



NGK INSULATORS, LTD.

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ENERGY STORAGE



NAS
Sodium Sulfur Battery

Safety of Sodium Sulfur (NAS[®]) Battery

August 2018

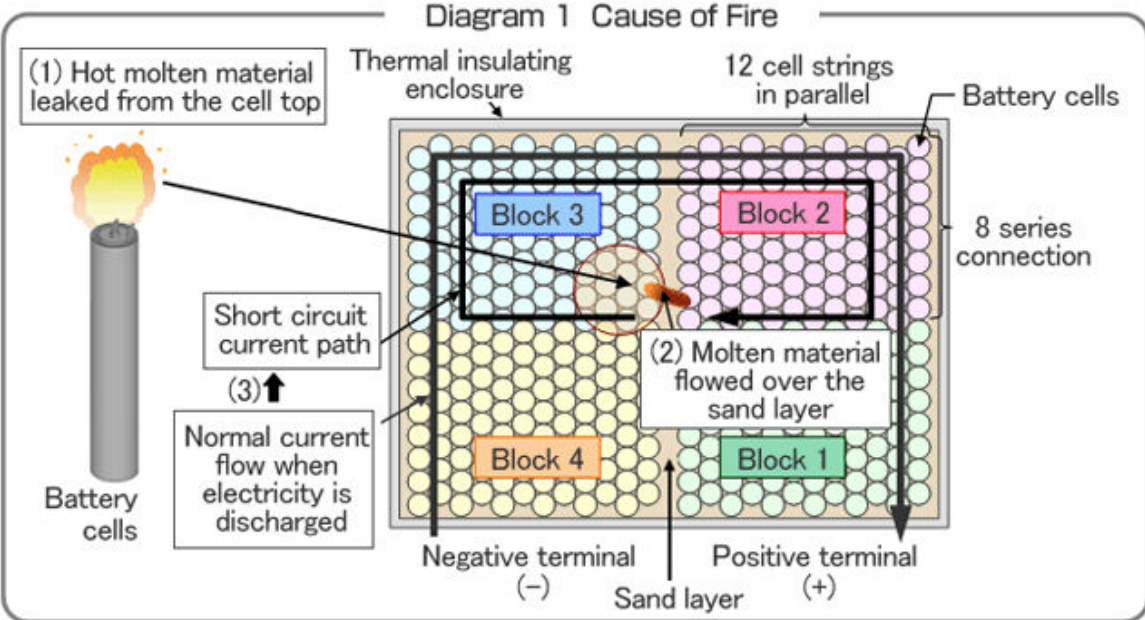
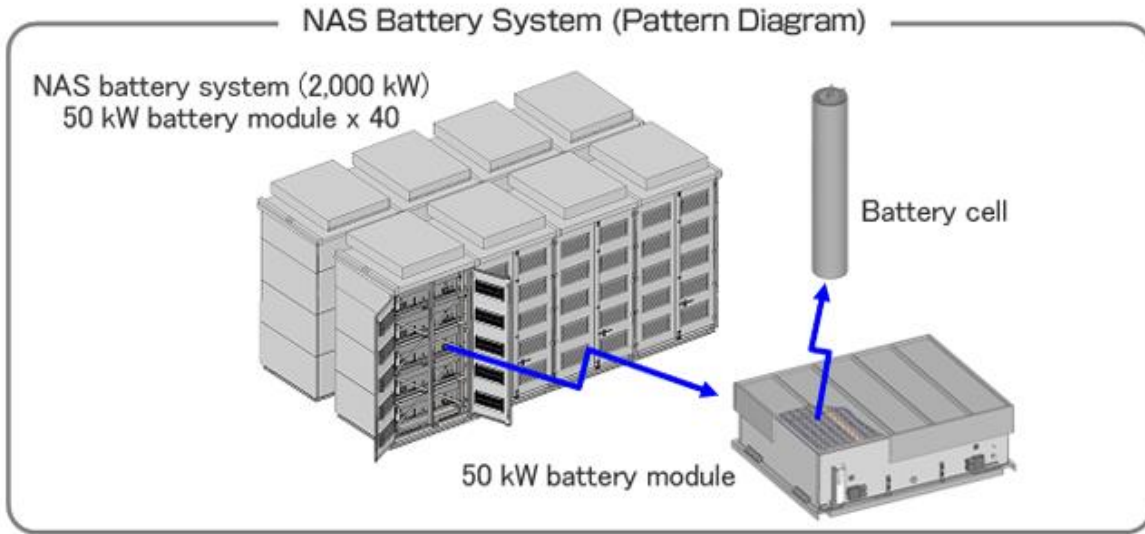


