Thermal Analysis of a Pipe Over-pack Container with a Combustible Waste Matrix for Los Alamos National Laboratory-17307

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Abstract

Los Alamos National Laboratory (LANL) Technical Area 55 (TA 55) utilizes several different container types to store and transfer special nuclear material and waste for numerous programs. The Nuclear Process Infrastructure – Infrastructure Operations Group (NPI-2) analyzes and certifies containers to meet the specifications for distinct processes and storage. Engineering analysis performed on these containers include but are not limited to: leak testing, filter efficiency testing, pressure drop test, drop testing, water penetration testing, polymer (o-ring) hardness testing, and thermal steady state testing. Of all of these tests, thermal steady-state testing is most crucial to ensure critical components for specific containers do not fail under an internal heat payload. This testing provides data for setting heat payload limits for different containers. The Pipe Over-pack Container (POC) is a vented carbon steel container with a removable lid designed for storing or transferring nuclear waste. Additionally, TA 55 has been tasked to manage and store all of its Transuranic (TRU) waste for the foreseeable future. Being able to place more material into a single container conserves the physical storage space available at TA 55. The Pipe Over pack Handling and Operations Manual requires each user to ensure that the maximum temperature of each component in the POC is not exceeded. Conducting a thermal steady-state test with a combustible waste matrix on the POC can benefit stakeholders on increasing the material limits of the container. The results of these measurements will establish new wattage limits to meet LANL's transportation requirements. The current LANL Transportation Safety Document (TSD) limits the amount of heat source plutonium to 10 grams per POC, corresponding to approximately 5 Watts of heat. The result of this test was provided to the Packaging and Transportation (OS-PT) group to evaluate new wattage limits that can satisfy the needs of TA 55, while maintaining a safe packaging configuration.

1 Introduction

The POC is designed as a payload container within a TRUPACT-II and HalfPACT packages. The pipe component is surrounded by softwood-based fiberboard dunnage and plywood dunnage within a vented 55 gallon drum with a rigid high density polyethylene (HDPE) liner [1]. Inner packaging within the pipe component consists of either a Hagan container, SAVY 4000 container or a bag out bag. The POC's are designed to be a Type-A package for non-fissile or fissile exempt, radioactive materials of normal form [1]. Material thermal limitations are defined by Table 1 (below). Table 1 can be found in the POC handling and operations manual [1]. As mentioned in the handling and operations manual, it is the responsibility of the shipper to identify the thermal load resulting from decay heat and to ensure that the decay heat does not exceed the maximum operating temperature limits of the packaging materials [1]. Currently there is a need for an in-depth thermal steady-state study with a combustible waste matrix to investigate component behavior under extreme thermal loading.

PO component	Material	Temperature Range (°C)
55-gallon Drum	Carbon Steel	-40 to 1,510
Rigid Drum Liner	High-Density Polyethylene	-40 to 121.1
Fiberboard Dunnage	Celotex® Fiberboard	-40 to 121.1
Plywood Dunnage	Plywood	-40 to 100
Pipe Container	Stainless Steel	-40 to 1,426.67
Neutron Shielding	High-Density Polyethylene	-40 to 121.1
Gamma Shielding	Lead	-40 to 326.67
Cap Screws	Stainless Steel	-40 to 1,426.67
Filter Vent	Stainless Steel	-40 to 70
O-ring Seal	Elastomeric Rubber	-40 to 121.1

Table 1 POC Component thermal limitations

Waste contents will include but are not limited to: cellulosics, plastics, rubber and other contents such as tape. A concentrated heat load test will be achieved by using an electric bullet, this represents a worst case scenario of packed POC's. A temperature limit of 140 °F (~60 °C) will be applied to the waste matrix. This limit is introduced from previous testing involving sensitivity studies of nitrate contaminated combustibles in packaged containers. The testing revealed no significant increase in sensitivity to ignition or explosion within temperature condition around 140 °F [8]. Limiting our test to 140 °F will ensure the data will include potential nitrate contaminated combustibles. Waste components of interest are within the combustible category due potential fire ignition, explosion and dangerous gases produced from high heat loading, metal waste will not be considered in testing.

