

Prüfbericht-Nr.: <i>Test report no.:</i>	CN25FA2W 001	Auftrags-Nr.: <i>Order no.:</i>	326096316	Seite 1 von 27 Page 1 of 27
Kunden-Referenz-Nr.: <i>Client reference no.:</i>	2371109	Auftragsdatum: <i>Order date:</i>	2025-02-21	
Auftraggeber: <i>Client:</i>	CSI Energy Storage Co., Ltd. No.348 Lushan Road, SND, Suzhou, 215129 Jiangsu, P.R. China			
Prüfgegenstand: <i>Test item:</i>	Battery Energy Storage System			
Bezeichnung / Typ-Nr.: <i>Identification / Type no.:</i>	CSI-SolBank-S-5016-2h-NA, CSI-SolBank-S-5016-4h-NA, CSI-SolBank-S-5016-2h-EU, CSI-SolBank-S-5016-4h-EU			
Auftrags-Inhalt: <i>Order content:</i>	Assessment report			
Prüfgrundlage: <i>Test specification:</i>	This report provides evaluation and CFD analysis of the deflagration venting system in energy storage system referring to NFPA68:2023.			
Wareneingangsdatum: <i>Date of sample receipt:</i>	2025-06-03			
Prüfmuster-Nr.: <i>Test sample no.:</i>	Engineering sample			
Prüfzeitraum: <i>Testing period:</i>	2025-06-03- 2025-06-19			
Ort der Prüfung: <i>Place of testing:</i>	TÜV Rheinland (Shanghai) Co., Ltd.			
Prüflaboratorium: <i>Testing laboratory:</i>	TÜV Rheinland (Shanghai) Co., Ltd.			
Prüfergebnis*: <i>Test result*:</i>	See main report			
geprüft von: <i>tested by:</i>			genehmigt von: <i>authorized by:</i>	
Datum: <i>Date:</i>	2025.10.27	Shiheng Zhang	Ausstellungsdatum: <i>Issue date:</i>	2025.10.27
Stellung / Position:	Project Engineer		Stellung / Position:	Authorizer
Sonstiges / <i>Other:</i>				
Zustand des Prüfgegenstandes bei Anlieferung: <i>Condition of the test item at delivery:</i>	Prüfmuster vollständig und unbeschädigt <i>Test item complete and undamaged</i>			
* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
* Legend:	P(ass) = passed a.m. test specification(s)	F(ail) = failed a.m. test specification(s)	N/A = not applicable	N/T = not tested
Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens. <i>This test report only relates to the above mentioned test sample as. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.</i>				

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1. General Production Information:

1.1. Cell

The product information and parameters are provided by the client as below.

Product	Rechargeable Lithium Ion Cell
Type/model	CSI314
Constructed	Prismatic cell
Cell Capacity [Ah]	314
Nominal voltage [V]	3.2
Rated capacity [kWh]	1.0048
Upper limit charging voltage [V]	3.65
Discharge cut-off voltage [V]	2.5
Maximum continuous current for charging and discharging [A]	314
Recommend charging method by manufacturer	157A CC charging to 3.65V, CV cut off 15.7A
Recommend discharging method by manufacturer	157A constant current discharging to 2.5V
Temperature range for charging [°C]	0 to 60
Temperature range for discharging [°C]	-20 to 60
Dimension [mm] (W*H*T)	(173.7±0.5) * (207.2±0.5) * (71.5±0.5) with terminal
Weight [kg]	5.6±0.2

1.2. Module

The product information and parameters are provided by the client as below.

Product	Rechargeable Li-ion Battery pack
Type/model	CSI-SolBank-P-104.5-2h-A
Constructed	104* CSI314
Cell Capacity [Ah]	314
Cell Quantity	104
Battery structure	104S
Nominal voltage [V]	332.8
Rated capacity [kWh]	104.5
Upper limit charging voltage [V]	374.4
Discharge cut-off voltage [V]	265.2
Max continuous power for charging and discharging [kW]	52
Maximum continuous current for charging and discharging [A]	240
Recommend charging method by manufacturer	52kW constant power charging to cell max 3.6V
Recommend discharging method by manufacturer	52kW constant power discharging to cell min 2.55V
Temperature range for charging [°C]	0 to 55
Temperature range for discharging [°C]	0 to 55
Dimension [mm] (W*H*T)	2180±5.0*790±3.0*248±5.0 L * W*H (mm)
Weight [kg]	670±15
Ingress Protection (IP)	IP67
Cooling type	Liquid cooling and liquid heating for cell

1.3. Energy Storage System

The product information and parameters are provided by the client as below.

Product	Battery Energy Storage System	
Type/model	CSI-SolBank-S-5016-2h-NA	CSI-SolBank-S-5016-4h-NA
Constructed	12* CSI-SolBank-R-418-2h-A	12* CSI-SolBank-R-418-4h-A
System Capacity [Ah]	3768	
Cell Quantity	4992	
Battery structure	((104S)4S)12P	
Nominal voltage [V]	1331.2	
Rated capacity [kWh]	5016	
Upper limit charging voltage [V]	1497.6	
Lower limit discharge cut-off voltage [V]	1060.8	
Recommend discharge cut-off voltage [V]	1164.8	
Max continuous power for charging and discharging [kW]	2400	1250
Peak current for charging and discharging [A]	2400	1200
Recommend charging method by manufacturer	2400kW constant power charging to cell max 3.6V	1250kW constant power charging to cell max 3.6V
Recommend discharging method by manufacturer	2400kW constant power discharging to cell min 2.55V	1250kW constant power discharging to cell min 2.55V
Ambient Temperature range for charging [°C]	0 to 55*	
Ambient Temperature range for discharging [°C]	0 to 55*	
Dimension [mm]	6058*2438*2896 mm	
Weight [kg]	Approx 43000	
Ingress Protection (IP)	IP55	
Protective Class	I	
Cooling type	Liquid cooling and liquid heating for cell	
Altitude	Below 3000m	
Note*: When cell min temperature $\leq 5^{\circ}\text{C}$, the system will not charge or discharge which controlled by the BMS until the liquid chiller heating the cell min temperature $> 5^{\circ}\text{C}$. The BESS will derating when cell max temperature $> 50^{\circ}\text{C}$.		

2. Product Description:

2.1. General Description

This product is used for Energy Storage System.

This EUT covered by this report is DC system for energy storage, which mainly consists of 12 Lithium ion battery racks, 1 liquid chiller, fire protection, some auxiliary power supply components integrated in 1 cabinet.

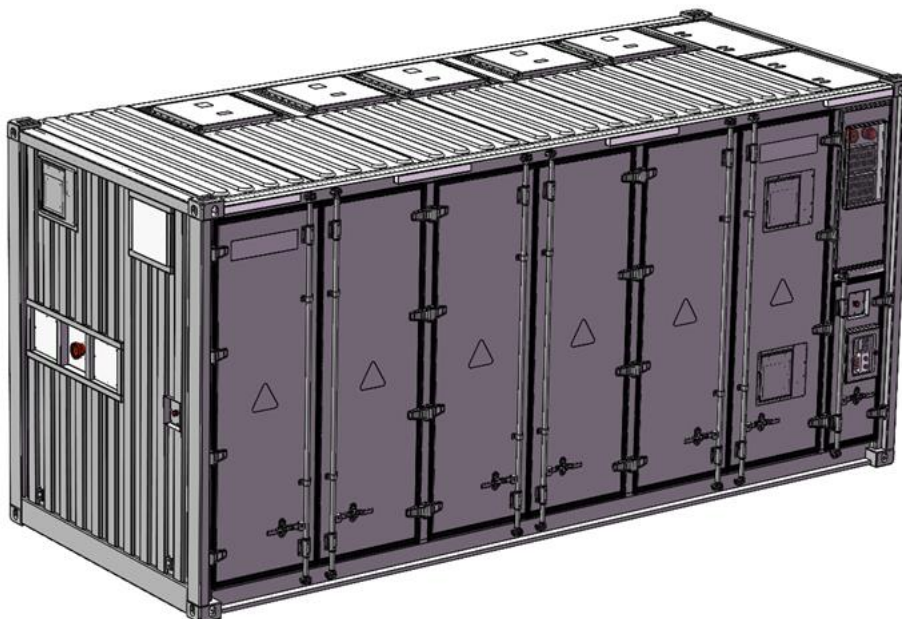
Each battery rack includes 1 master control box and 4 battery packs in series connection. Total 12 racks parallel connection for the completed system.

