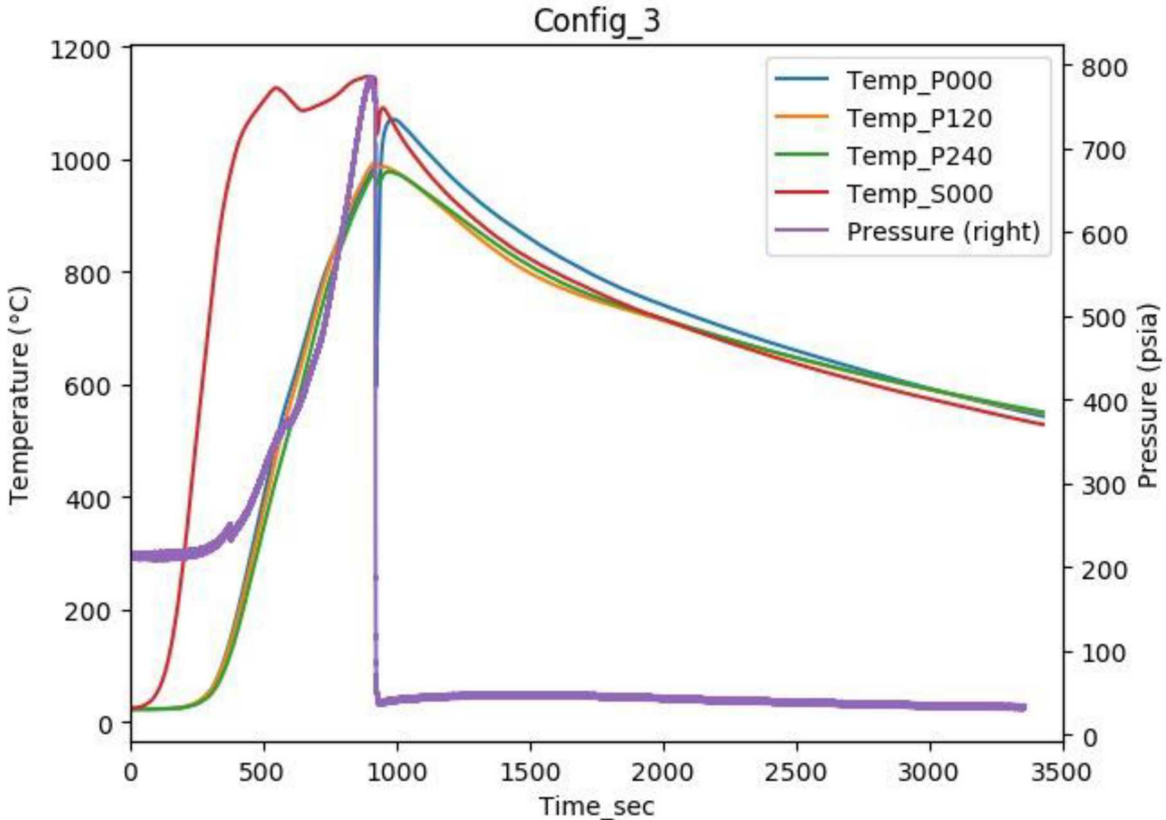



**Figure 18. Temperature and Pressure Profiles for Configuration 3.**

### 3.4. Configuration 4

The boundary conditions of Configuration 4 are identical to those of Configuration 3 except that heating of the PCV was applied non-uniformly in the angular direction by insertion of an insulating heat shield between the PCV and the shroud (see Figure 9(b)). The heat shield provided limited flux attenuation over approximately 240° of the PCV surface. It should be noted here that, because one of the boundary conditions for this configuration was a non-uniform heat flux, the shroud temperature provided for Configuration 4 cannot be used to determine the heat flux to the PCV. Also, as noted Section 2.3, the shroud temperature at 0° and the PCV temperature at 240° were not recorded through the MIDAS system. For the purposes of this report, however, non NQA-1 temperatures for these two locations are shown. Specific details of the full setup for this configuration were discussed in Section 2.4.4.

Figure 19 shows the resulting PCV for Configuration 4 at the end of the test. When visually compared to Configuration 3, the rupture experienced by the PCV in Configuration 4 was more severe. The plots in Figure 20 help explain why the rupture in Configuration 4 would be more severe than in Configuration 3. In this figure, it can be seen how the pressure almost reached 983 psia just before rupture, at which point the pressure immediately drops to atmospheric conditions. The higher pressure reached by Configuration 4 (when compared to Configuration 3) is attributed to the uneven heating. Note that the rupture in Configuration 3 (Figure 17) is a longitudinal tear at the 0° position, likely along the vertical seam of the PCV and the rupture in Configuration 4 (Figure 19) is a radial tear along the bottom end weld, also at the 0° position. Figure 20 shows how the 0° position on the PCV experienced the highest temperature while the 120° and 240° positions saw lower temperatures. This is consistent with the description given in Section 2.4.4, where it was described how the heat shield covered the area between 60° and 300°, thus shielding the 120° and 240° positions. At the point of rupture, the three thermocouples were reading 964 °C, 791 °C, and 729 °C for the 0°, 120°, and 240° positions, respectively.

Due to the inverted orientation of Configuration 4, it is likely that the O-rings were protected, as in Configuration 3, by the heat sink provided by the payload mass and solid steel lid construction, thus limiting the softening of the O-rings. Furthermore, the PCV rupture in Configuration 4 was also much more energetic than Configuration 3, which resulted in damage to the heater assembly by insulation debris (likely the heat shield) being forcibly ejected as can be seen in Figure 21. Note that PCV swelling for Configuration 4 was not evident around the circumference of the container as it was in Configuration 3, a condition supported by the shape of the tear peeling outward from the PCV. Figure 22 provides a comparison of the two and shows that the heat shield was sufficiently effective to delay weakening of the PCV sidewall on one side of the PCV. Consequently, the volumetric increase due to swelling was less in Configuration 4 than it was in Configuration 3. It is not clear how this volume difference might have affected pressurization and rupture. A few conjectures are discussed in Section 4.

Similar to Configuration 3, the temperature profiles show a slight drop in temperature at the instant the pressure was relieved when the PCV ruptured. Again, this temperature drop was more than likely a consequence of a brief and local convection current created by the gases expelled when the PCV ruptured. The subsequent steady temperature decline on the shroud and PCV corresponds to the point when the heaters were turned off.

Post test weights of Configuration 4 indicate a significantly greater mass loss than any of the other configurations except configuration 2. A total of 608 g of material was lost in this test. Using the same approach as described for Configuration 1, the upper bound powder mass loss fraction is calculated as 0.45 and the lower bound is 0.26. That is, between 26% and 45% of the original powder mass was ejected from this PCV at a release pressure of approximately 970 psig. The PCV was reported as being difficult to remove from the shroud after the test, but no indication of shroud deformation was found. Therefore, the shroud probably did not impede the release of material from the container as it might have in Configuration 3.

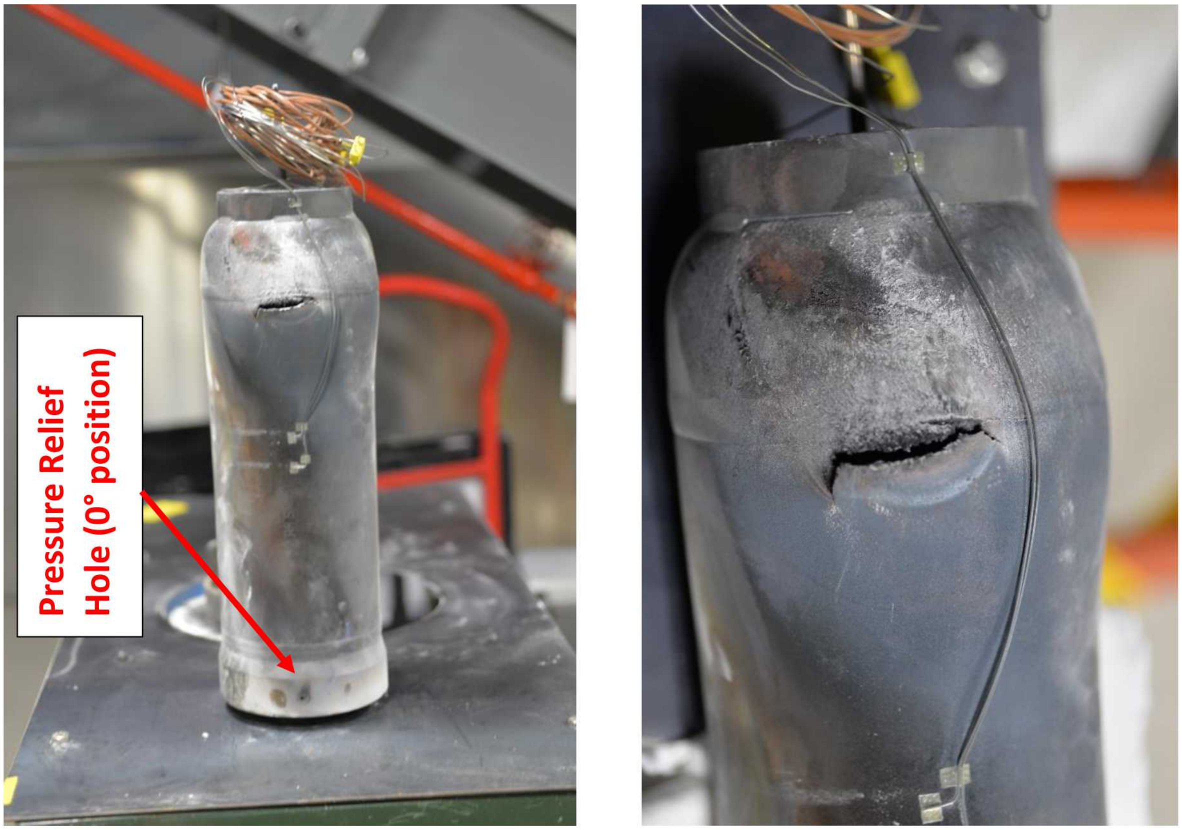



**Figure 19. Post-test PCV for Configuration 4. (a) is a full view of the PCV, and (b) zooms in on the rupture experienced by the PCV.**

