Collaborative Test Report

1. Title of Test

External fire exposure testing for energy storage systems（ESSs）

2. Objective of Test

ESS observation while exposure of external fire sources

3. Experiment

3.1 Date, Location, Test Operator

Date：Mon, Jan 23, 2017 - Thu, Jan 26, 2017
Location：Large Chamber
National LABoratory for advanced energy storage technologies（NLAB）
Global Center for Evaluation Technology（GCET）
National Institute of Technology and Evaluation（NITE）
Test Operator：Sony Energy Devices Corporation（SEND）/ NITE

3.2 Test Sample

Sample：Li-ion ESS
Battery cell：Olivine type iron lithium phosphate（LFP）
Model of sample：fORTELION
Nominal capacity：33.6 kWh（42 Ah）
Nominal voltage：819.2 V
Component：serially-connected 16 battery modules and one battery management unit (Fig. 1)
Weight: approx. 730 kg
External dimensions：W680（mm）×D547（mm）×H2200（mm）

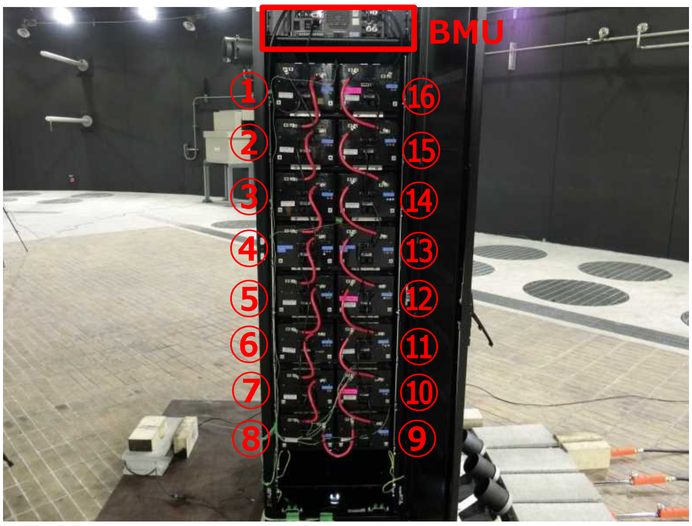

Fig. 1 Photograph of sample configuration.

Denoted number corresponds to battery module number in the text.

3.3 Test Procedure

Test procedures and key points are summarized as follows.

①The sample was charged to a full charge（SOC = 100 %）.

②Three propane burners were held using concrete blocks on the right side of the sample rack, as shown in Fig .3.

③Fire exposure was continued for approximately 60 minutes.

④After extinguishing the fire by gas-valves off, after 60-minute exposure, sample observations was carried out.

※In this fire exposure test, the duration of exposure was extended to 90 minutes, in consideration of the observation results after 60-minutes.

3.4 Evaluation Setup

3.4.1 Sample Positioning

The sample was put on the refractory-brick floor in Large Chamber provided in Fig. 2, the temperature of Large Chamber was set at 25 ℃. At the start of the test, flue-gas treatment by gas exhausting facility of Large Camber was operated at air-flow rate of approximately 1000 m^3/min. Because both flue-gas treatment and temperature control cannot be conducted simultaneously, the temperature in Large Chamber was not controlled during test period.