2 Background

The need for this testing derives from two primary sources: 1) The Pipe Overpack Handling and Operations Manual (POC-MAN-0001) [1] and the LANL Transportation Safety Document (TSD, P&T-SA-002) [2]. LANL desires to pack more heat source plutonium into POCs than it has historically [6]. Testing would aid waste generators by limiting the number of times a waste item would need to be split and by limiting the number of operations required to manage waste [6]. This would reduce costs and reduce worker exposure to radiation. Currently TA 55 has been managing and storing all of its TRU waste on site and inside its facilities [6]. Due to the wattage limit [2], more material needs to be stored into a single container to conserve on physical space. To help raise the TSD limits, tests are required to study the thermal effects at different temperatures. The objective of the testing is to determine the temperature the waste contents experience under certain heat loading scenarios while maintaining a safe configuration. Results have assisted in presenting a new wattage limit to the Packaging and Transportation (OS-PT) group and the LANL Nuclear Materials Storage and Disposition Board (NMSB).

3 Testing setup

The POC was subject to testing using thermistors, an electric bullet heater and waste contents. The testing has been set up in a temperature controlled laboratory to mimic the current POC storage environment. Therefore, transient heat from insolation effects or other environmental effects were not considered in the testing. Baseline testing was also conducted without the bullet heater or the waste contents to ensure accurate data, equipment performance and tolerance checks. Thermistors locations include the pipe component steel sintered filter, pipe component o-ring, various locations on pipe component body, the 55 gallon drum liner, various locations on fiberboard and plywood dunnage, the external wall of the 55 gallon drum and within the POC for ambient air recordings.

The bullet heater used is from Tempco, part number HDC0005 ¼” diameter bullet, 1” sheath length and max power of 150 Watts [9]. The configuration consisted of connecting the bullet heater to a power supply. The power supply is a Kepco model JQE 150-1.5M configured for constant voltage control. The current was measured by monitoring the voltage across a precision 0.1 ohm resistor. A three inch aluminum cube was machined to hold the bullet heater in place for testing. Figure 1 (below) shows a drilled hole that supports the bullet heater. The overall goal of the aluminum block is to hold the bullet heater upright so the connecting wires are not in contact with the surroundings to prevent the wires from burning. In addition, DOW Corning 340 silicone heat sink grease was applied to the bullet heater prior to inserting into the drilled hole. This allowed the bullet heater to dissipate the heat efficiently in its confined configuration.

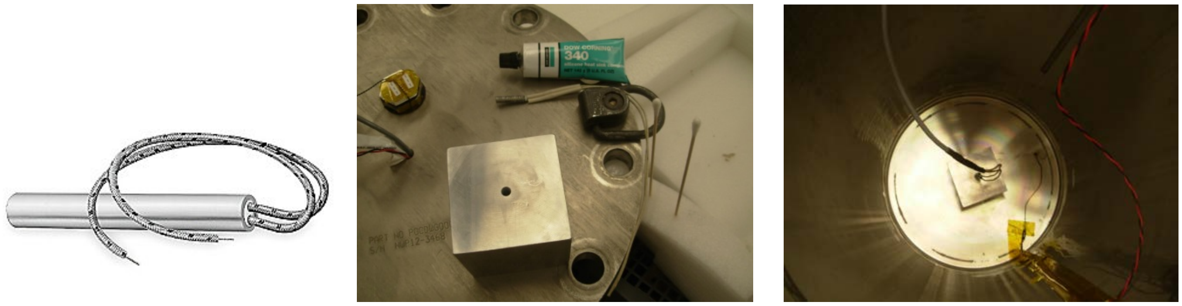
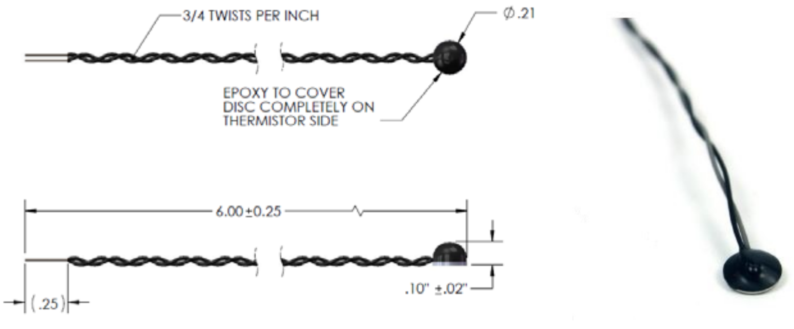


Figure 1 Bullet heater and configuration

The testing used QT06022 thermistors from Qti Solutions. A thermistor is a solid state, electronic device which detect thermal environmental changes for use in temperature measurement, control and compensation circuitry. The QT06022 series have a resistance of 10K ohm @ 25 °C, wire size #24 and a tolerance of ±5% [3]. Overall, the Steinhart-Hart equation is the most useful tool for interpolating the negative temperature coefficient (NTC) thermistor resistance/temperature curve characteristic [4]. As seen in equation (1), the Steinhart-Hart equation is a third order polynomial which provides excellent curve fitting for specific temperature spans within the temperature range of -80 °C to 260 °C [4]. Figure 2 (below) shows the thermistors used in the testing.