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Safety is of Paramount Importance to NGK

- **NGK's NAS[®] storage has an outstanding overall safety record**
 - Over 5.2 million battery cells have been deployed - over 200 projects & wide range of environments
 - Experienced no critical failure
 - However, on September 21, 2011 there was a fire in a 2 MW system
- **NGK hired Japan's Hazardous Materials Safety Techniques Association, an independent 3rd party investigator to conduct a joint internal analysis of the cause**
 - As we will describe, the cause was a rare and unforeseen combination of factors
- **To ensure this never happens again, NGK took following steps:**
 - Design changes made in all future systems, which add multiple, independent safety measures:
 - Changes that, by design, ensure that the combination of factors can not re-occur
 - Changes that will more tightly localize and more rapidly extinguish any fire within a module
 - Retrofitted installed systems:
 - NGK voluntarily spent over JPY 60 Billion to retrofit all in-field systems
- **NGK is committed to providing safe, high quality systems.**

Cause of Fire



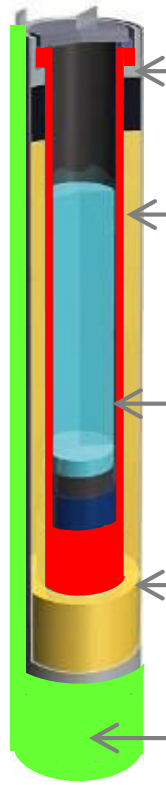
Findings from 3rd party Investigation Company

- 2MW system has 40 modules, each 50 kW.
- Based on collected data from the system, of total of 384 cells inside one module, 1 cell had possible manufacturing defect.
- Faulty cell breached and leaked hot molten material.
- Leaked molten material, which is conductive, created an unforeseen path that shorted to the battery cells in the adjacent block.
- Because this path was unforeseen, there were no protective fuses on it. So the short circuit emitted heat until the cells were fully discharged. This continuous heat emission destroyed a number of other battery cells, spreading the fire.
- The fire spread within the module and to the surrounding modules.

Safety Measures Added

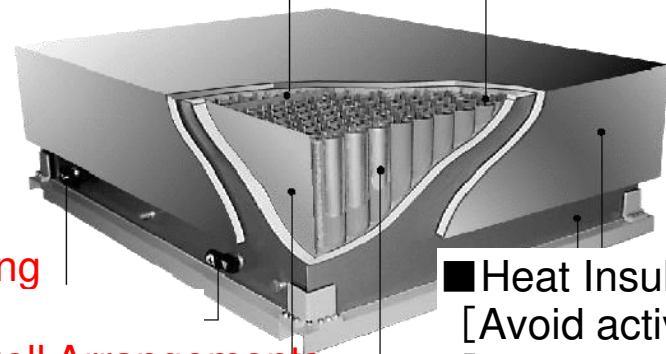
Introduced multiple additional safety measures to prevent recurrence

- ① Removed possible cause of cell failure during production [Prevent future cell failures]
- ② Limit any failure to small region [Prevent failure spreading beyond troubled section]
- ③ Increase heat resistance and fire resistance of module [Prevent fire from spreading]
- ④ Enhance self-extinguishing performance [Self-extinguish fire more rapidly]



- Joint area between metal and ceramics [Air Tightness, High Durability]
- Beta Alumina Tube [High Strength]
- Safety functional Components [Maintain safety during malfunction]
100% Inspection to remove manufacturing defects
- Stainless steel canister [High durability]
- Additional heat-resistant and fire-resistant components [Enhance self-extinguishing performance]