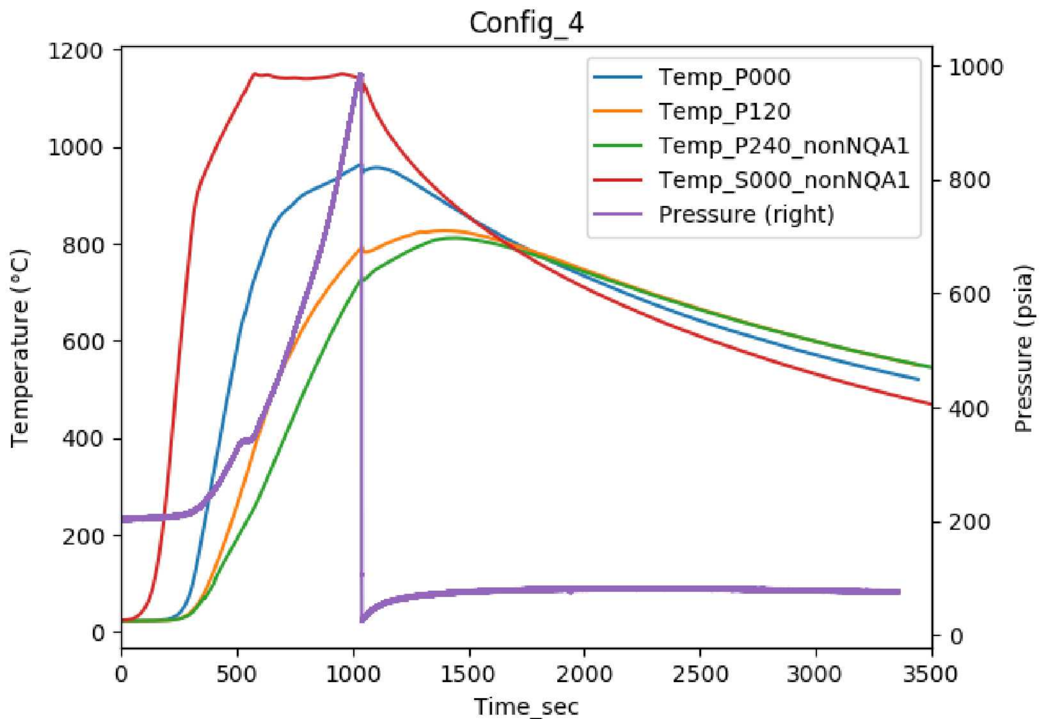



**Figure 20. Temperature and Pressure Profiles for Configuration 4.**

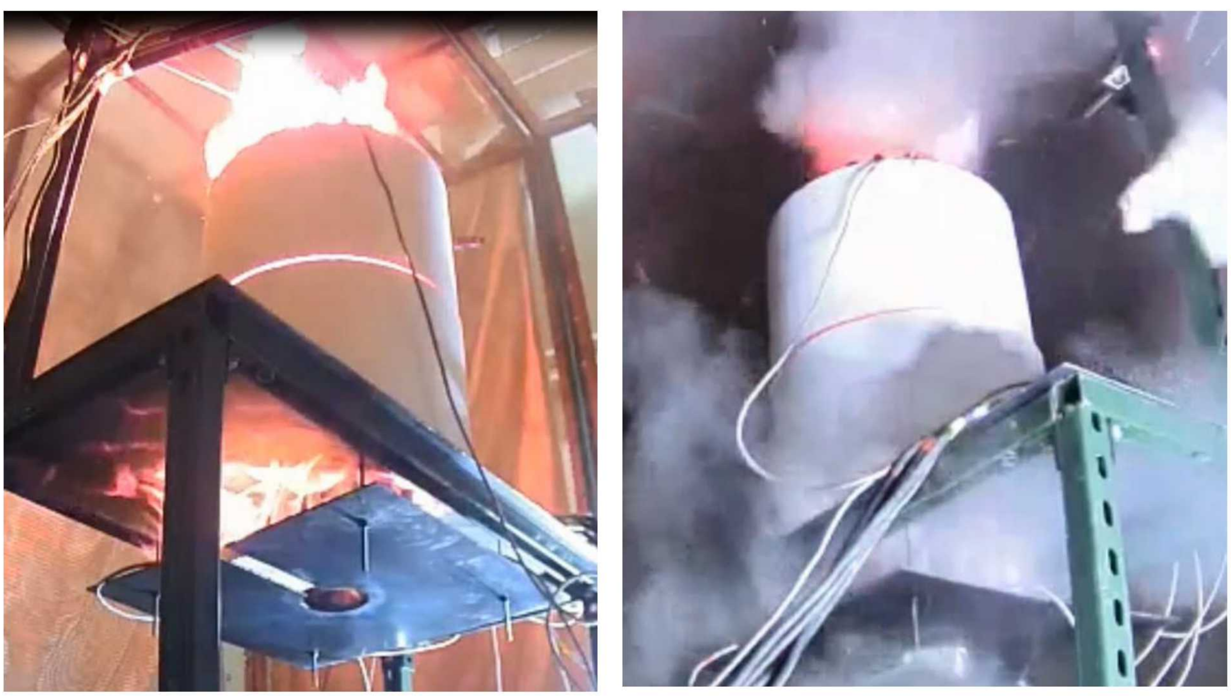


**Figure 21. Comparison Video Screen Shots of Configuration 3 (left) and Configuration 4 (right).**

**Figure 22. Comparison of PCV Swelling Between Configuration 3 (left) and Configuration 4 (right).**

### 3.5. Configuration 5

As previously mentioned, the results of Configuration 2 inspired modifications to what was originally planned for Configuration 5. As mentioned in Section 1.1, the original configuration was set up to have the O-ring section of an inverted PCV exposed to a water jacket to maintain that region cool. That original setup would have been a more extreme case of Configuration 3. However, Configuration 2 proved that, in a scenario where the O-ring section is cooled by the ambient while the PCV is in a recumbent position, the test ends in a catastrophic rupture of the PCV at high pressure. Configuration 5 was then redesigned to provide insight on whether Configuration 2 ruptured due to the insulated O-ring region or to the orientation. Therefore, the modified Configuration 5 was designed to be almost identical to Configuration 2, but heating of the O-ring region was allowed and cooling of that region by the ambient was prevented. This test would simulate a PCV falling on the floor and rolling into an engulfing pool fire, as in a seismic event.

Figure 23 shows the resulting PCV after completion of the test on Configuration 5, where it can be seen that a rupture of the PCV did not occur even though some minor swelling was observed. Figure 24 shows the resulting temperature and pressure profiles for the test, and several differences can be noted when compared to Configuration 1. First, the pressure reached by the PCV was approximately 300 psi higher than what was experienced by the PCV in Configuration 1, reaching a pressure of about 780 psia. As with Configuration 1, but much less severe, a pressure drop occurred prior to final rupture. The pressure dropped slightly (about 3 psi) over a period of only 3 seconds as the mid-height sidewall temperature reached about 563°C and then continued to rise again. This could potentially indicate some minor O-ring degradation that released a little pressure then plugged itself to permit continued pressurization. The stainless-steel lid would serve as a heat sink for configuration 5 just as it did for Configuration 1. But for Configuration 5, the internal payload contents of the PCV would provide additional mass in the O-ring region to add additional heat absorption capacity. The effect of this is observed by the disparity in temperature between the thermocouples at the 0° position and the other two thermocouple positions, 120° and 240°. This disparity was as high as 220°C and can be seen in Figure 24. In the end, while the vessel did show some minor expansion along the wall, PCV rupture did not occur and pressure was released past the degraded O-rings. The release occurred at about 773 psia with the 0° thermocouple reading 913°C. Just like the test on Configuration 1, the imposed heat flux was kept on for about 20 minutes after seal failure to test if the vessel could re-pressurize. Figure 24 shows that this did not occur as can be seen by inspection of the pressure plot.