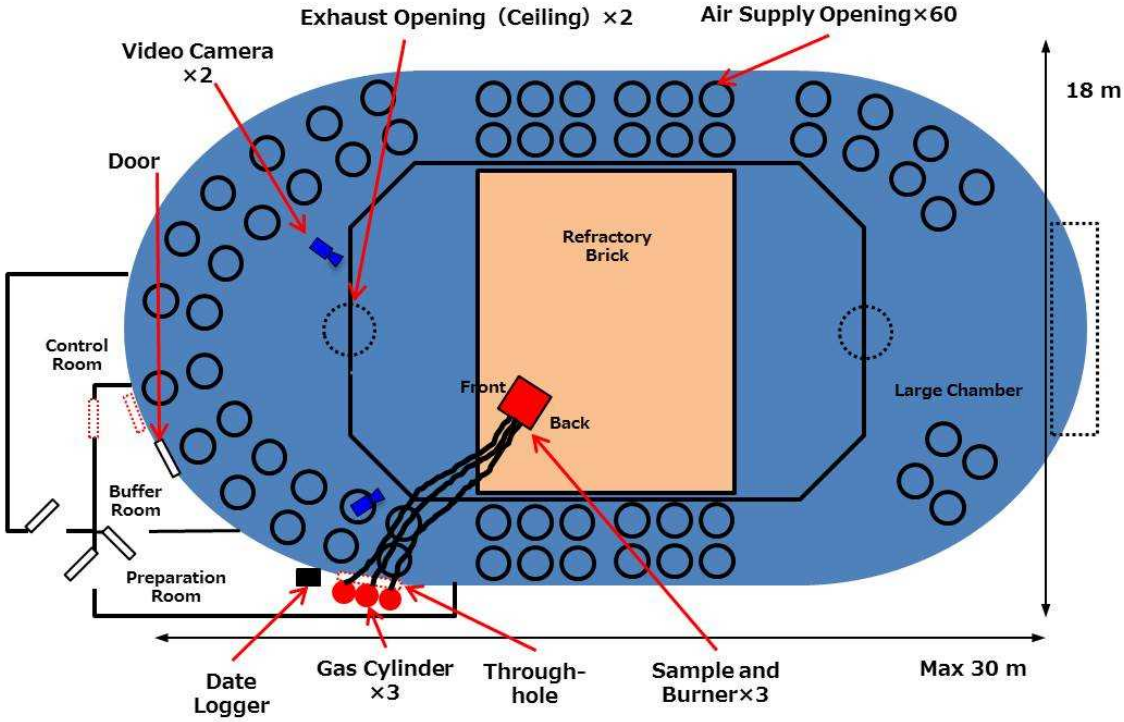

Fig.2 Figure of external fire exposure test setup in Large Chamber

3.4.2 Burning-test setup utilized burners

The specification of burner is indicated in Table 1. Three burners were held using concrete blocks and refractory bricks as shown in Fig. 3 so that the fire reached to the height of battery module number 10. Three propane gas cylinders were set in the Preparation Room, these burners and gas cylinders were connected by hoses of 10-m long, by utilizing through-holes settled in the concrete wall of the large chamber. After conducting the experiment, fire extinguishing was performed by closing valves of gas cylinders, without entering into Large Chamber.

Table 1 Specification of burner

	Propane Burner L-10 (Shinfuji Burner Corporation)
Length	980 mm
Flame Length	950 mm rod-shaped flame
Tip Diameter	100 mm
Flame Temperature	1500 ℃
Calorific Value	167.4 kW (144000 kcal/h)