Fgiure 2 QT06022 thermistors

The Steinhart-Hart equation is expressed as:

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3 \qquad (1)$$

Where;
T= temperature (Kelvin)
R=resistance (ohms)
A=resistance/termperature coefficent
B= resistance/termperature coefficent
C= resistance/termperature coefficent

Coefficients
A=0.001026033423396
B=0.000239630543563
C=0.000000154875335

Table 2 Manufacture recommended Steinhart-Hart coefficients

Table 2 shows the coefficients received from the manufacture to implement into the program used to calculate a temperature at a given resistance [4]. In addition, baseline testing was conducted to ensure the thermistors were operating with respect to their specifications. A total of 20 thermistors were purchased from Qti and samples of 8 thermistors were baseline tested. A piece of aluminum plate was set in the laboratory for 24 hours to reach room temperature. After 24 hours, the eight thermistors were connected to the surface of the block as seen in figure 3.

Figure 3 Baseline testing of thermistors

The thermistors recorded the aluminum block temperature for a total of 72 hours as seen in Table 3. The objective of the baseline testing was to observe the behavior of the thermistors with respect to each other. If any thermistors were not working properly we could adjust the coefficients to the Stienhart-Hart equation to compensate for the error. As seen in the Table 3 the difference between the highest recorded temperature and the lowest recorded temperature is approximately 0.65 °C. With the small difference in measurement after 72 hours of baseline testing the thermistors are said to be operating within the manufacture recommended coefficients.

Thermistors Baseline (°C) for 72 hours							
T1	T2	T3	T4	T5	T6	T7	T8
23.74	23.81	23.50	23.43	23.23	23.16	23.55	23.58

Table 3 Baseline results

Figure 4 (below) shows the POC assembly depicting all the components that make up the contianer [1] .

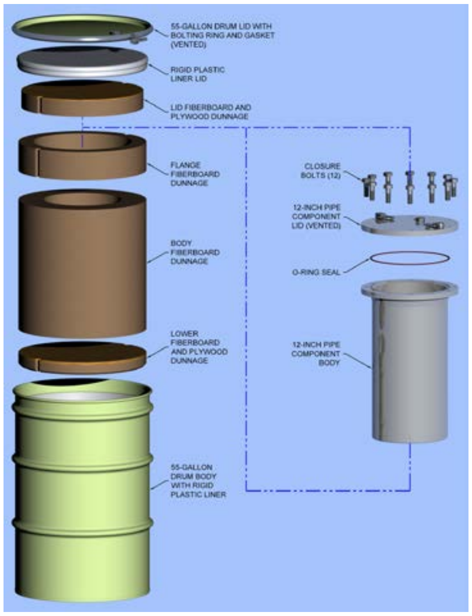


Figure 4 POC assembly diagram

The waste matrix inside the POC will be observed at various temperatures throughout a test cycle. Each test will be closely monitored to ensure the combustible test temperature does not exceed the 140 ºF limit. If the testing temperature limit is not reached and shows signs of ignition or extreme degradation the testing will be terminated. The recorded data will be plotted in the form of graphs and tables depicting maximum temperatures for each test. In addition, pictures of each test will also be taken for documentation. Figure 5 (below) shows the various thermistor locations on the POC.