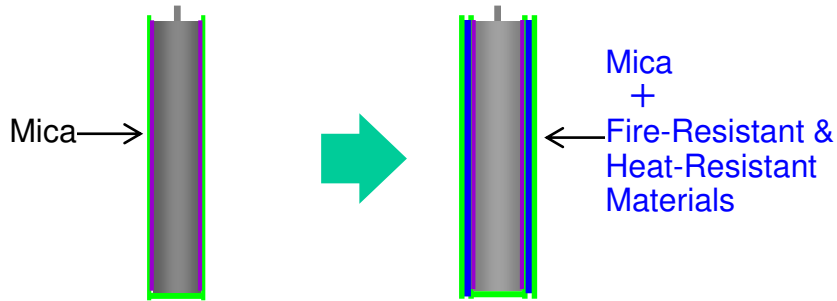
- Dry Sand [Absorption of Active Materials]
- Fuses [Avoid over current]
■ Additional fuses added
- Heat Insulated Container [Avoid active material leak] [Heat shielding] [Shock Absorption]
- New Cell Arrangements
- Insulation barrier and fire-resistant barrier installed.
- Additional heat-resistant and fire-resistant components [Prevent fire from spreading]



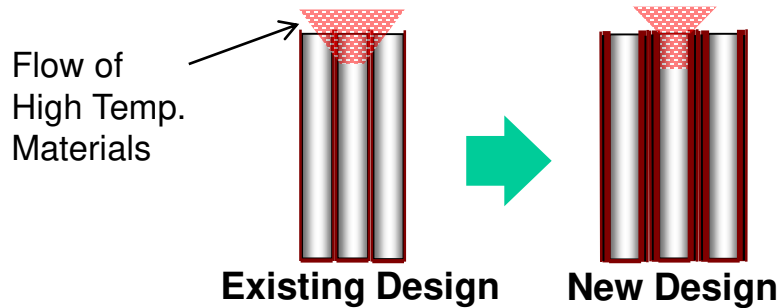
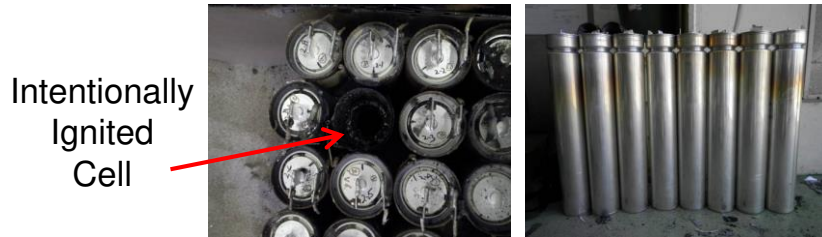
Outline of added safety features

■ Prevent multiple cell fire (Self Containment)

Add heat-resistant, fire-resistant materials

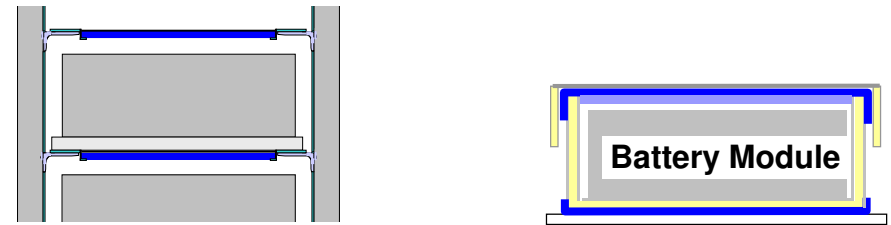


Test by Intentionally Destroying and Igniting One Cell
(Result: Fire was contained to that one cell)



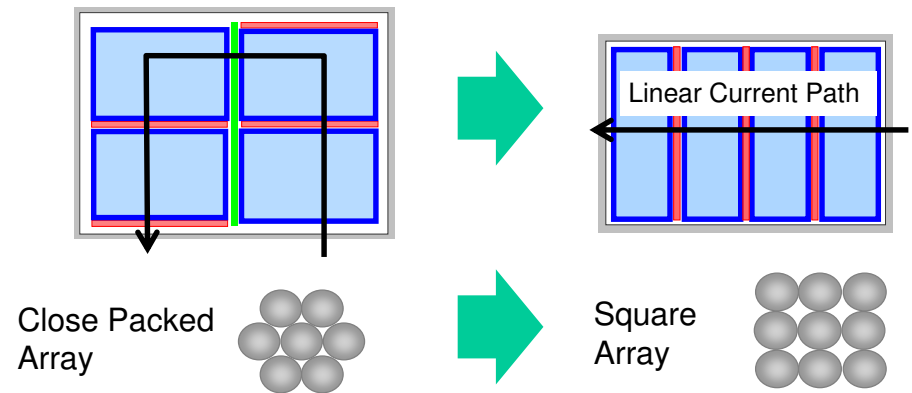
■ Prevent material leakage and contain fire

