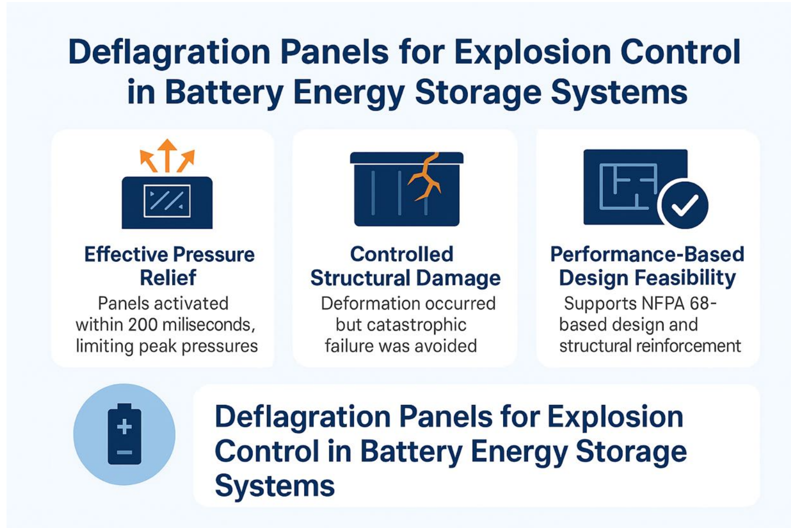
FIRE & RISK ALLIANCE

Evaluation of Deflagration Panels for Explosion Control in Battery Energy Storage Systems (BESS)

Executive Summary



Battery energy storage systems (BESS) present unique fire and explosion risks. In particular, gas accumulation and delayed ignition events can result in rapid pressure rises within BESS enclosures. This white paper presents the results of a large-scale deflagration test campaign performed by Fire & Risk Alliance (FRA) to evaluate the performance of various VIGILEX ARC-VENT® deflagration panels and panel configurations. The goal was to assess whether these passive venting devices could effectively mitigate overpressure in a BESS container to prevent catastrophic failure.

The tests varied the total surface area covered with panels, ignition location, as well as the gas mixture fraction utilizing a simulated battery gas mixture composed of 48% H_2, 14% CH_4, 11% CO, and 27% CO_2 by volume. The results demonstrate that while container deformation will occur, the use of appropriately sized and specified deflagration panels will reduce the resulting overpressure to levels that typically will not result in catastrophic failure of a BESS enclosure.

Background and Context

BESS installations have become critical for grid reliability and renewable integration. However, the fire safety community continues to explore effective mitigation strategies for thermal runaway and gas explosion events. Conventional explosion protection systems, such as NFPA 68 deflagration vents, have limited guidance specific to BESS.

To address this gap, testing was conducted using realistic battery off-gas mixtures (hydrogen - H_2, methane - CH_4, carbon monoxide - CO, carbon dioxide - CO_2) in a full-scale container equipped with VIGILEX ARC-VENT® panels. These panels are designed to relieve internal pressure upon a deflagration event, protecting against risk of catastrophic failure.

Test Description and Methodology

A 20-ft CONEX container was used to simulate a typical BESS enclosure. Ten (10) deflagration panels were installed on the roof and/or sides. The container was sealed and instrumented with up to 8 piezoelectric and 4 static pressure transducers.

Tests were conducted at both 2× the Lower Flammability Limit (LFL) and stoichiometric concentrations. Gas was introduced for 9–17 minutes, followed by spark ignition. Pressure sensors sampled up to 6,250 Hz, and results included the transient duration and rate of pressure rise.

Dynamic Pressure Test Results Overview

Battery Energy Storage System (BESS) Deflagration Panel Testing

- **Test 1 (2× LFL):** Lower average and maximum pressures, but longer event duration (260 ms).
- **Test 9 (Stoichiometric):** Higher average and peak pressures, but shorter event duration (160 ms).

Key Takeaways

1. **Rapid Pressure Relief:** Panels consistently opened in under 200 milliseconds, effectively controlling internal pressures.
2. **Contained Structural Impact:** No catastrophic failures observed—even at higher pressures—demonstrating the effectiveness of vent panels, though container deformation was observed.
3. **Supports Performance-Based Design:** Results reinforce the viability of NFPA 68-based venting strategies when paired with proper panel sizing calculated to prevent the explosion pressure from increasing beyond the container pressure resistance.

See Figure 2 and Figure 3 for visual dynamic pressure and deflagration comparisons between tests.