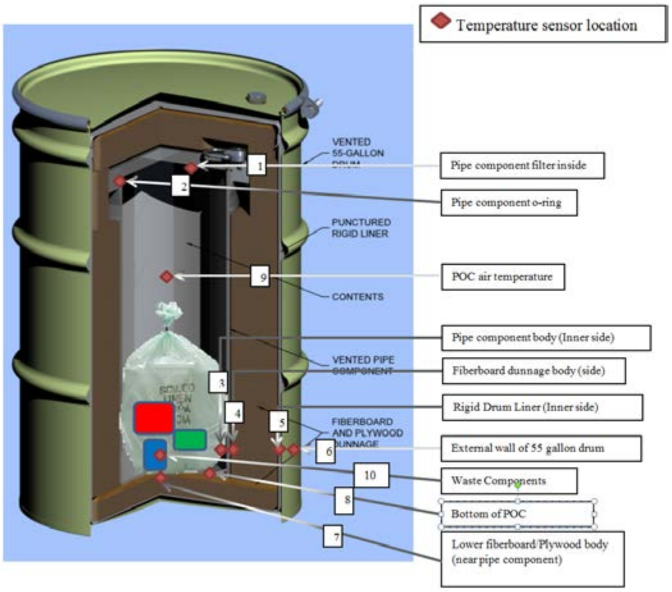


Figure 5 Thermistor locations for testing

Once the thermistors were wired to their respective location, additional verification was performed by utilizing sealed Pu-238 heat source standards. The sources are American National Standard Institute (ANSI) certified and are traceable to National Institute of Standards and Technology (NIST) [7] as seen in figure 6. According to the certification of each source, they hold powers of 1.1 watts, 1.0 watts, 3.0 watts and 3.1 watts. Various combinations of the sealed sources allowed for three tests of 2.2 watts, 6.3 watts, and 9.3 watts [7]. The verification testing included measuring the temperature output from the standard heat sources while cross referencing with bullet heater at the same power output.

Figure 6 Certified Pu-238 sealed sources

The plots in figure 7-8 show two different tests at 2.2 watts and 9.3 watts using the sealed sources and the bullet heater separately. Each test is conducted until the system reaches a state of thermal equilibrium. The percent error was not greater than 5% for any particular location. With close agreement between the two tests the bullet heater was determined to be working within the manufactured specifications.