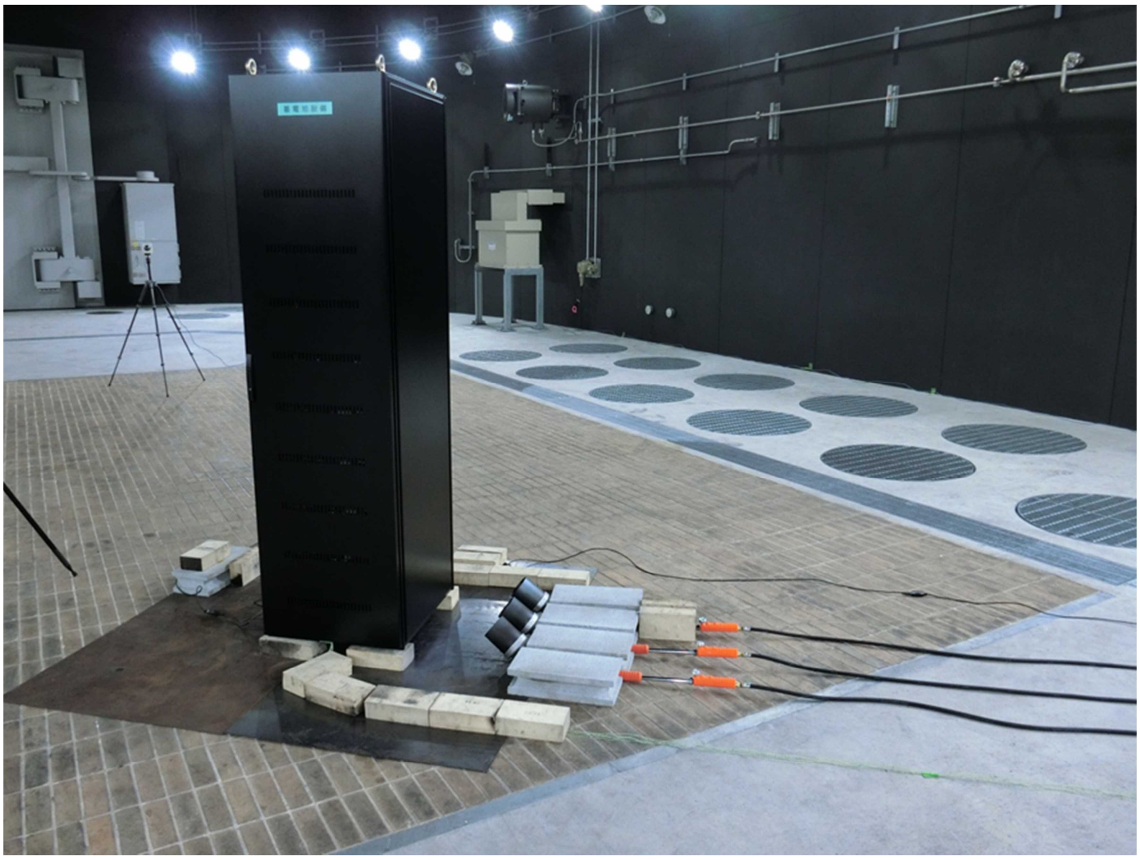

Fig. 3 Photograph of burner's position held by concrete blocks

3.4.3 Procedure of Temperature Measurement

Temperature was monitored with Type K thermocouples, seven thermocouples were placed as shown in Table 2. The data logger (Logger Station：LR8410, Voltage and Temperature Unit：LR8510) manufactured by HIOKI E.E. Corporation was utilized to collect temperature data in this evaluation.

Table 2 Thermocouple locations

Thermocouple(TC) No.	Measurement Location
TC1	Interior of battery module 10
TC2	Back of battery module 10
TC3	Top of battery module 10
TC4	Atmosphere around the sample
TC5	Inside wall of rack around battery module 10 (burner side)
TC6	Top of battery module 13
TC7	Top of battery module 16

3.4.4 Monitoring of Generated Gas Concentration

Gas analyzer which attached to the flue-gas treatment installation was utilized to monitor of evolved gas concentration in this test. The specification of Gas Analyzer is indicated in Tables 3-1 and 3-2. Gas-sampling locations are provided in Fig. 4.

Table3-1 Specification of gas analyzer for oxidized gas

Gas	Stack Gas Analyzer ENDA5800 (manufactured by HORIBA, Ltd.)		
	Sensor	Range	Repeatability
CO	NDIR	0～100/1000 ppm	F.S.±1.0 %
CO_2	NDIR	0～10/25 %Vol.	F.S.±0.5 %
O_2	Magnetic Pressure	0～10/25 %Vol.	F.S.±1.0 %
NO_x	NDIR	0～100/500 ppm	F.S.±1.0 %
SO_2	NDIR	0～50/500 ppm	F.S.±1.0 %

※Each range is automatically switched according to a measured value.

Table3-2 Specification of gas analyzer for HCl and HF

Gas	Laser system HCl and HF Analyzer Laser Gas Ⅱ (manufactured by NEO Monitors AS)		
	Sensor	Range	Accuracy
HF	NIRS	0～10 ppm	±1.0 %
HCl	NIRS	0～50 ppm	±1.0 %