The main output circuit for the system is optional for a set of ports (for 12 racks), or two sets of ports (each for 6 racks), depends on the main output busbar. Suitable disconnect device(s) should be provided for main circuit(s) in end-installation.

The insulation between the DC circuit and the metal enclosure is basic insulation. And the insulation between the DC circuit and communication ports is reinforced insulation or double insulation.

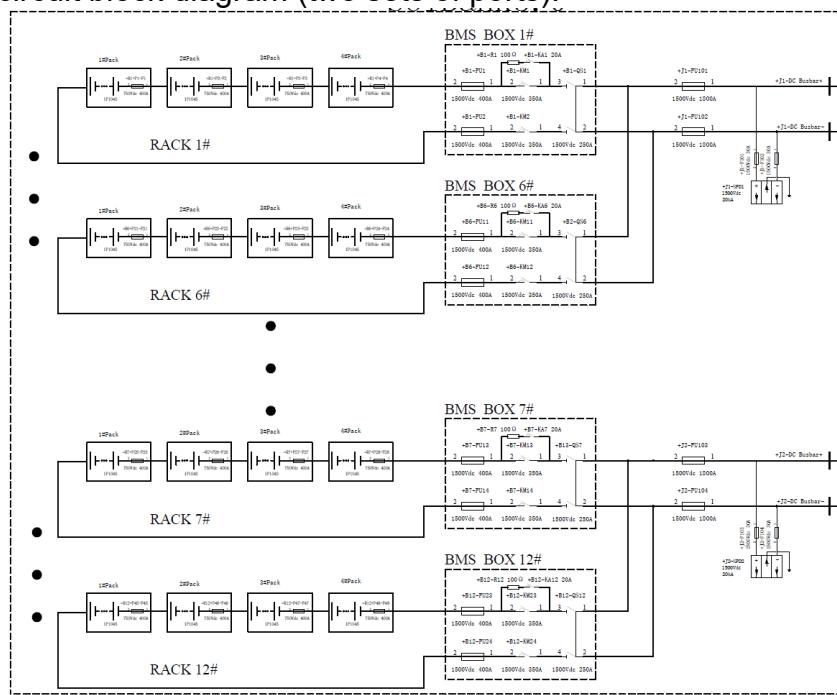
The battery system has overcharge, over-discharge, over current and short-circuits proof circuit. The electronic circuits and software controls for the battery system replied upon protective functions of the battery management system have been evaluated in accordance with UL 60730-1 Annex H.

The EUT is outdoor type with IP55 degree, PD2 was evaluated for inside and PD3 for outside.

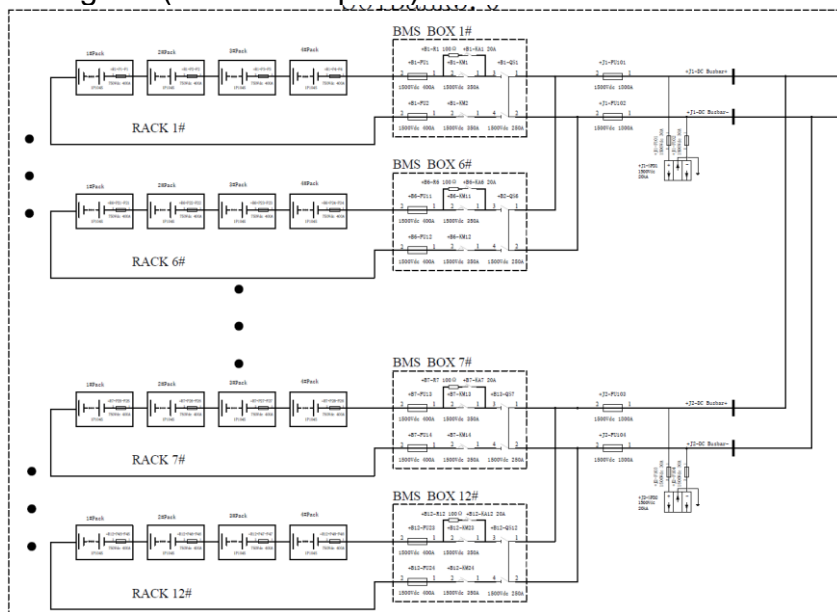


2.2. Energy Storage System Block Diagram

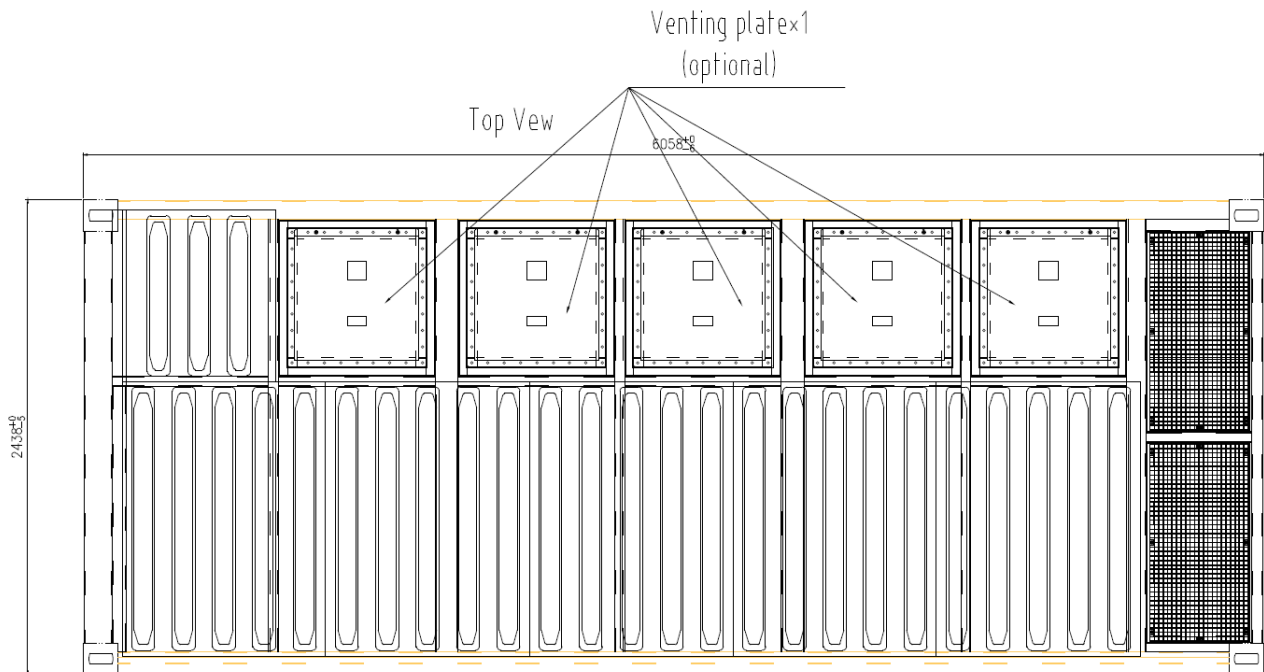
1 PC DC Main circuit block diagram (two sets of ports):



Main circuit block diagram (one sets of ports):