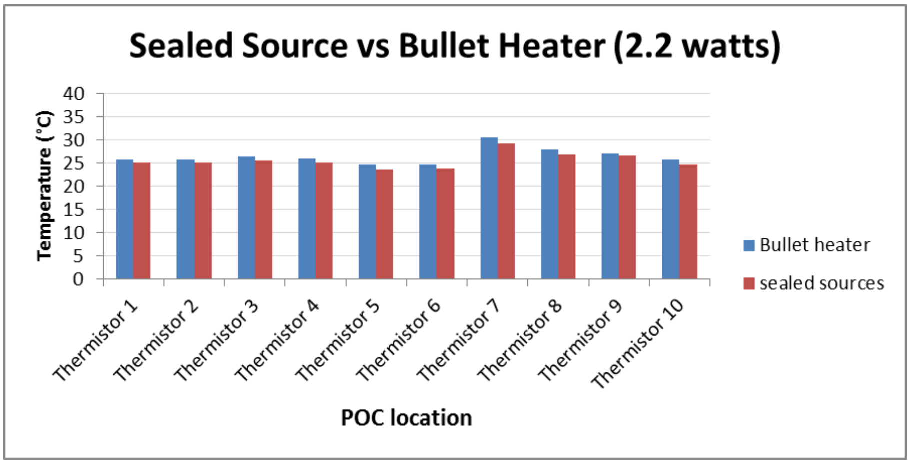


Figure 7 System verification at 2.2 watts

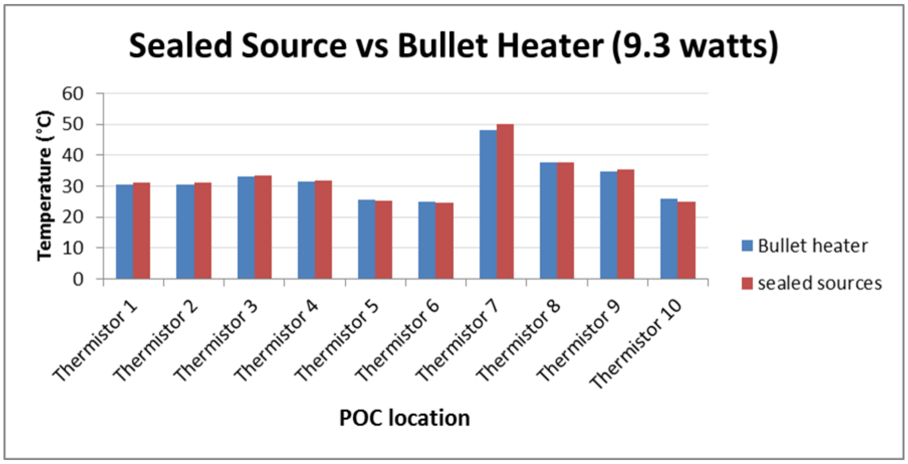


Figure 8 System verification at 2.2 watts

An algorithm within the data acquisition program was utilized to determine thermal steady state. This algorithm uses the slope of each curve as well as the standard deviation [5]. The slope indicates a change in temperature with respect to time. When the slope reaches a value close to zero, the system is said to reach equilibrium or steady-state due to the temperature no longer changing with respect to time. The standard deviation shows the spread of the data and is used as an estimate of uncertainty. The algorithm is implemented by calculating the slope for each curve then calculating the standard deviation at twenty minute sliding intervals [5]. Figure 9 (below) shows the diagram of implementing the algorithm. Once the slope and standard deviation have fallen below the user defined threshold, the system has reached steady-state. The threshold limits are set by the user based on engineering judgment of the data. After both conditions are met, the maximum value is then returned and represents a temperature limit that a certain location has reached after steady-state.

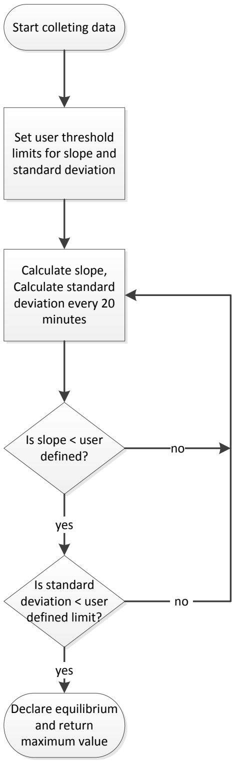


Figure 9 Algorithm used in analysis

The waste contents were chosen to represent actual materials used in various processes in the plutonium facility. The chosen contents were configured in a bag out bag in an arrangement that represents loaded POC’s. Waste contents can be seen in Figure 10 which includes: cellulosics, plastics, rubber and other contents such as tape.

Figure 10 Waste contents

Two new thermistors were introduced to the test setup, located on the cheese cloth and the aluminum block housing the bullet heater. These were chosen to monitor the temperature on the waste contents and the temperature from the block. Introducing the bag out bag with the waste matrix creates a well insulted environment around the block; these additional thermistors will ensure we are not exceeding our 140 ºF limit. Figure 11 (below) shows the new thermistors wired to the waste contents and the aluminum block.

Figure 11 Thermistors on cheesecloth and aluminum block

The waste components were loaded in the bag out bag in a configuration such that each of the different contents were in direct contact with the aluminum block. This configuration allows similar, and presumably bounding, heat loading onto the various content types. Figure 12 (below) shows the configuration within the bag out bag. Furthermore, the loaded bag out bag was taped into a "pig tail" configuration to mimic loaded bag out bags.

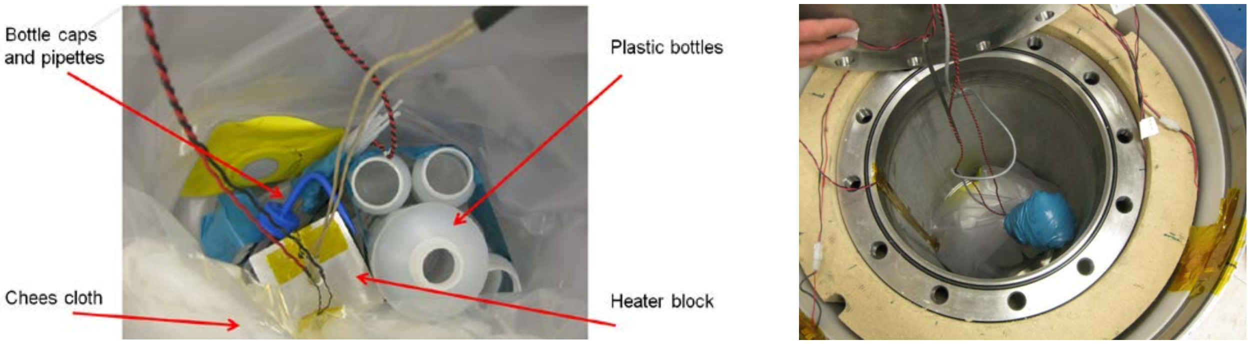


Figure 12 Packaged waste matrix

The thermistors were connected to volt meters which displayed the difference of resistance the thermistors were measuring at each surface. The volt meters were then connected to the data acquisition program MulitCal 4.0 as seen in Figure 13. The MultiCal software package provides a robust multi-tasking operating system capable of operating multiple calorimeters from a single computer system [5].