Post test weights of Configuration 5 indicate the exact same weight loss as Configuration 1 and Configuration 3 (254 g). the upper and lower bound powder mass loss fraction is 0.19 and 0.0, also identical to Configurations 1 and 3.

**Figure 23. Configuration 5 Post-test PCV and Video Image Showing Flames During Test.**

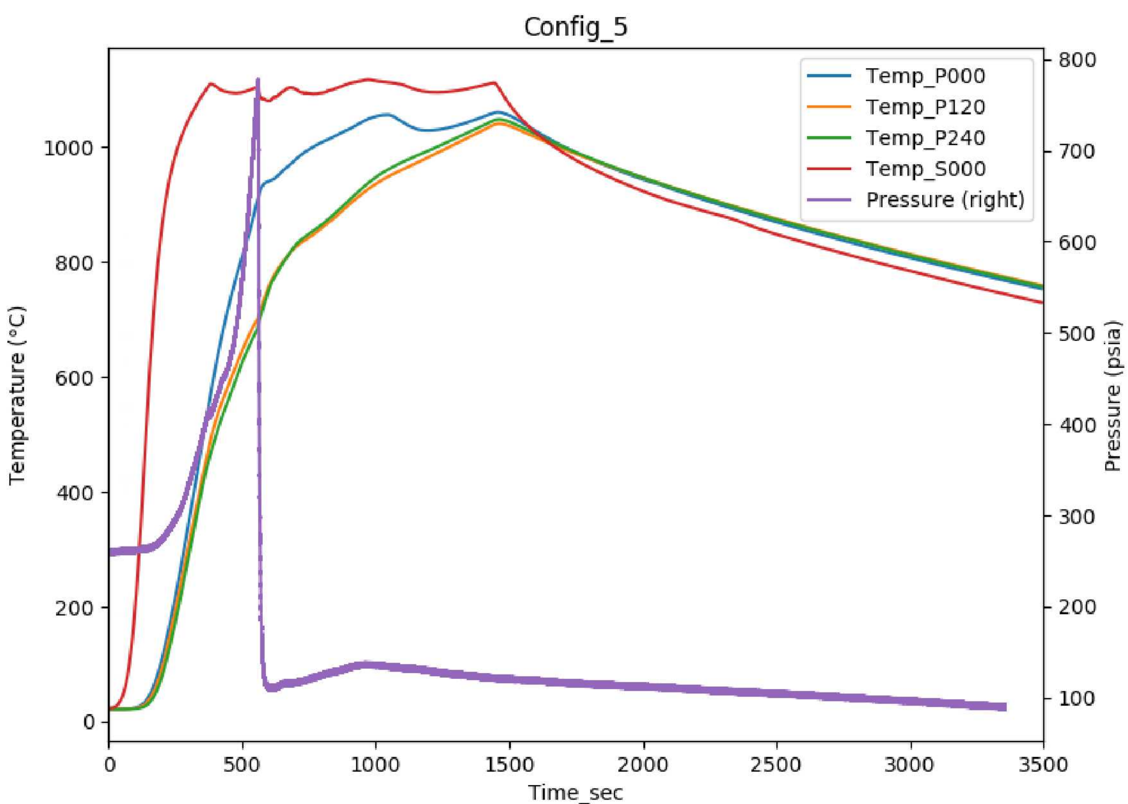



**Figure 24. Temperature and Pressure Profiles for Configuration 5.**

# 4. CONCLUDING REMARKS

The five tests conducted for the SRNS Phase 1 test series were presented in this report. The purpose of these tests was to characterize the response of the PCV to severe thermal stress conditions to determine which configurations suffered damage and in what manner. Specifically, the intent was to characterize the container wall of the PCV when filled with a bounding payload, at a high initial pressure, and exposed to an ASTM-E1529 standard fire environment. Details of the five different configurations were presented in Section 2, while the temperature, pressure, and weight measurements taken during each test were discussed in Section 3. Figure 25 helps visualize the differences in pressure evolution between different tests by plotting all pressure profiles in one plot, where dashed lines (configurations 2, 3, & 4) correspond to tests where the vessel failure mechanism is considered to be a rupture, as opposed to an O-ring failure. Table 4 summarizes the outcome of the five tests, indicating whether the PCV experienced a rupture or not. The time of release after test start, the peak pressure, and the peak temperature (of three mid-height PCV thermocouples) observed by each configuration is also shown.

Any assessment should also consider that the pressure at the beginning of each test varied since ambient temperature fluctuations changed between initial vessel pressurization and the beginning of the test, which ultimately caused pressure differences between the five PCVs at the beginning of each test. A normalized initial pressure was determined by reading the PCV pressure at a point consistent throughout all tests; when the shroud temperature reached 300°C. It is noted that the initial part of the test process involved heating each assembly to an initial temperature of 300°C to ensure there would be no condensation formed in the pressure manifold before starting the ASTM E1529 temperature profile. The PCV pressure for each configuration at this temperature is provided in Table 4.

The amount of material lost for each configuration is also documented in Table 4. All PCV "Post-Test Weights" were measured on the same scale as the "Pre-Test Weights" with thermocouples attached. For Configuration 3, the post-test weight was initially measured with the pressure fitting attached (due to an inability to remove), which was not done in the pre-test weight. However, an identical pressure fitting was independently weighed, and that isolated weight was subtracted from the post-test weight that included the unremovable pressure fitting. When analyzing Table 4, it is noted that the mass lost is exactly the same for Configurations 1, 3, and 5. Configurations 1 and 5 are characterized as O-ring failure which provides a close-fit tortuous path for oxide to leave the container (see Figure 1), a type of constricted release. Inverted Configuration 3 failed by a longitudinal tear (rupture). However, the PCV swelling actually deformed the shroud, resulting in a tight fit between the PCV and shroud at the location of the tear. It is suspected this tight fit created a release path that was similar to the tortuous release path for Configurations 1 and 5; hence the same amount of material escaped.

Inverted Configuration 4 ruptured by radial tear in nearly the same location as the Configuration 3 tear. The uneven heating of Configuration 4 prevented expansion of the PCV wall where the heat shield was installed causing less overall PCV volume expansion than was experienced in Configuration 3. This resulted in an approximately 200 psi higher release pressure in Configuration 4. In addition, the unrestricted nature of the tear resulted in a much more severe release with much more material lost than in Configuration 3.

The release pressure for Configurations 3 and 5 is nearly the same, and both are about double that of Configuration 1; but the amount of material lost was the same for all three configurations. This suggests that a constricted release of powder is relatively independent of the release pressure, at least in the range of the release pressures of these three configurations, 455 – 770 psig. Figure 26 is a video screen shot at the point of release for Configurations 1 (the first release), 3, and 5. On the other hand, where the PCV ruptured and released without restriction, as in Configurations 2 and 4, the amount of material lost was significantly higher. Configuration 4 lost between 25% and 45 % of the original powder mass in the container with a radial tear in the PCV at about 970 psig. In the case of Configuration 2, a catastrophic rupture at nearly 1,100 psig, almost all of the material was ejected from the container; see Table 5.

Finally, it is important to note that bounding internal and external conditions were purposefully established for this Phase 1 testing in order to maximize pressurization in the container. These would likely not be representative of field conditions in realistically postulated fire scenarios. The principal conditions of interest include a high initial pressure of 200 psig, a moisture content of 3 wt %, a high plastic content of 135 g PE, a severe ASTM E1529 heating profile to represent an engulfing hydrocarbon pool fire, use of a surrogate material less dense than Pu oxide, and a minimum free volume in the PCV. All of these factors should be considered in applying the test results to real-conditions or scenarios. Phase II testing will consider more realistic PCV payloads.