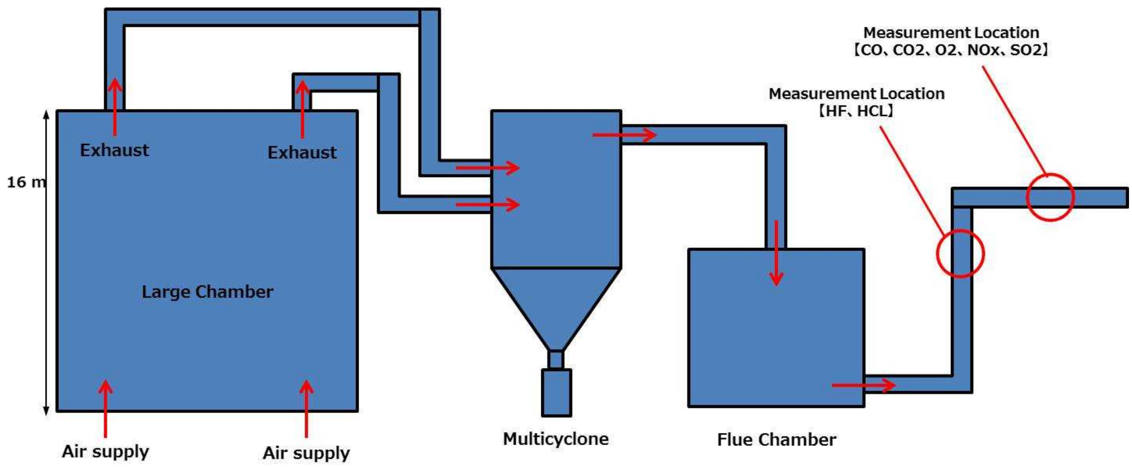

Fig.4 Gas flow and measurement points of generated-gas concentration

3.4.5 Still-Photography and Video-Camera Images

Still images were taken before and after the fire exposure test. Two video cameras were positioned at the indicated points, as shown in Fig. 2.

4. Exposure-Test Results

4.1 Test Condition in Large Chamber

During the fire-exposure test, the chamber temperature around the sample was between 17.73 ℃ and 21.54 ℃. The wind speed around the sample driving the flue-gas treatment installation was at most 0.17 m/s both upward and crosswise, the wind was almost calm at the sample position.

4.2 Observed Events in Fire-exposure Test

The key events observed during the test were summarized in Table 4. Representative images about some events are provided in Figs. 5, 6, 7 and 8. Only in 1-minite burning, white smoke was escaped from gaps mainly of the front door for the upper half of the sample. However, just after ignition, no explosions or bursts of battery modules were observed. White smoke was not observed any more, about 30 minutes later, and abnormalities of battery modules were not also observed. Furthermore, additional exposure for about 30 minutes was conducted. However, abnormalities of battery modules were not observed for the test sample. After 90 minutes after fire ignition, valves of propane gas cylinders were shut off and the evaluation-test was terminated.

Table 4 Key events

No.	Time (h:m:s)	Observed Event	Figure No.
1	–	Start measurement and video cameras recording Drive the flue-gas treatment system	–
2	10:30:15	Ignition【Evaluation Start】	Fig. 5
3	10:30:37	Occurrence white smoke generation	Fig. 6
4	11:00:00	Stop of white smoke generation	Fig. 7
5	11:30:00	Extension of exposure time	–
6	12:00:20	Gas-valves shut off【Test End】	Fig. 8

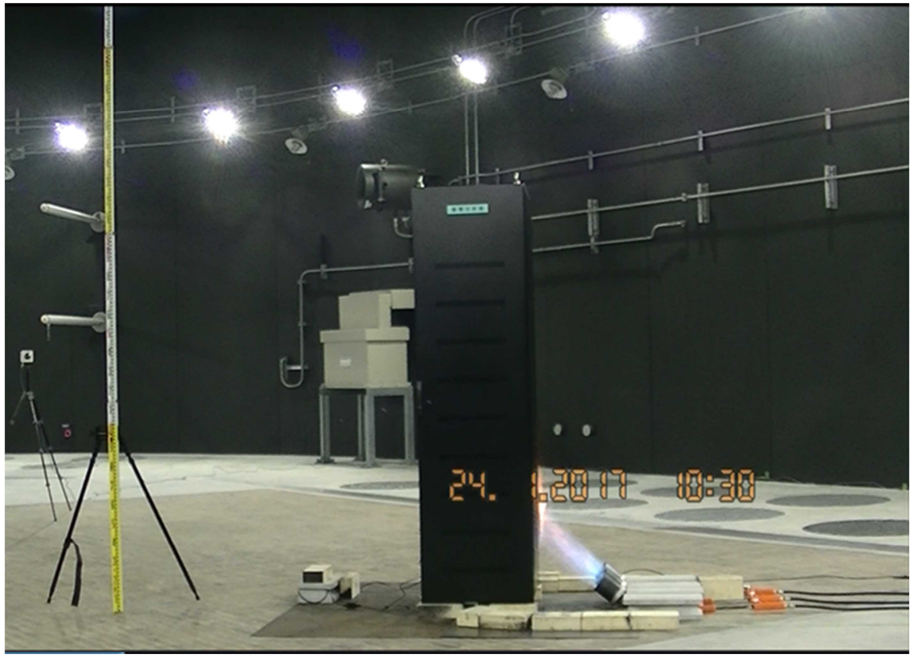

Fig. 5 Rack image at evaluation start
(Burners ignition)