Although MultiCal has been primarily used for calorimetry measurements, the inputs can also be used for NTC thermistors and probes as well [5]. MultiCal allows the user to make simultaneous measurements with multiple power/temperature devices. Associated with each device on the system is a special window, and its popup menu provides access to information about that device. The thermistor curves given by the manufacture along with the coefficients as mentioned above were implemented into MultiCal for temperature profiling. The data that accumulates during a run can be displayed as either a graph or a status display. The time period displayed by the graph can be adjusted from one minute to one week. Data was exported into Microsoft Excel 2010 for analysis. The laptop shown in Figure 6 runs the program MultiCal.

Figure 13 Testing setup, POC wired up (left) and volt meters along with MultiCal program (right)

4 Results and Analysis

Two tests were conducted at powers of 9.3 watts and 15 watts. The tests were not allowed to meet steady state conditions due to safety concerns of the waste contents igniting or causing severe degradation while the system was unattended. To reach steady state the test would need extensive time to be operating unattended. The goal for the current testing configuration is to examine the components after they have reached the 140 ºF limit. Figure 14 (below) shows the maximum temperatures at certain locations with respect to power. The three locations here represent the contents close to the bullet heater, the aluminum block housing the bullet heater and the air within the POC. The locations never approached the limit within an eight hour work day at 9.3 watts. Testing was continued at a higher power to reach the140 ºF limit. After five hours of testing at 15 watts the limit was reached and the test was stopped for examination. Figure 15 shows pictures of the waste contents after both tests. There were no visible signs of ignition or even slight degradation due to heat.

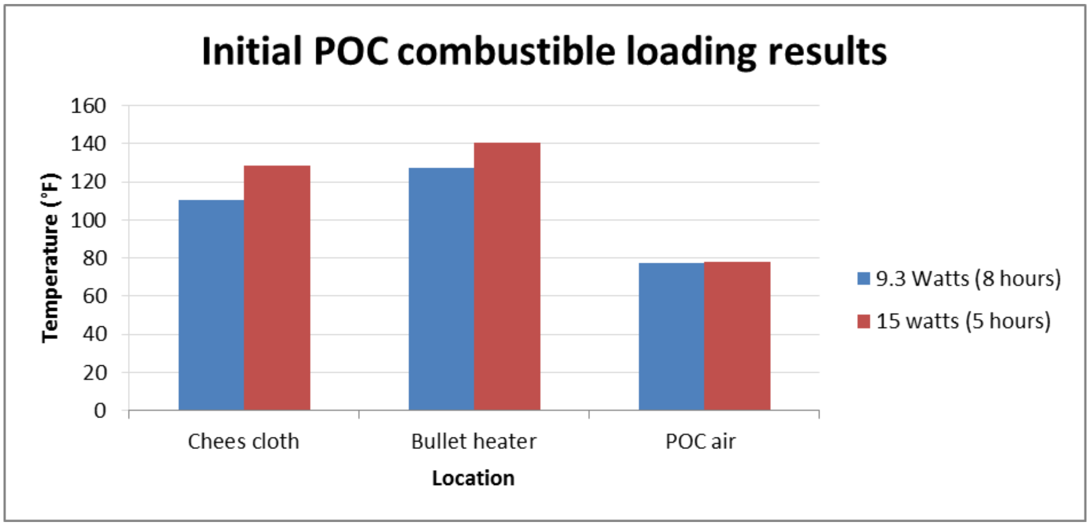


Figure 14 Plot of POC location vs Temperature

Figure 15 Waste contents after testing

6 Conclusion

The results of these experiments provide a technical basis for raising the LANL Transportation Safety Document (TSD) heat loading limits for POC's. This will help conserve on physical space, number of operations for splitting material/bag out operations and reducing worker exposure. This testing illustrates the effects of a concentrated heat source under the conditions of stored POC's. The tests that indicate that there is no significant degradation or ignition up to the 140 ºF limit. Additional testing is needed to understand material mass limits within POC's where the heat load is distributed more evenly. The next phase of testing is to introduce conductive wire to emulate a distributed heat load within the contents. The conductive wire will be connected to the same power supply as the bullet heater. In addition to the conductive wire, the integration of 100 ºC thermal fuses will allow the tests to be conducted unattended to reach steady state. The next phase will allow for further investigation of the waste contents after reaching steady state at various powers.

References

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