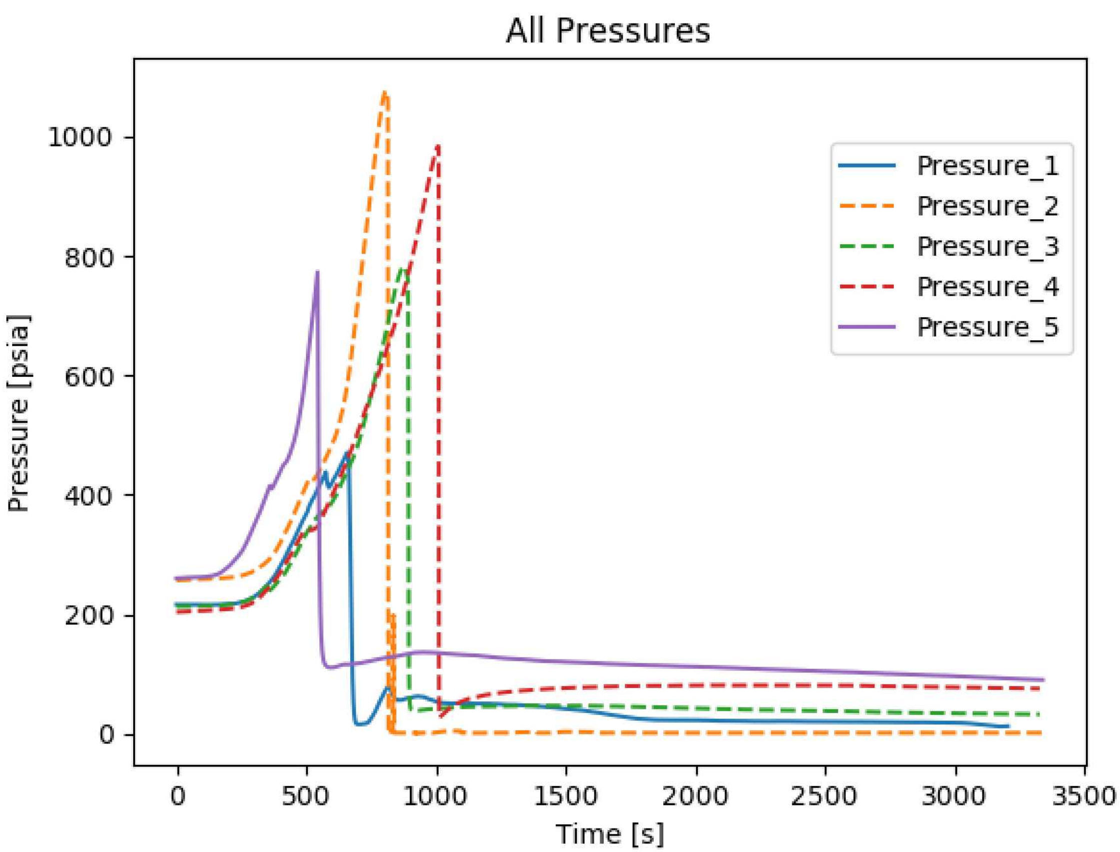



**Figure 25. Pressure Evolution of All Configurations.**

Table 4. Summary of Phase 1 Tests (Temperature, Pressure, and Time).

| Configuration | Initial Pressure (psia)ǂ | Pre-Test Weight* (g) | Post-Test Weight* (g) | Weight Loss (g) | Release Pressure (psia) | Temperature at Release (°C) | Time at Release (sec) | Failure Mechanism |
|---|---|---|---|---|---|---|---|---|
| 1 upright | ~215 (216) | 20,371 | 20,117 | 254 | 471 | 763 | 808 | O-ring Failure |
| 2 recumbent | ~260 (260) | 19,518 | N/A | N/A | 1,077 | 1,061 | 828 | Catastrophic Rupture |
| 3 inverted | ~215 (215) | 19,586 | 19,332 | 254 | 782 | 987 | 904 | Longitudinal Rupture |
| 4 inverted | ~210 (208) | 20,130 | 19,523 | 608 | 983 | 964 | 1,036 | Radial Rupture |
| 5 recumbent | ~260 (262) | 19,895 | 19,641 | 254 | 773 | 913 | 560 | O-ring Failure |

ǂ Approximate initial pressure based on field notes
(measured initial pressure after pressure manifold warmup, taken here as when shroud temperature reaches 300°C)
* PCV weight includes attached thermocouples

Table 5. Summary of Phase 1 Tests (Bounding Powder Fraction Loss Estimates).

| Configuration Number | Release Pressure, psigǂ | Powder Fraction Released | | Failure Mechanism |
|---|---|---|---|---|
| | | Upper Bound* | Lower Bound* | |
| 1 | 459 | 0.19 | 0.00 | O-ring Failure |
| 2 | 1,065 | 0.8 - 0.9** | | Catastrophic Rupture |
| 3 | 770 | 0.19 | 0.00 | Longitudinal Rupture |
| 4 | 971 | 0.45 | 0.26 | Radial Rupture |
| 5 | 761 | 0.19 | 0.00 | O-ring Failure |

** PCV not weighed post-test, fraction based on visual indication only, see Figure 15
ǂ based on pressure conditions at SNL's altitude; 0 psig = 12.1 psia
* Upper bound case assumes all mass lost is powder
* Lower bound case assumes all plastic and water are lost, powder makes up all the remaining mass lost
Neither case is physically realistic; actual values would fall between the upper and lower bound cases

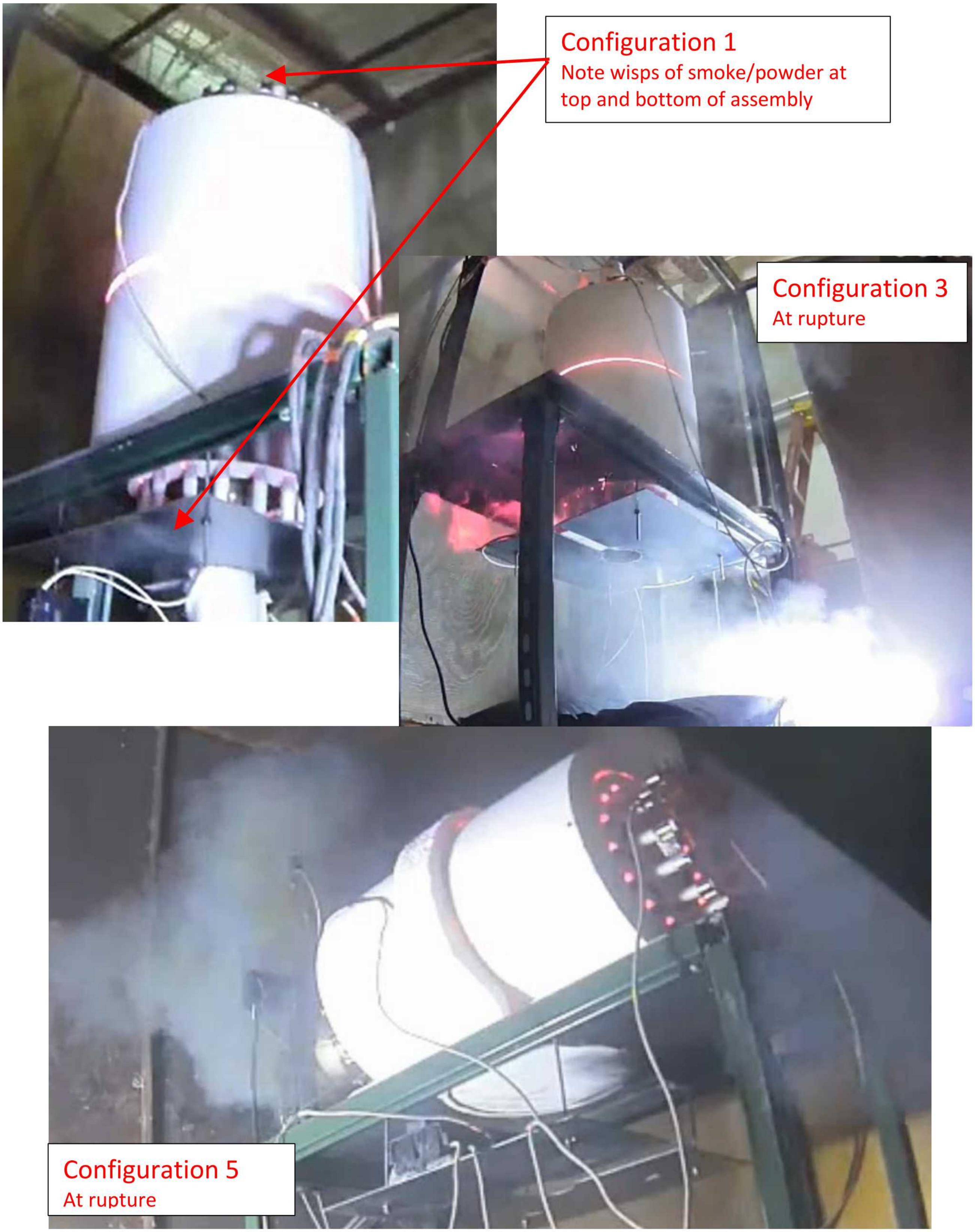



**Figure 26. Video Screen Shots at Release, of Configurations 1, 3, 5.**

# 5. REFERENCES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Uncapher, W. (2018). *Project Quality Plan Fire-Induced Pressure Response And Failure Characterization Of PCV/SCV/3013 Containers, PCV/SCV/3013-PQP .* Albuquerque, NM: Sandia National Laboratories.