2.3. Deflagration Venting Layout



3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
Chapter 6	Fundamentals of Venting of Deflagrations		--
6.1	Basic Concepts.		--
6.1.1	The deflagration index, K , shall be computed from the maximum rate of pressure rise attained by combustion in a closed vessel with volume, V , and shall be defined by the following equation [6.1.1]		N/A
6.1.2	For dusts, K_{St} and P_{max} shall be determined in approximately spherical calibrated test vessels of at least 20 L capacity per ASTM E1226, Standard Test Method for Explosibility of Dust Clouds.		N/A
6.1.2.1	It shall be permitted to determine K_{St} and P_{max} per ISO 6184-1, Explosion Protection Systems — Part 1: Determination of Explosion Indices of Combustible Dusts in Air.		N/A
6.1.2.2	The owner/user shall be permitted to test the dust with moisture content and particle size that deviates from the recommended conditions established by the method described in 6.1.2 or 6.1.2.1, provided a documented assessment acceptable to the authority having jurisdiction has been performed prior to using these K_{St} and P_{max} values to determine vent sizing.		N/A
6.1.2.3	For aluminum, hafnium, magnesium, tantalum, titanium, zirconium, and similar alloys or mixtures with adiabatic flame temperature higher than 3300°C, unless K_{St} and P_{max} are determined in nominal 1 m ³ or larger calibrated test vessels, the K_{St} value shall be multiplied by a factor of 2 for application of the design methods.		N/A
6.1.3	For gases, P_{max} shall be determined in approximately spherical calibrated test vessels of at least 5 L (1.3 gal) capacity with initially quiescent mixture with low energy ignition source (i.e., less than 100 J).	See cell level UL9540A test report.	P
6.2	Mixtures.		--
6.2.1	Gas Mixtures.		P
6.2.1.1	Where the hazard consists of a flammable gas mixture, the vent size shall be based on the fundamental burning velocity of the mixture.	See clause 4 and cell level UL9540A test report.	P
6.2.1.2	Where the gas mixture composition is not certain, the vent size shall be based on the component having the highest fundamental burning velocity.		N/A
6.2.2	Dust Mixtures		N/A
6.2.2.1	Where the hazard consists of a dust mixture, the vent size shall be based on the K_{St} and P_{max} of the mixture.		N/A

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
6.2.2.2	Where the dust mixture composition is not certain, the vent size shall be based on the highest K_{St} of all components and the highest P_{max} of all components.		N/A
6.2.3	Hybrid Mixtures		N/A
6.2.3.1	For hybrid mixtures, the vent size shall be based on the equivalent mixture K_{St} as determined by test.		N/A
6.2.3.2	Where test data are not available for hybrid mixtures with gases that have combustion characteristics similar to those of propane (fundamental burning velocity ≤ 1.3 times that of propane) and St-1 and St-2 dusts, the design shall be permitted to be based upon $P_{max} = 10$ bar-g and $K_{St} = 500$ bar-m/s.		N/A
6.2.4	Foams of Combustible Liquids. Design of deflagration venting for foams of combustible liquids shall be based on tests performed on the specific foam.		N/A
6.3	Enclosure Design and Support.		--
6.3.1	Enclosure Design Pressure Selection Criteria.		P
6.3.1.1	P_{red} shall not exceed two-thirds of the ultimate strength for the vented enclosure, provided deformation of the equipment can be tolerated.	See clause 4.	P
6.3.1.2	Where deformation cannot be tolerated, P_{red} shall not exceed two-thirds of the yield strength for the vented enclosure.		N/A
6.3.1.3	For enclosures designed using the ASME Boiler and Pressure Vessel Code or similar codes, the maximum allowable working pressure, herein designated as P_{mawp} , shall be determined by calculation.		N/A
6.3.1.4	Ductile design considerations shall be used for materials subject to brittle failure, such as cast iron.		N/A
6.3.2	Venting shall be sufficient to prevent the maximum pressure that develops within the enclosure, P_{red} , from exceeding the enclosure strength, P_{es} , including the dynamic effect of the rate of pressure rise, as expressed by a dynamic load factor (DLF) [6.3.2]		N/A
6.3.2.1	In the absence of detailed structural response analysis, it shall be permitted to assume a worst-case value of $DLF = 1.5$ and design based on the weakest structural element of the enclosure.		N/A
6.3.2.2	It shall be permitted to modify the value of DLF based on a documented analysis of the vented explosion pressure profile and enclosure structural response.		N/A
6.3.3	All structural elements and supports shall be included in the design calculations.		P

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
6.3.3.1	The weakest structural element, as well as any equipment or other devices that can be supported by structural elements, shall be identified.		P
6.3.3.2	Where designing an enclosure to prevent catastrophic failure while still allowing permanent deformation, the normal dead and live loads shall not be relied on to provide restraint.		P
6.3.3.3	Structural members shall be designed to support the total load.		P
6.3.3.4	Doors, windows, ducts, or other openings in walls that are intended to be pressure resistant shall also be designed to withstand P_{red} .		P
6.3.4	Relieving Walls or Roof.		N/A
6.3.5	Enclosure Support Criteria.	Eliminated according to 6.3.5.4.1	P
6.3.5.4.1	The calculation of reaction forces on the enclosure shall be permitted to be eliminated when all of the following conditions are satisfied: (1) Vent panels are of the rupture diaphragm type. (2) Vent panels are located at opposing positions on the enclosure. (3) The P_{stat} of each vent panel is equal and less than or equal to 0.1 bar-g. (4) Vent panels are of equal area.		P
6.4	Enclosure Length-to-Diameter Ratio and Vent Variables.		--
6.4.1	The L/D of an elongated enclosure shall be determined based upon the general shape of the enclosure, the location of the vent, the shape of any hopper extensions, and the farthest distance from the vent at which the deflagration could be initiated.		N/A
6.4.2	For enclosures that can be vented at more than one point along the major axis, the vents shall be permitted to be distributed along the major axis and sized based on the length to diameter (L/D) between vents.		N/A
6.4.2.1	The maximum effective vent area at any point along the major axis shall be the enclosure cross section.		N/A
6.4.3	L/D of Elongated Enclosures.		N/A
6.4.3.1	The L/D of an elongated enclosure shall be determined based upon the general shape of the enclosure, the location of the vent, the shape of any hopper extensions, and the farthest distance from the vent at which the deflagration could be initiated.		N/A

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
6.4.3.2	The maximum flame length along which the flame can travel, H , shall be determined based on the maximum distance, taken along the central axis, from the farthest end of the enclosure to the opposite end of the vent.		N/A
6.4.3.2.1	When multiple vents are provided, a single value of H , and L/D , shall be permitted to be determined for the enclosure based on the farthest vent.		N/A
6.4.3.2.2	When multiple vents are located along the central axis, the value of H , and L/D , shall be permitted to be determined for each section using the maximum distance from the closest end of one vent to the opposite end of the next vent.		N/A
6.4.3.3	The effective volume of the enclosure, V_{eff} , shall be determined based on the volume of that part of the enclosure through which the flame can pass as it travels along the maximum flame length, H .		N/A
6.4.3.3.1	Partial volume (see Section 8.4) shall not be considered in the determination of effective volume per this section.		N/A
6.4.3.3.2	When multiple vents are provided, a single value of V_{eff} shall be permitted to be determined for the enclosure based upon the farthest vent.		N/A
6.4.3.3.3	When multiple vents are located along the central axis, V_{eff} shall be permitted to be determined for each section using the maximum distance from the closest end of one vent to the opposite end of the next vent.		N/A
6.4.3.3.4	When V_{eff} is less than the total volume of the enclosure, only those vents located within the effective volume shall be considered as providing venting for the event.		N/A
6.4.3.4	It shall be permitted to conservatively determine both H and V_{eff} , or H alone, but not V_{eff} alone, based on the total enclosure, irrespective of vent location.		N/A
6.4.3.5	The effective area, A_{eff} , shall be determined by dividing V_{eff} by H		N/A
6.4.3.6	The effective hydraulic diameter, D_{he} , for the enclosure shall be determined based on the general shape of the enclosure taken normal to the central axis [6.4.3.6]		N/A
6.4.3.6.1	Where the enclosure and any hopper extension are generally cylindrical, the perimeter, p , shall be permitted to be determined based on a circular cross section, given the following [6.4.3.6.1]		N/A
6.4.3.6.2	Where the enclosure and any hopper extension are generally rectangular or square, and the aspect ratio of the largest cross section is between 1 and 1.2, the perimeter shall be permitted to be determined based on a square cross section, given the following [6.4.3.6.2]		N/A