Added fire/heat proof barrier inside module



■ Change cell arrangements inside module

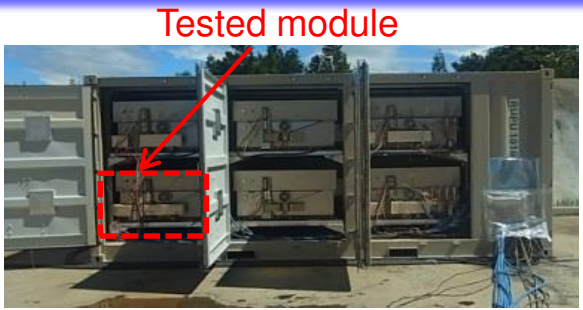
- Linear current path to separate big voltage differences
- Add additional fuses to protect against short circuits
- More sand between cells to enhance fire suppression



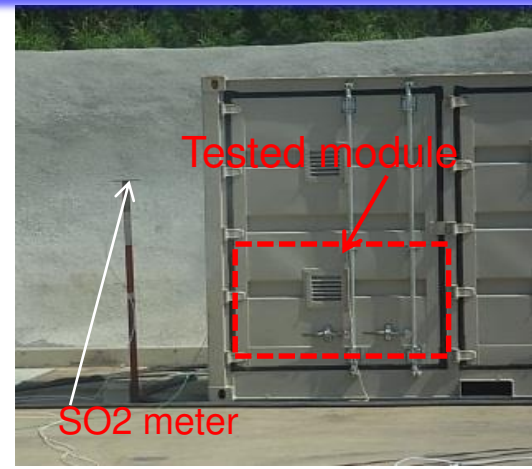
Fire Self-Extinguishing Test of NAS[®] System

One Battery Cell, in a Battery Module, in a Battery Container, was intentionally ignited.

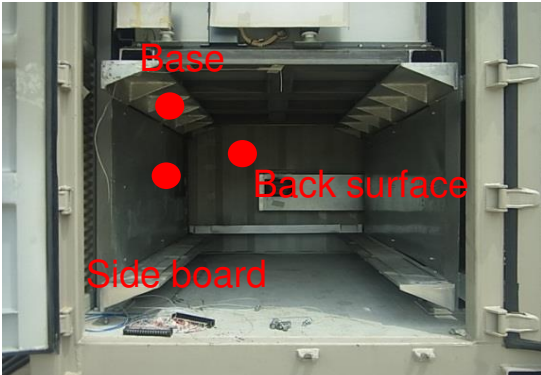
- There was no damage to the Battery Container.
- Self-extinguishing properties of the Battery Module and the Battery Container confirmed.
- SO2 gas external to the container was below the detection limit (1ppm)



Before test



During test



Temperature measuring points
(In Container around the tested Module)