# 6. APPENDIX

## 6.1. Payload Analysis

**Table 6. Payload Initial Conditions**

| Item | Phase 1Test | | Evaluated | |
|---|---|---|---|---|
| | Mass | Volume | Mass | Volume |
| Available Internal PCV Volume | | 3,729 cc | | 3,729 cc |
| Manifold Volume | | 20.15 cc* | | |
| Total Available Volume | | 3,749.15 cc | | 3,729 cc |
| | | | | |
| Plutonium Oxide | N/A | N/A | 1,500 g | 315 cc |
| Aluminum Oxide (Alumina) Powder | 1,337 g | 337 cc | N/A | N/A |
| Aluminum Oxide (Alumina) Spheres | 3,067 g | 792 cc | N/A | N/A |
| Aluminum Metal Spacers | N/A | N/A | 899.2 g | 333 cc |
| Carbon Steel Convenience Cans | N/A | N/A | 1,000 g | 375 cc |
| Water | 111 g | 111 cc | 111 g | 111 cc |
| Viton O-ring, (2) | 7.3 g | 4 cc | 7.3 g | 4 cc |
| Plastic, as Polyethylene (PE) | 135 g* | 123 cc* | 590 g | 283 cc |
| Snorkel | 136.08 g* | 19 cc* | N/A | N/A |
| Total Occupied Volume | | 1,386 c | | 1,421 cc |
| | | | | |
| Free Volume | | 2,363 cc* | | 2,308 cc |
| | | | | |
| Initial Pressure | 200 psig | | 0 psig | |
| Initial Temperature (ambient) | 20-25°C | | 25°C | |
| Lid torque | 60 +5/-0 ft-lbs | | No leakage | |
| * actual value as tested differs from Test Plan value, (Gill 2018); see Section 2.2. | | | | |

Table 6 summarizes the initial conditions of the payload for Phase 1, and Figure 2 in Section 2.2 showed a sample payload used inside the tested PCVs. The payload parameters shown in Table 6 are based on various thermal evaluations conducted by Savannah River National Laboratory to estimate pressure buildup in a PCV under varying internal and external conditions. They vary slightly from the evaluated conditions and include anticipated measurement uncertainties that were encountered in payload preparation. The analyses indicate that fire-induced pressurization is driven primarily from vaporization of moisture, pyrolysis of plastic (both of which covert to gas), and available free volume. Although additional mass can serve as a thermal heat sink to delay container heat-up, it also decreases free volume to substantially enhance pressurization. Payload mass is determined to be a second order parameter to container free volume. These determinations will be evaluated and verified during Phase 2 testing by altering the container contents.

Aluminum oxide (Alumina) was chosen as a surrogate for plutonium oxide in a PCV because it has a similar pycnometric density (3.97 g/cc) as compared to Pu oxide (4.8 g/cc) and is available as a high purity powder (99.5% alumina) with a particle density distribution also similar to Pu oxide. Alumina has not been evaluated for specific thermal/pressure response, but it is non-reactive at elevated temperatures and has a high melting point (2,072°C). Alumina spheres (pycnometric density 3.87 g/cc) were selected in these tests for adjustment of container volume normally displaced by various convenience cans and spacers that may be present in the PCV, some of which were included in various evaluations. As noted above, the available free volume is determined to be the primary order variable influencing pressurization. The alumina spheres added to attain the desired free volume in the PCV are less dense than the metal convenience cans their volume replaces while at the same time providing an increased surface area to permit enhanced convective flows within the matrix. The arrangement was expected to enhance heat transfer into the container contents to result in more conservative pressurization of the PCV.

The moisture content (3 wt. %) was considered bounding as it substantially exceeded expected conditions. Evaluations indicated that a higher moisture content would tend to render the oxide more like a paste than powder. Since moisture content was determined to be a primary order variable influencing pressurization, a reasonably high, yet attainable, moisture content was selected.

Plastic content was derived from estimates of the plastic material used for bagging convenience containers placed in a PCV (including filter vents) and the potential for a hydrogen getter or recombiner to be present in the PCV. The evaluations looked at pyrolysis of various plastics. The value chosen for plastic content in the Phase 1 test represents the amount of polyethylene that would generate the same amount of gas as that evaluated.

## 6.2. Determining Incident Heat Flux using the Shroud Temperature

During the mock testing performed to determine the appropriate test setups, a calorimeter test was performed along with an accompanying analysis to confirm that an imposed uniform heat flux could be determined using the measured shroud temperature in a heater assembly. The setup was such that it mimicked the baseline configuration, except that none of the measurements where NQA-1. The schematic of Configuration 1 was copied as Figure 27 below for reference to this appendix.

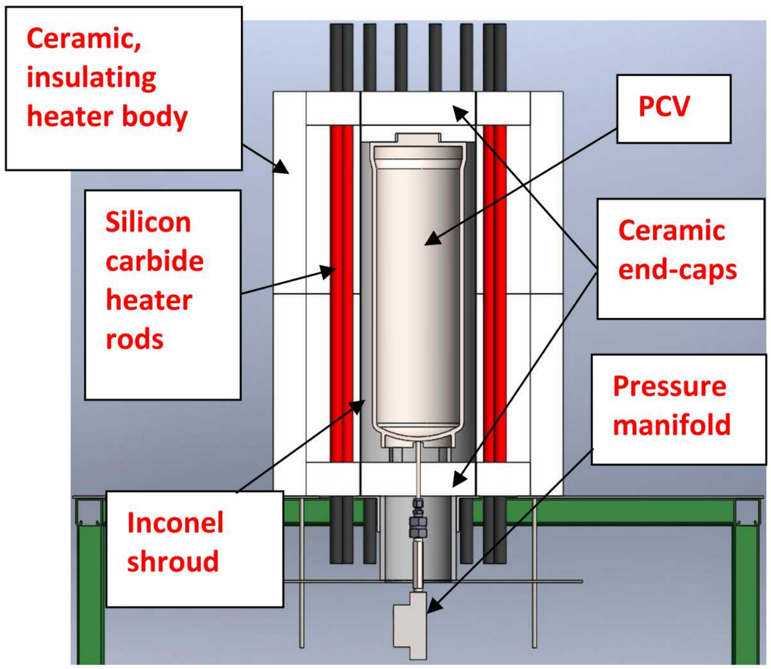


**Figure 27. Configuration used for calorimeter mock test**

For this mock test, a simple analysis was done by comparing the heat absorbed by the PCV with the heat calculated from using the Stefan-Boltzmann Law. The setup was as depicted in Figure 27, and three total thermocouples were used. Two thermocouples were placed 180° from each other at mid-height along the PCV, and one was placed on the shroud to measure shroud temperature. Using the PCV temperature, the software IHCP1D Version 7.1 (Beck, 1999) was used to determine the absorbed heat flux onto the PCV. IHCP1D is a one-dimensional, inverse heat conduction program that can calculate an absorbed heat flux with known transient temperature histories, material geometry, and material properties. Therefore, with the known PCV temperatures, material geometry, and material properties, the net absorbed heat flux ($q_{net,abs}$) onto the PCV was calculated. Equation ( 1 ) then describes how, for a scenario where an object is exposed to an incident flux such as occurs for the PCV in the test environment described here, the net absorbed heat flux is equivalent to the absorbed incident flux ($q_{inc,abs}$) minus the emitted heat flux ($q_{emit}$).

$$q_{net,abs} = q_{inc,abs} - q_{emit} \quad (1)$$

In Equation ( 1 ), $q_{inc,abs}$ can be defined using incident flux ($q_{inc}$) and the object's surface absorptivity ($\alpha$) as $q_{inc}\ \alpha$, while $q_{emit}$ can be described as $\varepsilon\sigma T_s^4$, where σ is the Stefan-Boltzmann constant (5.67 E-8 $Wm^{-2}$-$K^{-4}$), $\varepsilon$ is the objects surface emissivity, and $T_s$ is the objects surface temperature. In this study, the object of interest was the PCV. By substituting the above definitions into Equation ( 1 ), $q_{inc}$ can be described as:

$$q_{inc} = \frac{q_{net,abs} + \varepsilon\sigma T_s^4}{\alpha} \quad (2)$$

Therefore, using Equation ( 2 ), an incident heat flux could be calculated using the measured PCV temperatures, $q_{net,abs}$ as calculated by IHCP1D, and an assumed absorptivity and emissivity value of 0.5 for the PCV's stainless steel surface. Since, for this analysis, two temperatures were measured at 180° from each other, both were used to determine two different incident fluxes.

The goal of this analysis was to show that using the shroud temperature to determine the imposed heat flux was justified. Therefore, the two fluxes as determined by Equation ( 2 ) and the measured PCV temperatures were compared to the flux determined by using the shroud surface temperature ($T_{ss}$) with the Stefan-Boltzmann law for a blackbody ($\sigma T_{ss}^4$). The results of this analysis are plotted in Figure 28 for incident heat fluxes up to 185 $kW/m^2$. The figure shows how the shroud blackbody flux generally agrees with the incident flux calculated using Equation ( 2 ) with two different temperatures on the PCV.

