Abstract
Lithium batteries have a well-known tendency to fail violently under abuse conditions which can result in venting of flammable material. Understanding these events can aid in evaluating safety associated with individual battery cells and battery packs when these fluids are vented. The external fluid dynamics of the venting process, including liquid droplets and gases, is directly related to the internal pressure of the battery cell. In this work, battery case strain is measured on cells under thermal abuse which is then used to calculate the internal pressure via hoop and longitudinal stress relations. Strain measurement is a non-invasive approach which will have no bearing on the decomposition within batteries that leads to thermal runaway. Additional measurements include battery temperature and chamber pressure, temperature, and heat flux. Variables explored in these tests include cell chemistry, state of charge, and heating rate.

Direct pressurization of battery vent caps
An apparatus has been designed and constructed to accurately measure the burst pressure of battery vents under pressurization with dry air to best describe how venting will occur and to support the battery case strain tests. Typical 18650 construction includes a vent mechanism that is crimped in place as part of the positive terminal of a cell. The vents tested here are removed from actual cells, and the entire vent mechanism remains intact as seen in Figure 2.

Pressure calculation via battery case strain measurements during abuse testing
Strain gauges are used to perform noninvasive measurement of hoop and longitudinal strain of battery cases under thermal abuse conditions. Strain measurements are the sum of pressure and thermal expansion components. Internal pressure is analytically calculated from geometry, case material properties, and the two strain measurements.

Vent opening area calculation and validation tests
Since the battery vent has the minimum cross-sectional area of the test setup and pressure in the tank is sufficiently high, airflow will choke at the vent cap. Measurement of the stagnation pressure within the tank and static pressure at the known cross-section allows for calculation of the battery vent area. A series of circular test orifices were made in various sizes to validate this measurement. Test orifices were also made with patterned holes to represent the geometries seen on actual vent caps as shown in Figure 4. These orifices are used in lieu of the battery cap during validation tests. Figure 5 shows the accuracy of orifice area calculations.

References and Acknowledgements
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Figure 1: (a) An 18650 cell venting during abuse testing which lead to combustion of expelled material. (b) Schlieren images of a different test from end and side views.

Figure 2: (a) An intact 18650 format battery (LG HE2) and (b) the vent cap after removal.

Figure 3: (a) Schematic representation of the battery vent cap holder and (b) the completed test setup installed at New Mexico Tech.

Figure 4: (above) The internal surface of battery vent cap and orifice plates made to mimic the maximum possible opening area.

Figure 5: (right) Results of validation testing by comparing actual and calculated opening areas.

Figure 6: Calibrations of (a) gas temperature and (b) nominal rate

Figure 7: (a) The test chamber with viewing window, (b) instrumentation cap with a thermocouple probe, data lines, gas purge tubing, and chamber pressure transducer, (c) insulation structure, and (d) battery holder.