Maximum temperature in Battery Container

Base	130 degrees-C
Back Surface	210 degrees-C
Side Board	530 degrees-C

Safety Test Results with Safety Enhanced Battery Module

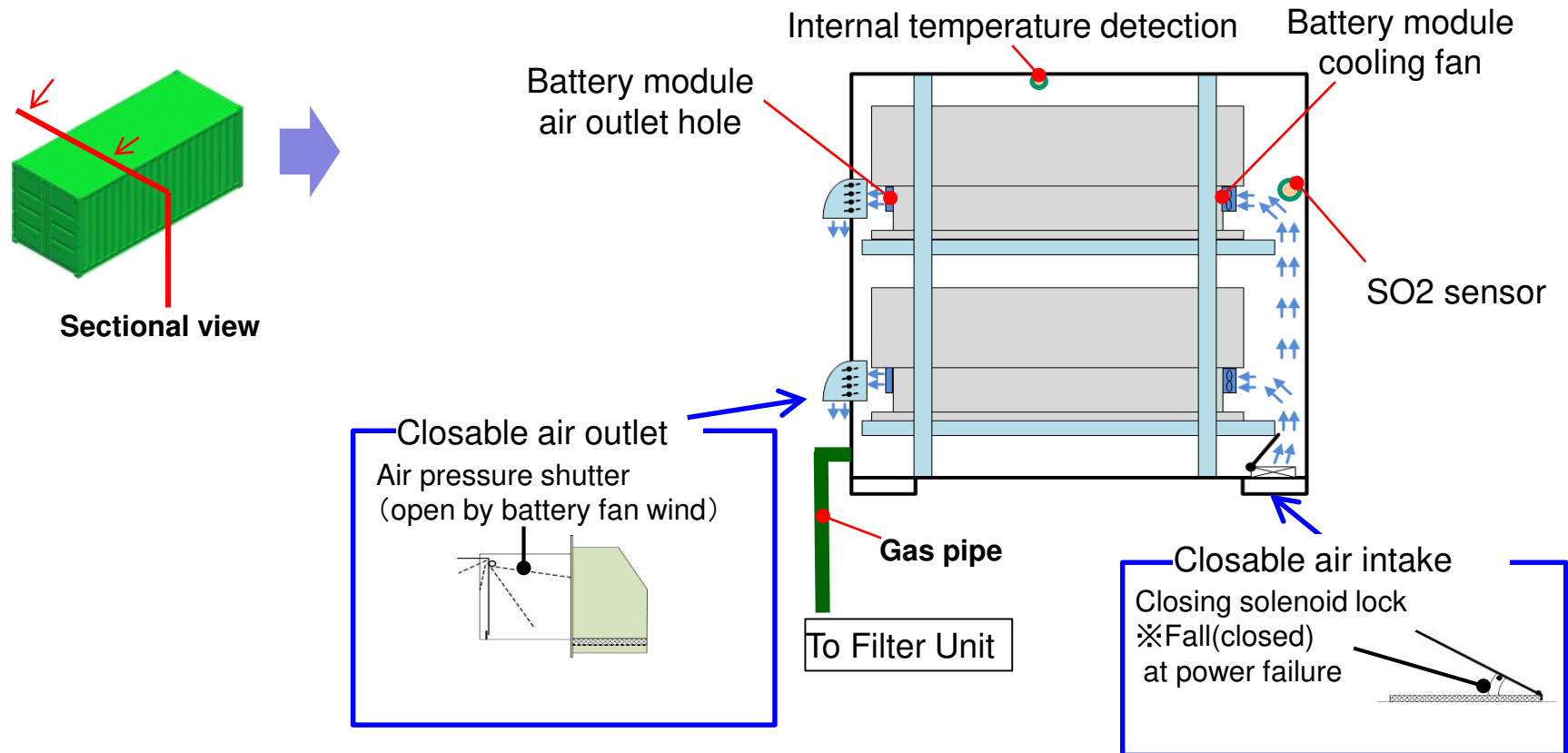
New Battery module was confirmed to be safe against mishandling or external accidents

(All tests were executed on hot battery modules except container drop test)

Test	Purpose		Test Results
External Short Circuit	Confirm Safety if External Short Circuit Occurred		<ul style="list-style-type: none"> - Current: 6400A x 1sec - Internal fuses activated in 1 sec - No cells damaged inside module
Fire exposure	Confirm Safety if subjected to External Fire		<ul style="list-style-type: none"> - Exposed to Fire for 35 minutes with outer temperature 890°C (Inside temperature: max. 360°C) - No cells damaged inside module
Submerge	Confirm Safety if Flooded		<ul style="list-style-type: none"> - Immersed in water for 3 days - No cells damaged inside module
Drop	Confirm Safety in Module and Container 6 meter (20ft) drop test	 <p style="text-align: center;">After Drop</p>	<ul style="list-style-type: none"> - Module and Container were deformed at points of impact - No cell breaches inside modules in either test

Function to minimize SO₂ gas emission

- If battery catches fire, it will be detected by SO₂ sensor and Battery Controller will perform the following actions to minimize SO₂ emissions outside of the Battery Container.
 - Send signal to PCS to stop discharging and charging
 - Stop fans of Battery Modules, then the air outlet will be closed
 - Close air intake
 - Turn on the Filter Unit



Filter unit for battery container (Optional)

- External Filter Unit can be installed upon customer's request to remove the combustion gas in the container after fire.
- The Filter Unit and each container is connected by a pipe with a valve.