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
6.4.3.6.3	Where the enclosure and any hopper extension are generally rectangular, and the aspect ratio, R, of the largest cross section is greater than or equal to 1.2, the perimeter shall be permitted to be determined based on the aspect ratio of the largest cross section, given the following [6.4.3.6.3]		N/A
6.4.3.7	L/D for use in this standard shall be set equal to H/D _{he} .		N/A
6.4.4	The vent areas shall be permitted to be reduced from those specified in Chapters 7 and 8 if large-scale tests show that the resulting damage is acceptable to the user and the authority having jurisdiction.		N/A
6.4.5	The owner/user shall be permitted to install vents that are larger in area, are lower in density, or relieve at lower pressure than the minimum requirements determined from application of Chapter 7 or Chapter 8, as appropriate.		N/A
6.5	Vent Closure Operation.		--
6.5.1	The vent opening shall be free and clear.		N/A
6.5.2	Vent closure operation shall not be hindered by deposits of snow, ice, paint, corrosion, or debris, or by the buildup of deposits on their inside surfaces.		N/A
6.5.2.1	The materials that are used shall be chosen to minimize corrosion from process conditions within the enclosure and from ambient conditions on the nonprocess side.		N/A
6.5.2.2	Clear space shall be maintained on both sides of a vent to enable operation without restriction and without impeding a free flow through the vent.		N/A
6.5.2.3	To prevent snow and ice accumulation, where the potential exists, and to prevent entry of rainwater and debris, the vent or vent duct exit shall not be installed in the horizontal position, unless any of the alternative methods in 6.5.2.3.1 are followed.		N/A
6.5.2.3.1	Any of the following alternative methods of protection for horizontal vent or vent duct exits shall be permitted: (1) Fixed rain hats where Pred effects on vent area are included in accordance with Section 8.5 and restraint design includes maximum force from Pred applied over the area (2) Weather covers mounted at an angle sufficient to shed snow, with restraints designed and tested to prevent the cover from becoming a free projectile, where inertia effects of the additional weather cover mass and P _{stat} of the cover are included (3) Deicing provisions such as a heated vent closure		N/A

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
6.5.3	Restraining devices shall not impede the operation of the vent or vent closure device. (See Chapter 10.)		N/A
6.5.4	A vent closure shall release at its P_{stat} or within a pressure range specified by the vent closure manufacturer.		P
6.5.5	A vent closure shall reliably withstand pressure fluctuations that are below P_{stat} .		P
6.5.6	A vent closure shall withstand vibration or other mechanical forces to which it can be subjected.		P
6.5.7	P_{stat} , including the manufacturer's negative tolerance, shall be greater than the anticipated loading equivalent to the local design wind speed such that wind load will not cause the vent to open.		N/A
6.5.7.1	The area calculation shall be performed using the nominal value of P_{stat} .		P
6.5.8	P_{stat} , including the manufacturer's positive tolerance, shall be less than the intended P_{red} .		P
6.5.8.1	The area calculation shall be performed using the nominal value of P_{stat} .		P
6.5.9	Vent closures shall be maintained in accordance with Chapter 11		N/A
6.6	Consequences of a Deflagration.		--
6.6.1	The material discharged from an enclosure during the venting of a deflagration shall be directed outside to a safe location.		N/A
6.6.2	Property damage and injury to personnel due to material ejection during venting shall be minimized or avoided by locating vented equipment outside of buildings and away from normally occupied areas. (See Sections 7.6 and 8.9 for gases and dusts, respectively.)		N/A
6.6.2.1	Deflagration vents shall not be located in positions closer to air intakes than the distances prescribed by the fireball length (see Sections 7.6 and 8.9).	See clause 4.	P
6.6.2.2	Deflagration vents shall be permitted to be located closer to buildings and normally occupied areas than the distances determined by Section 7.6 or Section 8.9, provided a documented risk assessment acceptable to the authority having jurisdiction has been performed.		N/A
6.6.2.3	Where a deflector is provided in accordance with 6.6.2.4 and 6.6.2.5, it shall be permitted to reduce the axial (front-centerline) hazard distance to 50 percent of the value calculated in 7.6.1 or 8.9.2. This method shall not be used to reduce the radial hazard distance as defined in 7.6.2 and 8.9.2.2.		N/A

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
6.6.2.4	A deflector design shall meet all of the following criteria: (1) The deflector for a rectangular vent shall be geometrically similar to the vent and sized with a linear scale factor of at least 1.75. For a round vent, the deflector shall be square shaped and at least 1.75 times the vent diameter. (2) The deflector shall be inclined 45 degrees to 60 degrees from the vent axis, as shown in Figure 6.6.2.4. (3) The centerline of the deflector shall be coincident with the vent axis. (4) The distance from the vent opening to the deflector on the vent axis shall be $1.5D$, where D is the equivalent diameter of the vent. (5) The deflector plate shall be mounted so as to withstand the force exerted by the vented explosion, calculated as P_{red} times the deflector area. (6) The deflector location shall not interfere with the operation of hinged vent closures.		N/A
6.6.2.5	A deflector to limit flame length shall not be used as follows: (1) For enclosure volume greater than 20 m^3 (706 ft^3) (2) With a tethered or translating vent closure		N/A
6.6.3	Warning signs shall be posted to indicate the location of a vent.		P
6.7	Effects of Vent Inertia.		--
6.7.1	Counterweights and insulation added to panels shall be included in the total mass.		P
6.7.2	A vent closure shall have low mass to minimize inertia, thereby reducing opening time.		N/A
6.7.3	If the total mass of a closure divided by the area of the vent opening does not exceed the panel densities calculated by Equation 7.3.2 and Equation 8.3.2 (for gas and dust, respectively), all vent area correlations presented in this standard shall be permitted to be used without correction.		N/A
6.7.4	Hinged closures shall be permitted to be used, provided the following conditions are met: (1) There are no obstructions in the path of the closure that prevent it from opening. (2) Operation of the closure is not restrained by corrosion, sticky process materials, or paint.		P
6.8	Fireball Dimensions.		P

3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

Clause	Requirement – Test	Result – Remark	Verdict
	Measures shall be taken to reduce the risk to personnel and equipment from the effects of fireball temperature and pressure.		
6.8.1	A documented risk assessment shall be permitted to be used to reduce the hazard distances calculated in 6.8.2, 6.8.3, and 6.8.7.		P
6.8.2	Gas Deflagration Fireball Dimensions.		P
	In the case of gas deflagration venting, L_F , the maximum axial length, width, and height of the fireball hazard zone distributed around the centerline of each vent discharge (see Figure 6.8.2) shall be expressed by Equation 6.8.2:		
6.8.3	Dust Deflagration Fireball Dimensions.		N/A
	In the case of dust deflagration venting, L_F , the maximum axial length, width, and height of the fireball hazard zone distributed around the centerline of each vent discharge (see Figure 6.8.2) shall be expressed by Equation 6.8.3		
6.8.4	Definition of Independent Vents.		N/A
	Independent vents shall meet the requirements in 6.8.4.		
6.8.4.1	For vents located at a single elevation and spaced around the circumference of a cylindrical vessel, the normal to the adjacent vents shall be separated by at least 60 degrees or 4 hydraulic diameters of the largest vent.		N/A
6.8.4.2	Vents located on different sides of a rectangular enclosure shall be considered independent.		N/A
6.8.4.3	For vents located along the axis of a cylindrical vessel or on the same side of a rectangular enclosure, the center of the vents shall be separated by at least four times the hydraulic diameter of the largest vent.		N/A
6.8.4.4	Vents that do not meet the requirements of 6.8.4 are allowed but shall not be counted separately to calculate n in 6.8.2 or 6.8.3.		N/A
6.8.5	Axial distance, calculated by Equation 6.8.3, shall be limited to 60 m [104].		N/A
6.8.6	Axial distance calculated by Equation 6.8.2 shall not be limited for gases.		N/A
6.8.7	Where venting is from a cubic vessel, the $P_{\max,a}$ value shall be indicated approximately by Equation 6.8.7 [108]		N/A
6.8.8	For distances longer than $\alpha \times L_F$, the maximum external pressure, $P_{\max,r}$, shall be indicated approximately by Equation 6.8.8		N/A

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3. Deflagration venting design evaluation referring to Chapter 6 in NFPA68: 2023