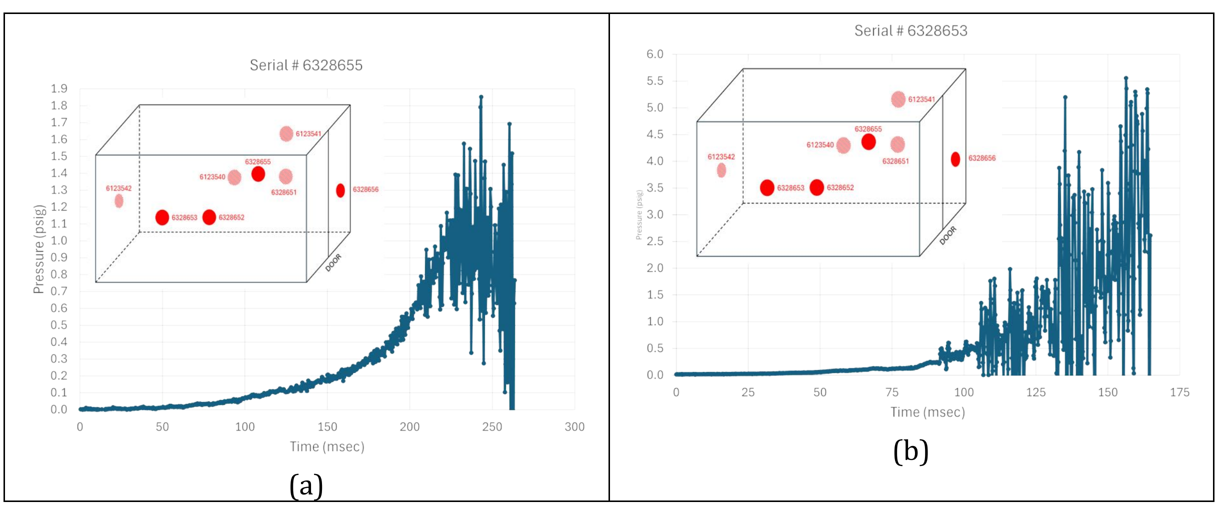


Figure 1: (a) Test 1 dynamic pressure; (b) Test 9 dynamic pressure

Figure 2: Test 1 deflagration

Figure 3: Test 9 deflagration

Discussion and Implications

These results support several important conclusions:

Effective Pressure Relief

Panels consistently opened within 200 milliseconds, limiting peak internal pressure and protecting the structural integrity of the BESS container regardless of ignition location

Controlled Structural Damage

While structural deformation of the container occurred, no catastrophic rupture or system-wide failure was observed. This indicates that deflagration panels can provide a safer failure mode

Performance-Based Design Feasibility

These findings validate the use of NFPA 68-based performance designs, especially when paired with proper vent sizing and container reinforcement strategies

Panel Configuration & Gas Composition

Worst-case ignition scenarios, panel sizing, and realistic battery gas mixtures significantly influence deflagration severity and should be carefully modeled or tested and venting area calculation according to NFPA 68

Recommendations for Use in BESS Applications

Based on test outcomes, deflagration panels should be considered in BESS deployments where:

- Gas accumulation is a credible scenario (e.g., thermal runaway or off-gassing events).
- Ignition sources are likely, possible, or known (e.g., internal arcing, sparking, or overheating).
- Structural support can be reinforced, or panel sizing can be optimized

It is also recommended that:

- Design teams consult NFPA 68 and NFPA 855 guidance when integrating venting systems.
- CFD modeling or scaled testing can be conducted to verify panel arrangement and performance.
- Assess credible scenarios for failure of active protection system based on risk analysis.
- Structural redundancy be included to account for possible deformation even if overpressures are low.
- Systems be designed with sacrificial components to reduce overall damage.

Conclusion

The testing campaign demonstrates that passive explosion protection systems, such as the VIGILEX ARC-VENT®, panels can significantly reduce overpressures inside a BESS container during a deflagration event. While structural deformation may still occur, the risk of catastrophic failure is minimized. These findings support the integration of such systems into BESS safety strategies, particularly in cases where active mitigation is insufficient or may fail.

Further analysis is encouraged to refine best practices for panel placement, sizing, and potential reinforcement. Overall, deflagration venting provides a valuable tool for mitigation of overpressure for BESS applications.

References

- Fire & Risk Alliance. BESS Explosion Control Guidance v1.1, 2025
- Fire & Risk Alliance. CFD Analysis of Performance-Based Explosion Protection Design for BESS. 2025
- National Fire Protection Association. NFPA 855 – 2026 Edition
- UL 9540A Ed. 5, Test Method for Evaluating Thermal Runaway Fire Propagation in BESS