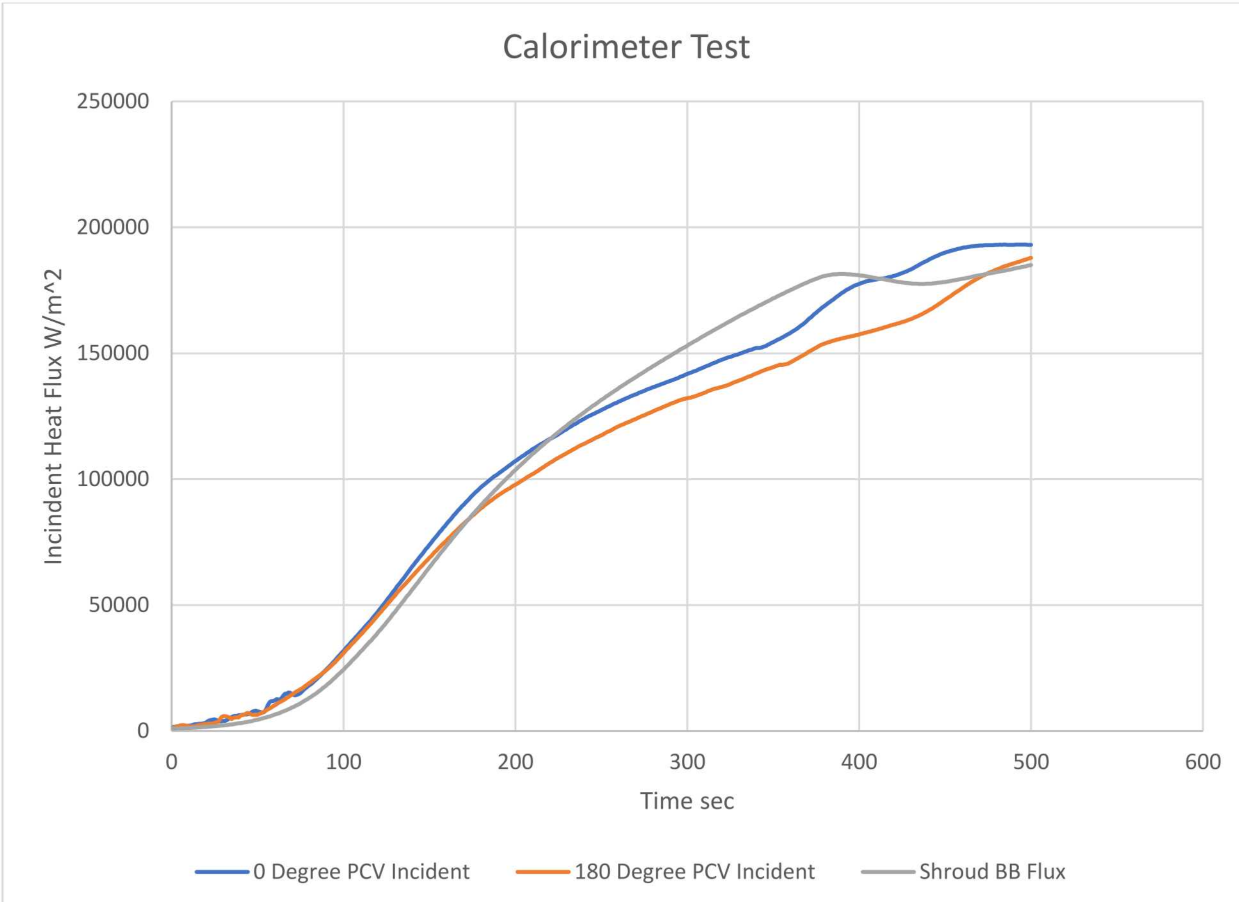


**Figure 28. Heat Flux Analysis for Calorimeter Test.**

## 6.3. Determining Drift for the Gefran Pressure Sensor

The Gefran KN2-series pressure sensors used during the tests described in this report were calibrated by SNL's Primary Standards Laboratory (PSL). Documentation for this calibration is provided within the Quality Assurance (QA) package provided by SNL under the pressure sensor calibration section. In that documentation, it is noted how the sensors were calibrated at a temperature of 23 °C for a range between 100 psi to 4,000 psi, where the output sensitivity was rated at 503.61 psi/Volt. However, the manifolds where the pressure sensors were mounted were heated to and maintained at 200 °C during testing, as shown by the example in Figure 29 (from Configuration 5). This figure shows that, by the time the test started (denoted by the rise in shroud temperature), the pressure reading had drifted from 200 psi to approximately 217 psi due to the heating of the manifold. There were no NQA-1 measurements performed to measure the manifold temperature and account for the drift on the pressure transducers as the manifold was heated, but the plots shown in Figure 29 correspond to data retrieved from the Control Room at the thermal test complex (TTC). Therefore, because the manifolds were heated from 25 °C to 200 °C in every test, the drift was approximately 1 psi per 10 °C based on this data.

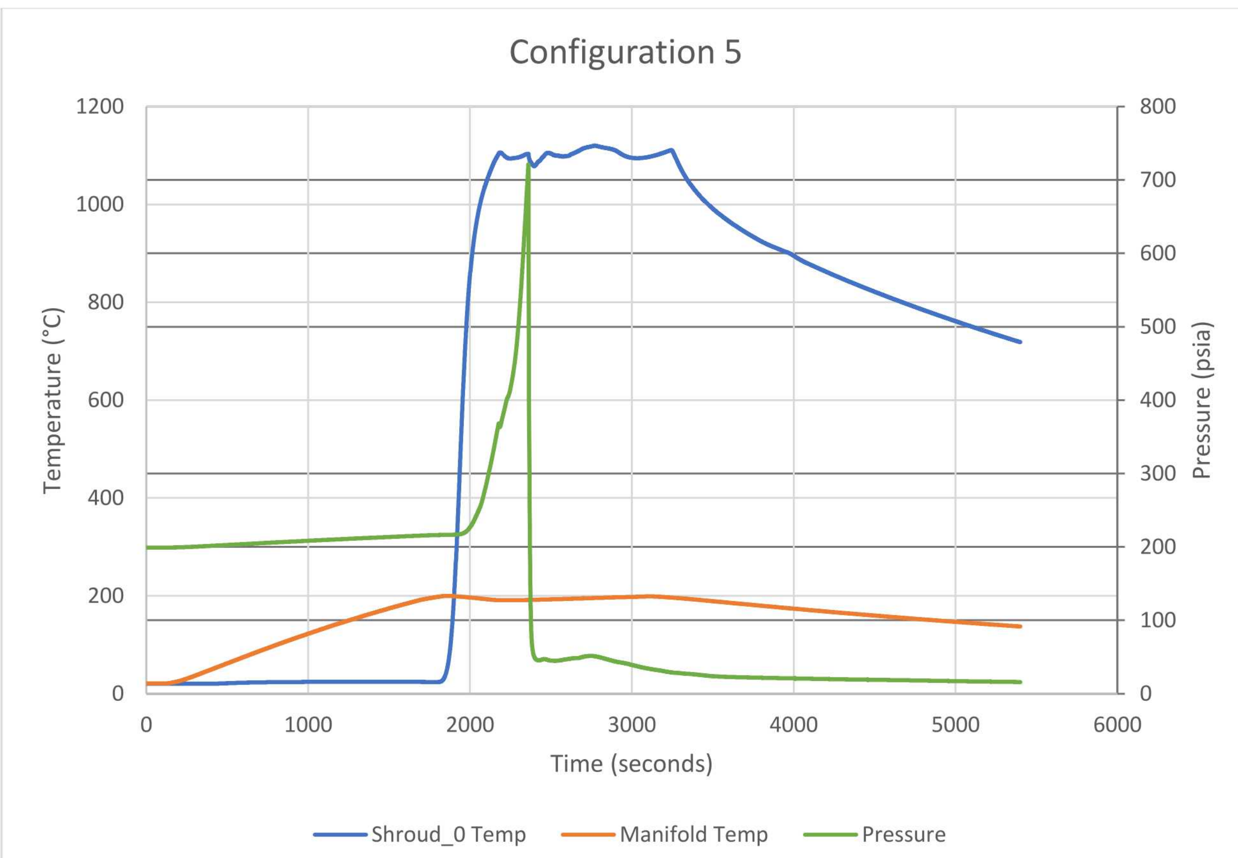


**Figure 29. Sample analysis on pressure drift**

## 6.4. Sandia National Laboratories Test Personnel Qualification Report

Sandia National Laboratories

Operated for the U.S. Department of Energy by

**Sandia Corporation**

P.O. Box 5800
Albuquerque, NM 87185
Phone: (505) 845-3635
Internet: sesanbo@sandia.gov

*date:* 10-26-2018

*to:* Victor Figueroa Training File

*from:* Scott Sanborn,
Fire, Risk, & Transportation Systems (8854) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Project Manager as defined in the Project Manager job description [Enclosed]. Additionally, I have reviewed Victor Figueroa's qualifications and checked that he is current on his assigned training. I have determined that Victor Figueroa is qualified to serve as the Project Manager for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

Summary of Qualifications

- Masters degree in Mechanical Engineering
- Prior experience as Test Engineer under a QA program
- Classroom instructor on modeling/testing RAM packages
- Prior experience as Project Engineer on thermal test series under a QA program
- Experience in thermal analysis of packages

This memo is a summary only and a full qualification record is available upon request.