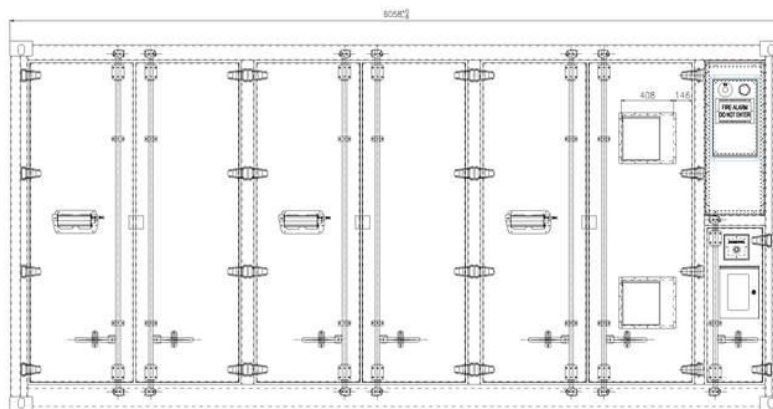
Clause	Requirement – Test	Result – Remark	Verdict
6.8.9	Equation 6.8.3, Equation 6.8.7, and Equation 6.8.8 shall be valid for the following conditions: (1) Enclosure volume: $0.3 \text{ m}^3 \leq V \leq 10,000 \text{ m}^3$ (2) Reduced pressure: $P_{red} \leq 1 \text{ bar-g}$ (3) Static activation pressure: $P_{stat} \leq 0.1 \text{ bar-g}$ (4) Deflagration index: $K_{St} \leq 300 \text{ bar-m/s}$ for Equation 6.8.3, $K_{St} \leq 200 \text{ bar-m/s}$ for Equation 6.8.7 and Equation 6.8.8 (5) $P_{max} \leq 9 \text{ bar-g}$		N/A
6.9	Effects of Vent Discharge Ducts.		N/A
6.10	Venting with Flame Arresting and Particulate Retention.		N/A

4. CFD analysis of the ventilation system

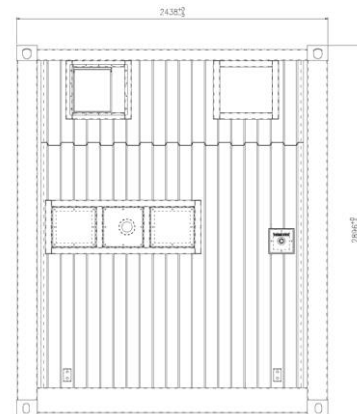
4.1. Basic Information of the system

The interior and exterior drawings provided by CSI was verified between TUV and CSI before running any calculation.

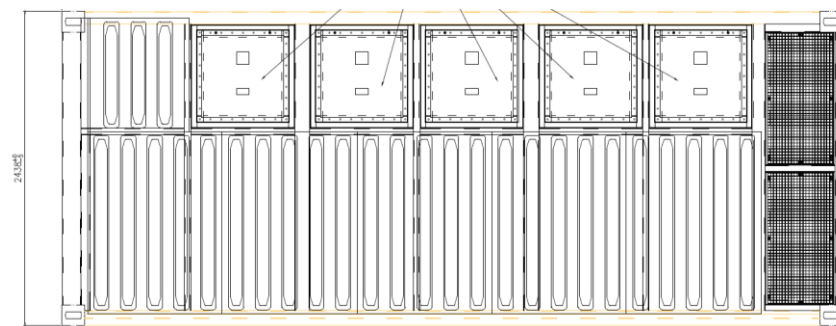
Figure 4-1 shows an external view of the container and the dimensions from a front and left view. The cube measures $6.058 \times 2.438 \times 2.896$ m including one battery cabinets, liquid coolant unit and Auxiliary power supply unit. The cabinet contains 48 modules in rack and 104 cells in each module. The overall internal volume of battery cabinet is approximately 31.38 m^3 . Subtracting the space filled by racks, modules, and the support structure, the actual open internal volume (efficient volume) is 8.74 m^3 .



Front view



Right view



Top view

Figure 4-1: Geometry of CSI energy storage system

4.2. Principles and Assumptions

The following safety systems and CFD analysis have been acknowledged for the basis of the study's assumptions. Note that the scenarios and assumptions are run according to cell level, module level and unit level UL9540A test to show progressively worse-case scenarios based on the information available and are considered to be conservative.

4.2.1. Thermal runaway and propagation

(1) Propagation between cells:

The UL 9540A test report of module level and unit level indicate that cell to cell propagation could happen within a submodule which contains 26 cells. According to the test report total 5 cells were failed in both module level and unit level test. Therefore, 5 cells failure is considered in this study.

Assumption 1: There are 5 cells failure within submodule is considered in this study.

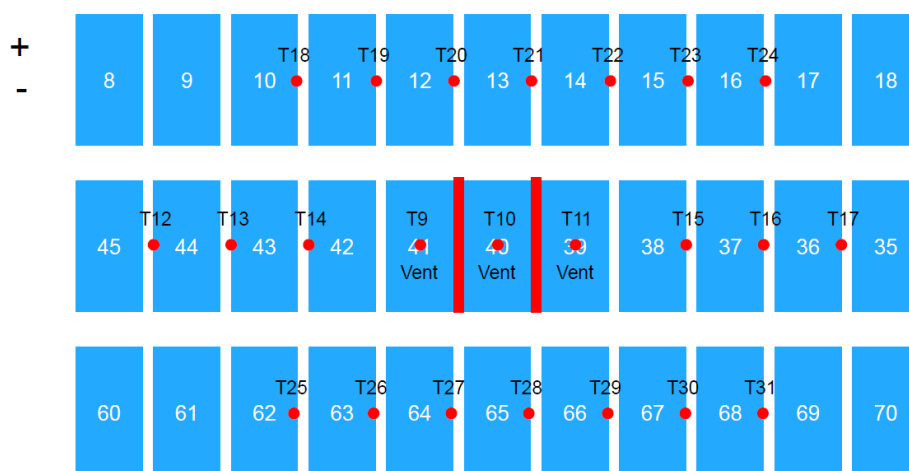


Figure 4-2: Initiating module set up in unit level UL9540A test report.

(2) Propagation between modules:

The UL 9540A test report of unit level did not indicate that it is possible to have propagation between modules.

Assumption 2: There is no module-to-module propagation.

4.2.2. Gas composition and ignition location

(1) Gas cloud:

The data and test phenomenon in cell level, module level and unit level UL 9540A test report provide total amount of released gas. According to the test report, total 5 cells were failed in both module and unit level test. Therefore, total amount of released gas at cell level will also consider the thermal runaway of 5 cells. The total quantity of flammable gas is 700.90 g in cell level test which is the highest value among cell, module and unit level test. (See Table 4-1)

Table 4-1: Gas quantity

UL 9540A test level	Gas volume	Gas temperature	Gas mass
Cell	180.70 L*5	25 °C	700.90 g
Module	1192.38 L	167.4 °C	626.01 g
Unit	1307.97 L	167.4 °C	686.70 g

In order to perform actual gas cloud explosion, 700.90 g flammable gas would be released into the container in 60s with a constant release rate of 11.68 g/s. While the gas is releasing, concentration and distribution of gas keep changing at different time step, which would generate different explosion pressure inside the container. Q8 is defined as 'the closed volume equivalent cloud at concentration for maximum expansion' and is the recommended variable for determining explosion hazard in enclosed situations. For conservative consideration, the worst explosion hazard would be performed with the gas cloud at highest value of Q8. (See Figure 4-3 and 4-4)

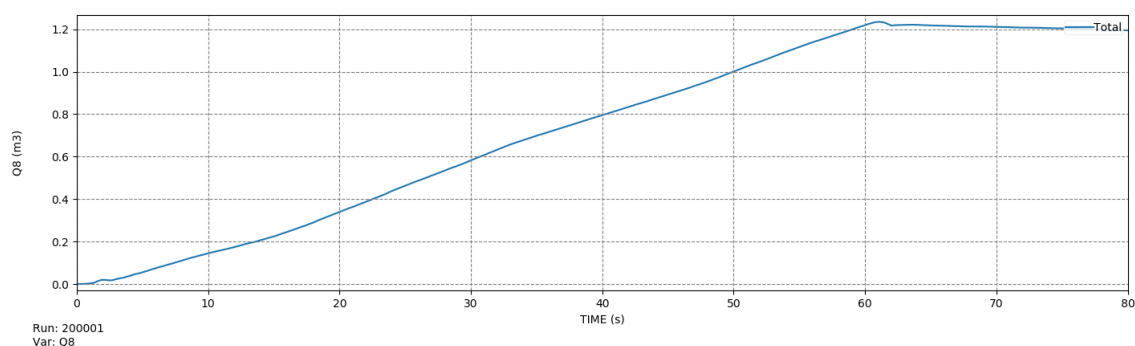


Figure 4-3: Q8 of the dispersion scenario.