# Job/Position Description

Position Name: ___Project Manager_______

Organization Number: _08853_____ Reports To: __Department Manager__

Work Location: __823, TAIII, 6630, Thermal Test Complex____

Required Education/Training of Position:

Advanced degree in engineering

SNL Corporate Required Training

Position Duties/Responsibilities:

The Project Manager is responsible for the implementation of all activities performed to attain quality objectives, as well as all Quality Assurance (QA) functions, including work executed by other SNL organizations, external organizations and contract personnel. The Project Manager has the authority to resolve disputes involving quality that arise from differences between the program QA Coordinator and program staff.

Physical Requirements of Position: None

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P.O. Box 5800
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*date:* 10-26-2018

*to:* Hector Mendoza Training File

*from:* Scott Sanborn,
Fire, Risk, & Transportation Systems (8854) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Test Engineer as defined in the Test Engineer job description [Enclosed]. Additionally, I have reviewed Hector Mendoza's qualifications and checked that he is current on his assigned training. I have determined that Hector Mendoza is qualified to serve as the Test Engineer for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

Summary of Qualifications

- PhD in Mechanical Engineering
- Prior experience as a Test Engineer in a container test program
- Classroom training on modeling/testing RAM packages
- Experience working on testing under a QA program
- Modelling experience under thermal and fire environments

This memo is a summary only and a full qualification record is available upon request.

# Job/Position Description

Position Name: ___Test Engineer_______

Organization Number: ____08853___ Reports To: _Project Manager______

Work Location: __823, TAIII, 6630, Thermal Test Complex__

Required Education/Training of Position:

Advanced degree in engineering

SNL Corporate Required Training

Position Duties/Responsibilities:

The Test Engineer has secondary responsibility for all of the activities that are listed for the Project Manager and will work directly with that person. In addition, the Test Engineer has the responsibilities for determining that the test hardware has been properly prepared and positioned for the test. The Test Engineer shall ensure the QA Coordinator and Project Manager have verified all test criteria. The Test Engineer will assure photographic coverage is completed as specified for the test and that instrumentation measurement devices have been installed and connected to the correct recording equipment and tested to assure a reasonable probability of obtaining data. He will also assure test procedures are performed in the proper sequence, if more than one procedure is needed. He will be responsible to assure all test procedures required are distributed to the individuals involved in the tests and document changes and test anomalies resulting from the tests. He will also collect the raw, processed and archived data from the Data Acquisition Coordinator. He will assure all post-test activities contained in the test plans/procedures are satisfactorily completed and all test results, data and other pertinent information are recorded, documented and filed. He will maintain the resultant files, disks, and photographs in retrievable storage. The Test Engineer will also be responsible for maintaining the test journal to document daily testing activities (who, what, when, how, etc.) that are not otherwise captured in the implementing plans/procedures. The test journal entries will be signed by the test engineer and SRNS Subcontract Technical Representative (STR) on a frequency determined by SNL and SRNS.

Physical Requirements of Position: None

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**Sandia Corporation**

P.O. Box 5800
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*date:* 10-26-2018

*to:* Danny Williams Training File

*from:* Scott Sanborn,
Fire, Risk, & Transportation Systems (8854) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Data Acquisition Coordinator as defined in the Data Acquisition Coordinator job description [Enclosed]. Additionally, I have reviewed Danny Williams's qualifications and checked that he is current on his assigned training. I have determined that Danny Williams is qualified to serve as the Data Acquisition Coordinator for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

Summary of Qualifications

- Bachelors in Electrical Engineering
- Prior experience performing data acquisition for testing.
- Experience working on testing under a QA program
- Qualified as MIDAS operator [MIDAS training record enclosed]

This memo is a summary only and a full qualification record is available upon request.

## PERSONNEL TRAINING REQUIREMENTS
## MOBILE INSTRUMENTATION DATA ACQUISITION SYSTEM

### MIDAS TRAINING FORM

MIDAS operators must complete a minimum of 40 hours of system training prior to being approved as an operator.

---

TRAINEE NAME Danny Williams Employer Sandia National Laboratories
ORG.: 06622

| ACTIVITY | HOURS | TRAINEE INITIALS | TRAINEE DATE | TRAINER INITIALS | TRAINER DATE |
|---|---|---|---|---|---|
| Tests 836 and 837 | 10 | DBW | 11/2012 | WY | 11/2012 |
| Tests 848 and 849 | 10 | DBW | 2/2013 | WY | 2/2013 |
| Tests 851 - 857 | 40 | DBW | 5/2013 | WY | 5/2013 |
| Tests 858 - 859 | 20 | DBW | 7/2013 | WU | 7/2013 |
| Tests 880, 882 | 40 | DBW | 3/2014 | WU | 3/2014 |
| Tests 884, 887, 890 | 40 | DBW | 6/2014 | WU | 6/2014 |
| Test 898, 899 | 20 | DBW | 11/2014 | WU | 11/2014 |
| Tests 918 - 921 | 40 | DBW | 12/2014 | WU | 12/2014 |
| Tests 936 - 946 | 20 | DBW | 7/2015 | WY | 7/2015 |
| Test 947 - 962 | 40 | DBW | 8/2015 | WY | 8/2015 |
| Test 968 | 10 | DBW | 10/2015 | WY | 10/2015 |
| Test 970 - 973 | 40 | DBW | 5/2016 | WY | 5/2016 |
| Test 976 | 10 | DBW | 7/2016 | WY | 7/2016 |
| Test 977-979 | 10 | DBW | 9/2016 | WY | 9/2016 |
| Tests 981 - 987 | 40 | DBW | 2/2017 | | |
| Tests 988 - 997 | 40 | DBW | 4/2017 - 6/2017 | | |

I verify that I have completed the above-mentioned, and meet the minimum 40 hour training requirements to be approved as a MIDAS operator.

D. B. Willi[illegible] 12/4/17
Signature Date

Approved: [illegible] 12/4/17
Task Leader Date

# Job/Position Description

Position Name: ___Data Acquisition Coordinator_______

Organization Number: ___06622____ Reports To: ___Project Manager__

Work Location: ___TAIII, 6630, Thermal Test Complex_____

Required Education/Training of Position:

High School Diploma

SNL Corporate Required Training; Required training per applicable TWDs; MIDAS Qualified Operator Training

Position Duties/Responsibilities:

It will be the responsibility of the Data Acquisition Coordinator to operate the Mobile Instrumentation Data Acquisition System (MIDAS) and support the installation of the instrumentation and field cable between the test unit and the data collection system. He will assure that approved procedures are followed, recording equipment is within calibration periods and approved instrumentation check-out procedures are available to the Instrumentation Coordinator and that they are followed and documented. The Data Acquisition Coordinator, in conjunction with the Instrumentation Coordinator, will be responsible for the installation of all measurement devices associated with the test program. The Data Acquisition Coordinator in conjunction with the Project Manager and Test Engineer will be responsible for post-test processing of the PCV/SCV/3013 instrumentation data. Copies of the raw, processed and archived data will be delivered to the Test Engineer.

Physical Requirements of Position: Ability to perform light lab/field work.

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*date:* 10-26-2018

*to:* Travis Fitch Training File

*from:* Carlos Lopez,
Fire Science and Technology (1532) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Instrumentation Coordinator as defined in the Instrumentation Coordinator Position Description [Enclosed]. Additionally, I have reviewed Travis Fitch's qualifications and checked that he is current on his assigned training. I have determined that Travis Fitch is qualified to serve as the Instrumentation Coordinator for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

Summary of Qualifications

- Thermocouple installation on Stainless Steel and mild steel
- Thermocouple installation Aluminum
- Pressure Transducer Operation
- Pressure and Leak Checks
- Thermocouple routing prior to installation
- Thermocouple verification station operation
- Basic DAQ setup and data collection
- DAQ programming
- DAQ UCQ process
- DATA Acquisition System Programming
- DATA Acquisition System Uncertainty Verification
- DATA Acquisition System Calibration
- Pressure Safety Data Package Development
- Pressure System Design
- Pressure System Operation
- Lead Technologist

This memo is a summary only and a full qualification record is available upon request.

I have evaluated the qualifications of  Travis Fitch and certify that this individual's training and experience are accuratly listed in the training qualification record. This document is updated annualy or when required by significiant changes.

# Job/Position Description

Position Name: Instrumentation Coordinator

Organization Number: 1532 Reports To: Program Manager

Work Location: 823, TAIII, 6630, Thermal Test Complex

Required Education/Training of Position:

High School Diploma

SNL Corporate Required Training; Required training per applicable TWDs

Position Duties/Responsibilities:

The Instrumentation Coordinator will install and connect the instrumentation measurement devices specified in the SRNS PCV/SCV/3013 plans/procedures to the proper recording equipment. He/she will work in conjunction with the Data Acquisition Coordinator to assure that approved procedures are followed, recording equipment is within calibration periods, approved instrumentation check-out procedures are available and that these procedures are followed and documented. The Instrumentation Coordinator will be responsible for completing the instrumentation pre-test and post-test field wire data sheet tables.

Physical Requirements of Position: Ability to perform light lab/field work.