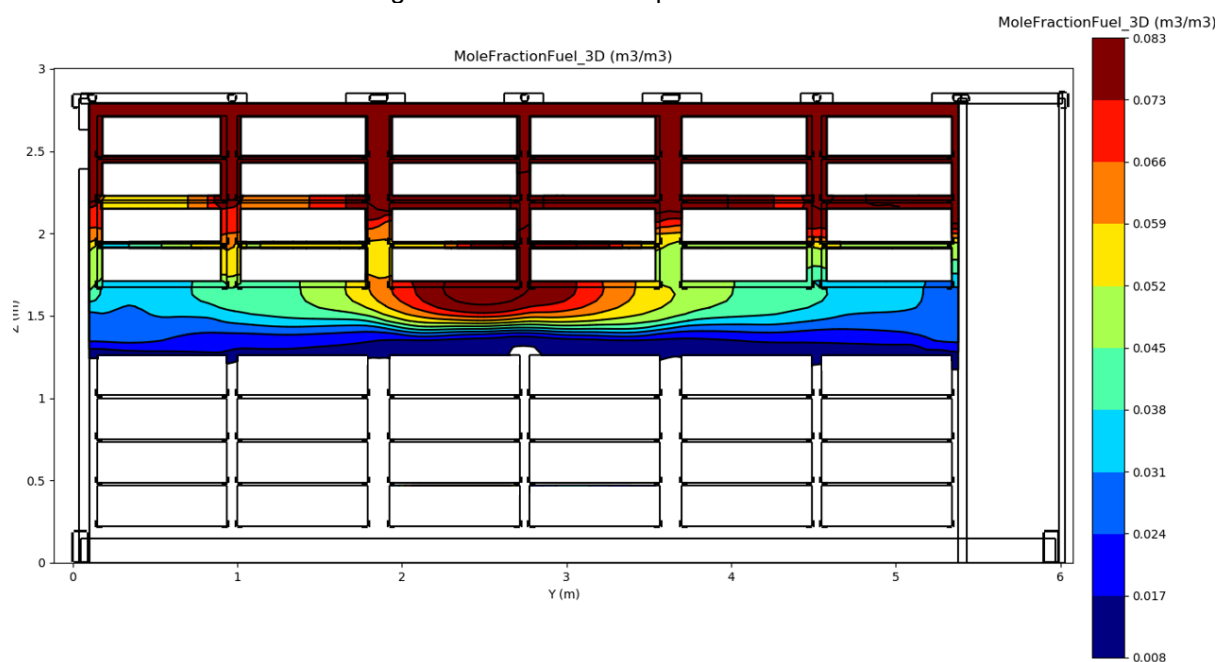


Figure 4-4: 2D cut of the gas cloud inside the container at highest Q8.

Assumption 3: The gas cloud at highest Q8 value around 60s was set to be ignited.

(2) Gas composition:

Gas composition was provided in the test data of cell level UL 9540A report. Table 4-2 lists the release gas composition by volume.

Table 4-2: Gas composition by volume

Gas component		Concentration % (v/v)
Methane	CH ₄	4.495
Acetylene	C ₂ H ₂	0.157
Ethylene	C ₂ H ₄	2.299
Ethane	C ₂ H ₆	0.729
Propyne	C ₃ H ₄	0.012
Propylene	C ₃ H ₆	0.952
Propane	C ₃ H ₈	0.211
Butylene	C ₄ H ₈	0.616
Butane	C ₄ H ₁₀	0.080
Hydrogen	H ₂	49.725
Carbon Monoxide	CO	13.898
Carbon Dioxide	CO ₂	26.826
Total	-	100

Assumption 4: Gas composition is as above.

(3) Ignition location:

The ignition location was selected to be a single point in front of the modules and towards the top. The fire and pressure waves travel further when gas cloud ignited near corner, so top corner ignition was chosen. Since all the wiring and openings to the modules are on the front, it is assumed that the ignition sources are most likely to occur in front of the modules. However, we set another ignition point in the top center of the gas cloud for comparison where the local concentration is the highest in the container (See figure 4-5).

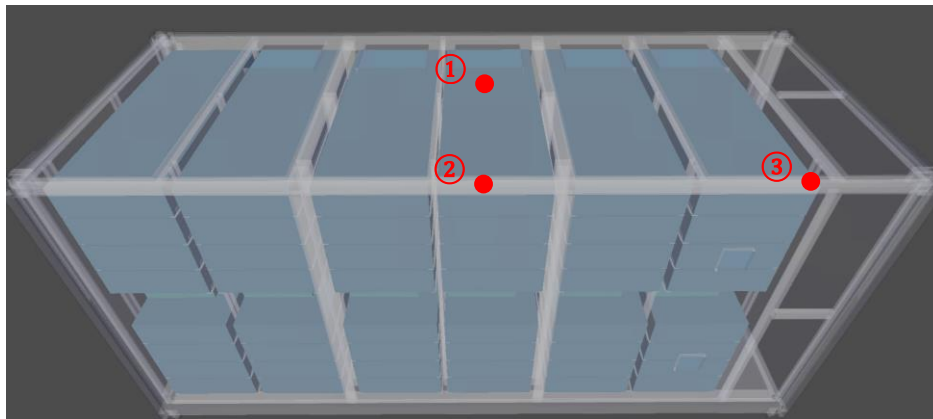


Figure 4-5: Ignition positions

4.2.3. System safety

(1) Ventilation system:

The container is fitted with 1 exhaust fan and two passive air inlet louvers.

Assumption 5: No ventilation system acts in this report.

(2) Thermal runaway control:

No thermal runaway prevention system is installed.

Assumption 6: Thermal runaway occurs in the module.

(3) Deflagration panels:

Five deflagration panels are installed on the container, 0.610*0.610 m effective area for each panel and act at 0.1 bar pressure difference.

Manufacturer name	Type number	Dimension	Trigger pressure
BasCo	EPS-CP-610*610	610*610 mm	0.1 bar

Assumption 7: Deflagration panels acts as above.

4.3. Simulation Results

A total of three gas explosion scenarios were run representing progressively worse-case scenarios based on the assumptions made in the previous sections. The modelling covered the failure of 5 cells with different ignition positions.

Table 4-2 presents a summary of the scenarios and the results from the simulation. The maximum over pressure inside enclosure is presented according to NFPA 68.

Table 4-3: Maximum wall pressure inside enclosure

Scenario	Ignition Position	Maximum pressure (bar-g)
001	1	0.350
002	2	0.250
003	3	0.170

(1) Pressure curve

Figure 4-6 to 4-8 shows the wall pressure for each scenario.

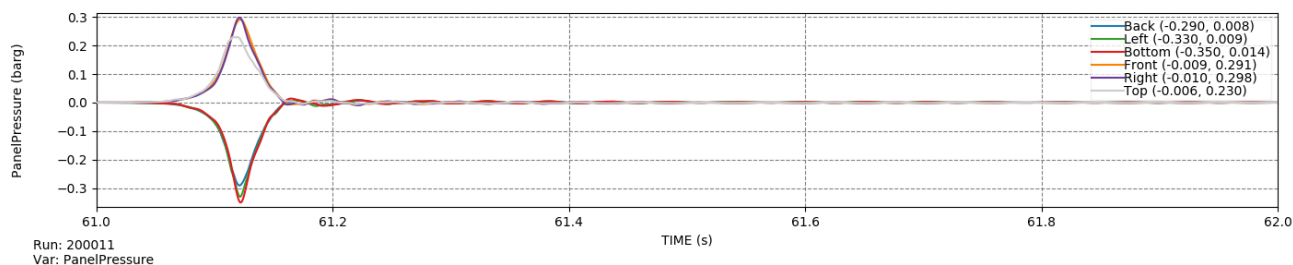


Figure 4-6: Top center ignition pressure curve.

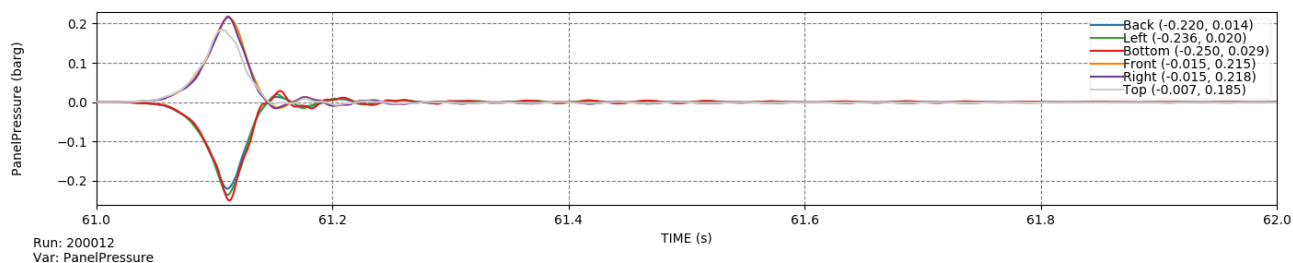


Figure 4-7: Top front center ignition pressure curve.

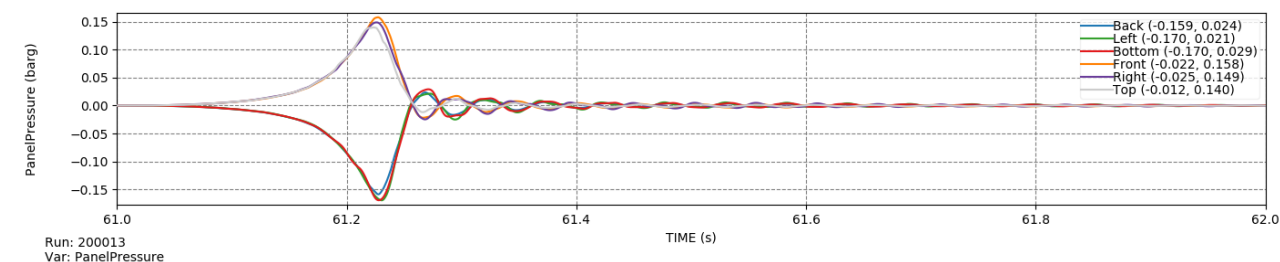


Figure 4-8: Top front corner ignition pressure curve.

Figure 4-9 and 4-11 shows the maximum pressure outside cabinet.

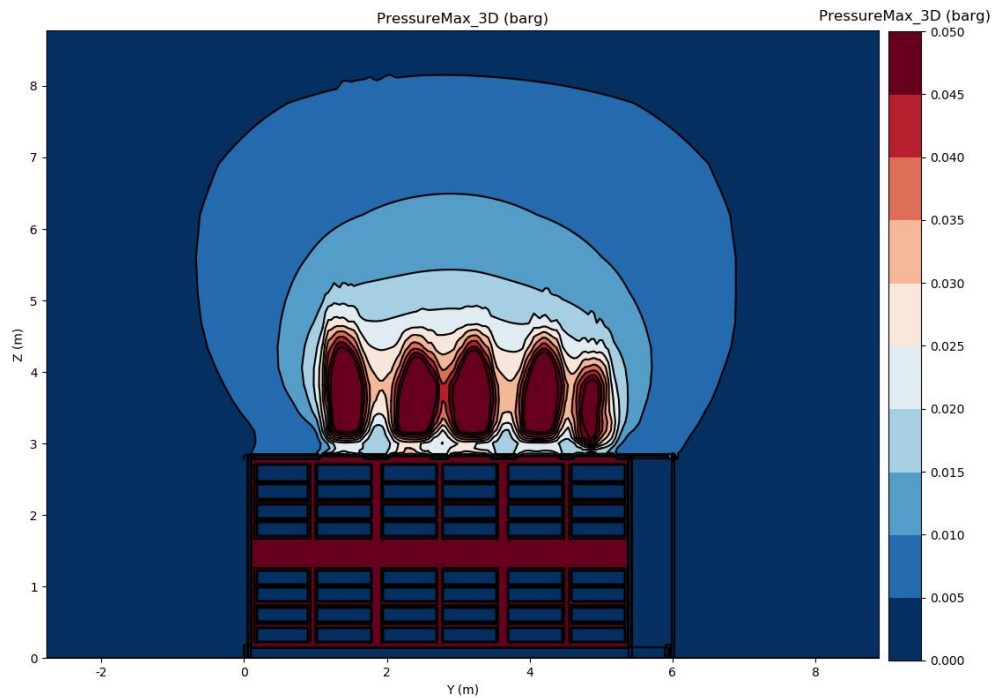


Figure 4-9: Top center ignition pressure map (outside).

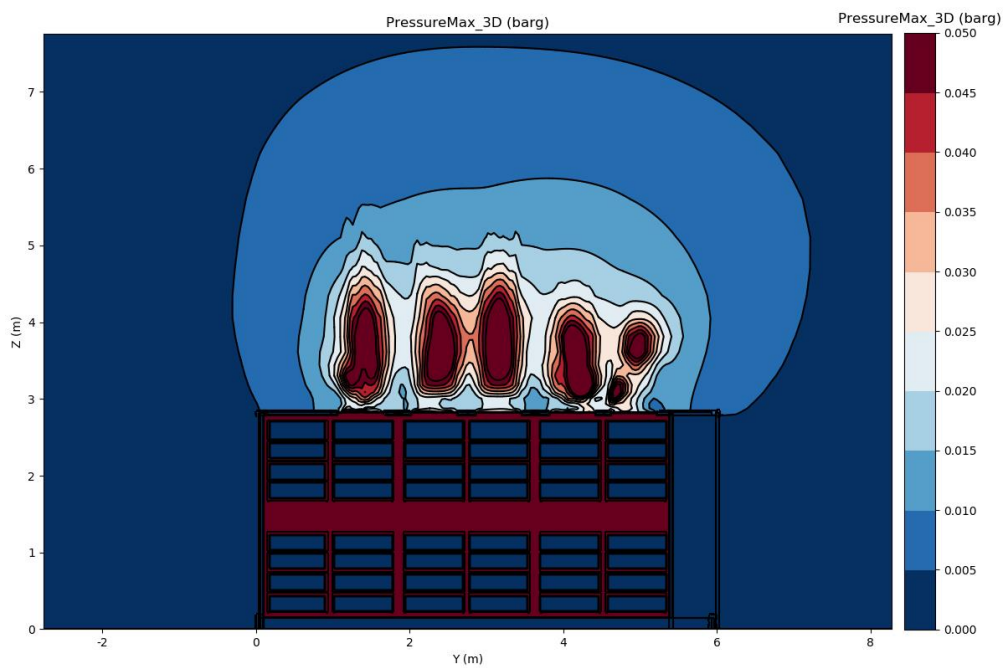


Figure 4-10: Top front center ignition pressure map (outside).

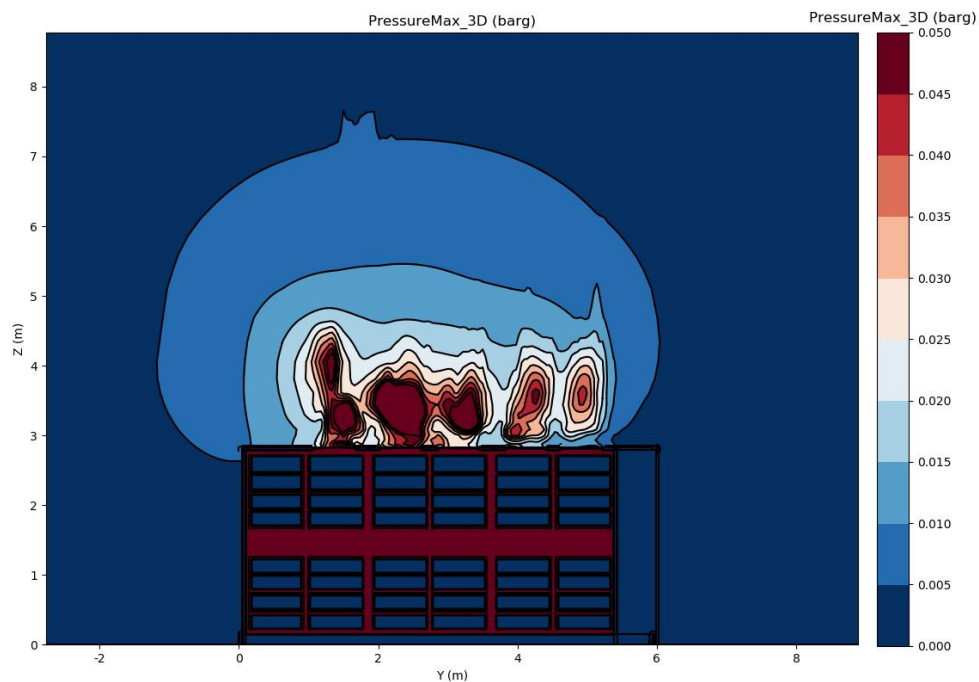


Figure 4-11: Top front corner ignition pressure map (outside).