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P.O. Box 5800
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*date:* 10-26-2018

*to:* Kelly Urvanejo Training File

*from:* Carlos Lopez,
Fire Science and Technology (1532) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Package Coordinator as defined in the Package Coordinator [Enclosed]. Additionally, I have reviewed Kelly Urvanejo's qualifications and checked that she is current on her assigned training. I have determined that Kelly Urvanejo is qualified to serve as the Package Coordinator for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

Summary of Qualifications

| | |
|---|---|
| • Thermocouple installation on Stainless Steel and mild steel | • DAQ UCQ process |
| • Thermocouple installation Aluminum | • DATA Acquisition System Programming |
| • Pressure Transducer Operation | • DATA Acquisition System Uncertainty Verification |
| • Pressure and Leak Checks | • DATA Acquisition System Calibration |
| • Thermocouple routing prior to installation | • Pressure Safety Data Package Development |
| • Thermocouple verification station operation | • Pressure System Design |
| • Basic DAQ setup and data collection | • Pressure System Operation |
| • DAQ programming | • Lead Technologist |

This memo is a summary only and a full qualification record is available upon request.

I have evaluated the qualifications of Kelly Urvanejo and certify that this individual's training and experience are accuratly listed in the training qualification record. This document is updated annualy or when required by significiant changes.

# Job/Position Description

Position Name: Package Coordinator

Organization Number: 1532 Reports To: Program Manager

Work Location: 823, TAIII, 6630, Thermal Test Complex

Required Education/Training of Position:

High School Diploma

SNL Corporate Required Training; Required training per applicable TWDs

Position Duties/Responsibilities:

It will be the responsibility of the Package Coordinator to perform the required pre-test and post-test assembly/disassembly and visual inspections of the SRNS PCV/SCV/3013 test containers. The Package Coordinator will also support post-test measurements/observations, as required, to document the containers.

Physical Requirements of Position: Ability to perform light lab/field work.

Sandia National Laboratories

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*date:* 04-01-2019

*to:* Walt Gill Training File

*from:* Carlos Lopez,
Fire Science and Technology (1532) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Thermal Test Facility Director as defined in the Thermal Test Facility Director description of the Project Quality Plan.

*"The Thermal Test Facility Director is responsible for the thermal test execution. The Thermal Test Facility Director is also responsible for all facility safety including all documentation associated with the safe execution of the tests. It will be the responsibility of the Thermal Test Facility Director to oversee placement of the SRNS PCV/SCV/3013 containers and ensure proper orientation. Other responsibilities include directing the operation of the thermal test facility and the safe execution of the testing."*

I have reviewed Walt Gill's qualifications and checked that he is current on his assigned training. I have determined that Walt Gill is qualified to serve as the Thermal Test Facility Director for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

Summary of Qualifications

- PhD in Mechanical Engineering
- Test Director with NQA-1 requirements
- Program Manager
- Lead Technical Designer
- Test Director for multiyear experiments
- Principal Investigator
- Technical Lead

A full qualification record is available upon request.

# Job/Position Description

Position Name: ___Thermal Test Facility Director_______

Organization Number: ____01532___ Reports To: _Project Manager______

Work Location: __823, TAIII, 6630, Thermal Test Complex__

Required Education/Training of Position:

Advanced degree in engineering________________________________________

SNL Corporate Required Training______________________________________

Position Duties/Responsibilities:

The Thermal Test Facility Director is responsible for the thermal test execution. The Thermal Test Facility Director is also responsible for all facility safety including all documentation associated with the safe execution of the tests. It will be the responsibility of the Thermal Test Facility Director to oversee placement of the SRNS PCV/SCV/3013 containers and ensure proper orientation. Other responsibilities include directing the operation of the thermal test facility and the safe execution of the testing.

Physical Requirements of Position: None

Sandia National Laboratories

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**Sandia Corporation**

P.O. Box 5800
Albuquerque, NM 87185
Phone: (505) 845-3635
Internet: sesanbo@sandia.gov

*date:* 04-01-2019

*to:* Project Training File

*from:* Scott Sanborn,
Fire, Risk, & Transportation Systems (8854) Dept. Manager

*subject:* Management Certification of Personnel Qualification

I have reviewed the job description of the Leak Test Coordinator as defined in the Leak Test Coordinator job description [Enclosed]. Additionally, I have reviewed Sandia's contract with Leak Testing Specialists, Inc (LTS) and have determined that by meeting the requirements in the statement of work of the contract LTS meets the requirements of Leak Test Coordinator for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

The relevant statement of work requirements are:

A) Provide leak testing for modified primary containment vessels (PCV) with two independent test techniques
   a. Main closure o-ring using standard test technique
   b. Pressure manifold modification using low pressure He sniffer technique
   c. Leakage level to be less than $10^{-3}$ cc/sec
   d. There will be 5 PCV with modifications to test to be conducted in a single campaign

B) Document test procedures and results consistent with NQA-1

LTS provided David Kuhn to perform the role of Leak Test Coordinator. LTS also provided David Kuhn's certification record for inspection. David Kuhn has certification for American Society for Nondestructive Testing (ASNT) nondestructive testing (NDT) Level III in leak testing. This certification qualifies him to perform leak testing in accordance with the standards referenced in the Leak Test Coordinator job description.

# Job/Position Description

Position Name: __Leak Test Coordinator______

Organization Number: Leak Testing Specialist      Reports To: _Project Manager__

Work Location: __TAIII, 6630, Thermal Test Complex___

Required Education/Training of Position:

Qualifications specified in contract

Position Duties/Responsibilities:

It will be the responsibility of the Leak Test Coordinator to prepare and conduct pre- and post-test helium leak tests of the PCV/SCV/3013 containment vessels. Leak Testing Specialist is contracted to provide qualified personnel and equipment to conduct the helium leak tests. This testing will be performed in accordance with ANSI N14.5-1997 and ASME 2013 Boiler and Pressure Vessel Code Section V, Article 10 and detailed further in the PCV/SCV/3013 leak test section of the test plan/procedure.

Physical Requirements of Position: None

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Internet: sesanbo@sandia.gov

date: 04-01-2019

to: Project Training File

from: Scott Sanborn,
Fire, Risk, & Transportation Systems (8854) Dept. Manager

subject: Management Certification of Personnel Qualification

I have reviewed the job description of the Quality Assurance Coordinator as defined in the Quality Assurance Coordinator job description [Enclosed]. Additionally, I have reviewed Sandia's contract with Aspen Resouces Limited, Inc and have determined that by meeting the requirements in the statement of work of the contract Aspen meets the requirements of Quality Assurance Coordinator for the FIRE-INDUCED PRESSURE RESPONSE AND FAILURE CHARACTERIZATION OF PCV/SCV/3013 CONTAINERS test program.

The relevant statement of work requirements are:

> The Subcontractor personnel shall have a detailed knowledge of the packaging Quality Assurance (QA) requirements as provided in Title 10 of the Code of Federal Regulations, Part 71, subpart H (10CFR71H). The Subcontractor personnel must also be familiar with test quality assurance, and specifically with QA as it relates to digital data acquisition, and specifically with the Nuclear Quality Assurance (NQA-1) certified MIDAS at SNL. The Subcontractor personnel shall have a detailed knowledge of the Department of Energy (DOE)/National Nuclear Security Administration (NNSA) complex of laboratories and sites and the regulations associated with transport, storage, treatment, and disposal of radioactive waste/material.
>
> The Subcontractor shall provide the following: 1) At least one individual with at least five years of experience with American Society of Mechanical Engineers / Nuclear Quality Assurance (ASME NQA-1) and United States (US) Nuclear Regulatory Commission (NRC) 10CFR71 subpart H quality assurance requirements. 2) At least one individual with at least ten years of experience with plutonium processing, including waste generation and transportation packaging. 3) At least one individual with at least two years of experience with transportation safeguards/security requirements for nuclear materials. 4) The Subcontractor shall propose at least one individual with the ability to obtain a Q-clearance at Sandia National Laboratories or other DOE sites.

Aspen Resources Limited, Inc provided Arlene French and Robert Davis to perform the role of Quality Assurance Coordinator along with their qualifications. After reviewing their qualifications, it was found that by providing Arlene French and Robert Davis Aspen Resources Limited, Inc. has met or exceeded the statement of work requirements in their contract with Sandia.

# Job/Position Description

Position Name: __Quality Assurance Coordinator______

Organization Number: ____Aspen____ Reports To: _Department Manager__

Work Location: __TAIII, 6630, Thermal Test Complex___

Required Education/Training of Position:

Qualifications specified in contract

Position Duties/Responsibilities:

The Quality Assurance Coordinator will verify that the test and support procedures are implemented and are in accordance with the requirements of the SRNS PCV/SCV/3013 Test Program. He/she is responsible for verifying calibration, inspection, and verification of system equipment and for maintaining the documentation in the program file. In the event of a nonconformance, this person has the authority to halt activities until the nonconformance is corrected or resolved.

Physical Requirements of Position: None

# DISTRIBUTION

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203 Laurens St. SW
Aiken, SC 29801

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Attn: Alex Shefferman
203 Laurens St. SW
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