(3) Temperature map

Figure 4-12 and 4-14 shows the temperature map.

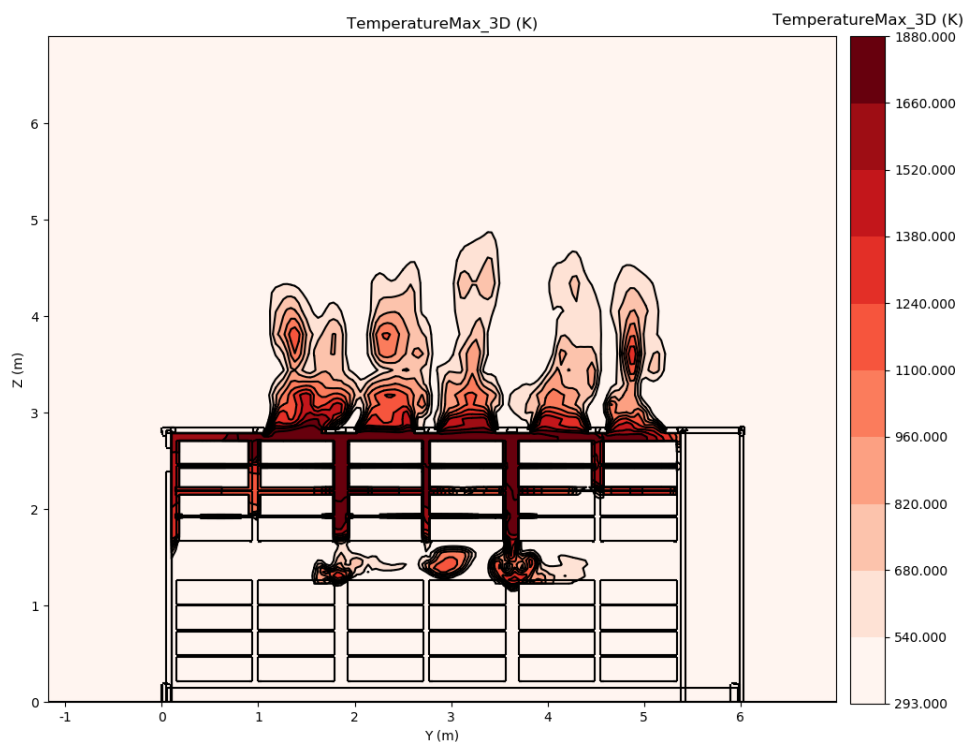


Figure 4-12: Top center ignition temperature map (outside).

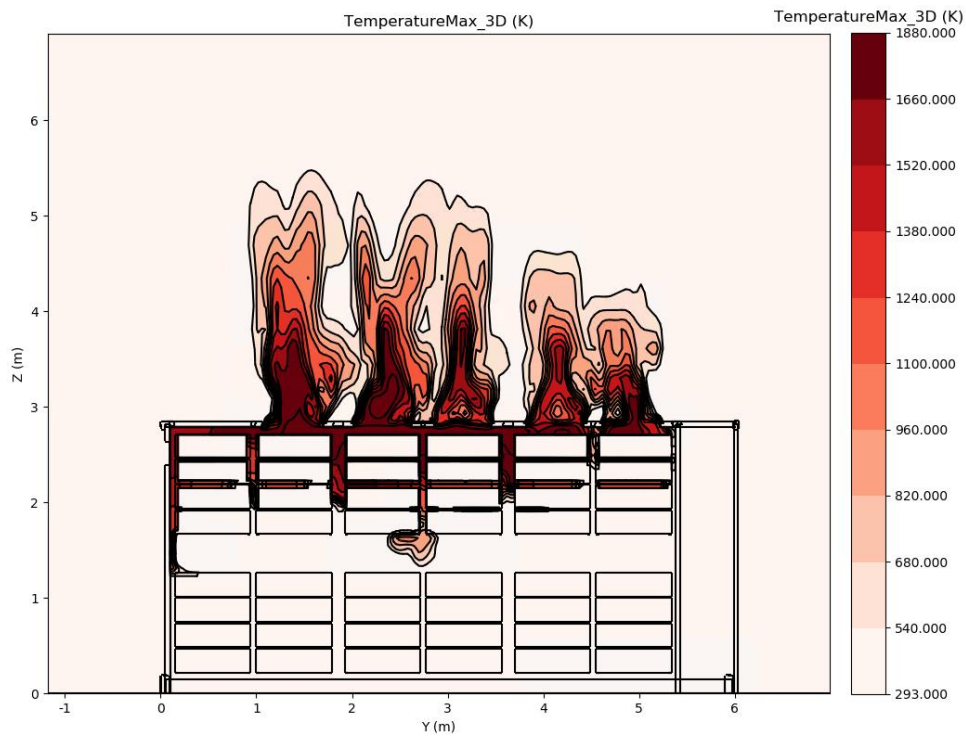


Figure 4-13: Top front center ignition temperature map (outside).

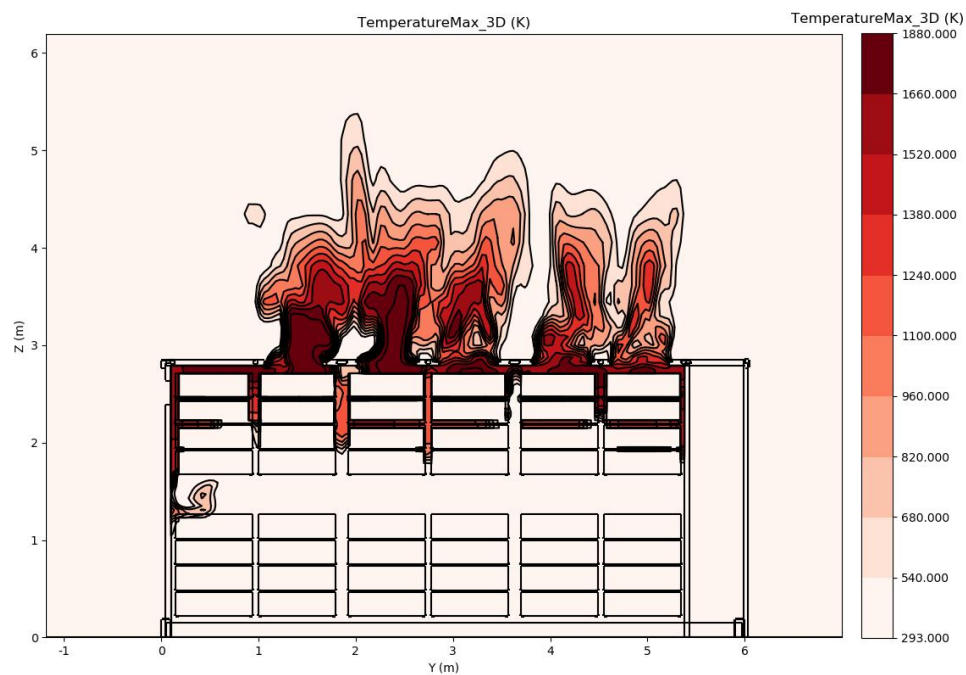


Figure 4-14: Top front corner ignition temperature map (outside).

5. Conclusions

This CFD model has shown that the predicted maximum average pressure on the wall is 0.350 bar-g. The enclosure mechanical analysis report is provided by CSI, and CSI is responsible for the enclosure's mechanical strength. The enclosure mechanical analysis report indicates that the enclosure could maintain at least 0.55 bar-g of pressure. According to section 6.3.1.1 P_{red} shall not exceed two-thirds of the ultimate strength for the vented enclosure, provided deformation of the equipment can be tolerated. Therefore, P_{red} shall not exceed 0.367 bar-g, which confirms that this design meets the requirements of NFPA 68.

6. References

- (1) NFPA68:2023 Standard on Explosion Protection by Deflagration Venting
- (2) Cell Level UL9540A Report: CN243TAR 001
- (3) Module Level UL9540A Report: CN25HYJ6 001
- (4) Unit Level UL9540A Report: CN25DK3S 001
- (5) Explosion Simulation Report from CSI

End of Report