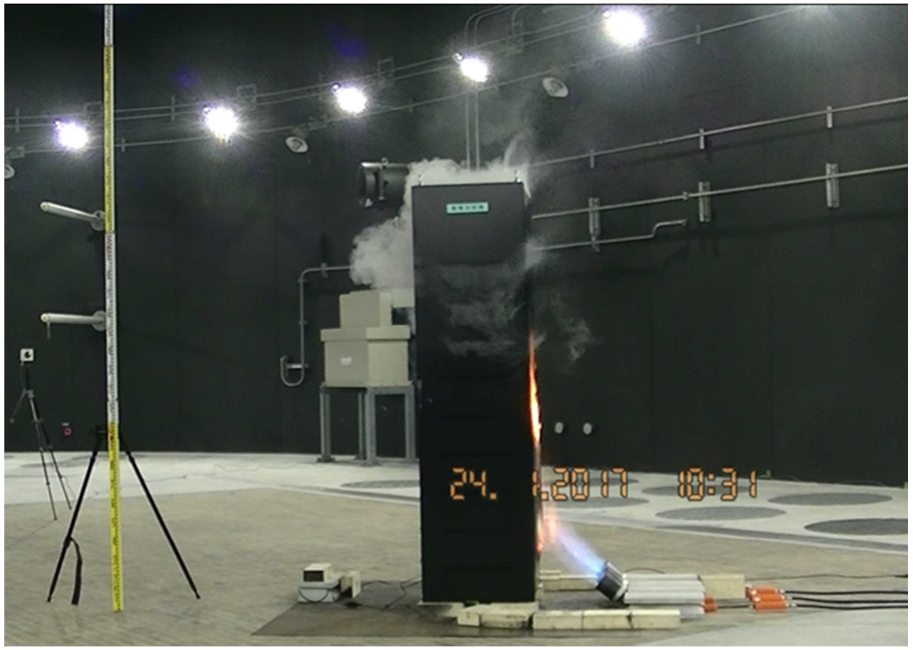

Fig. 6 Rack image after 1-minite burning

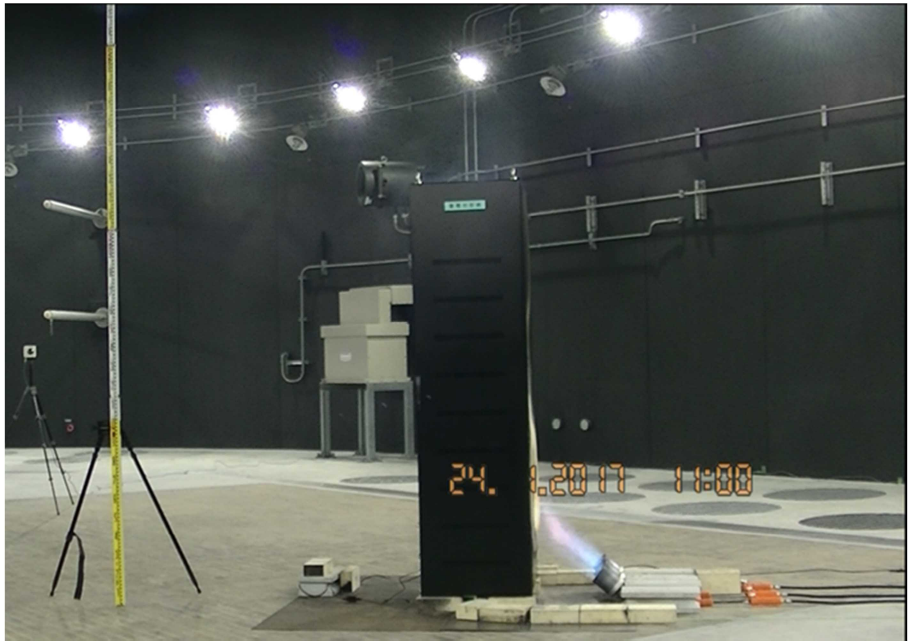

Fig. 7 Rack image after 30-minutes burning

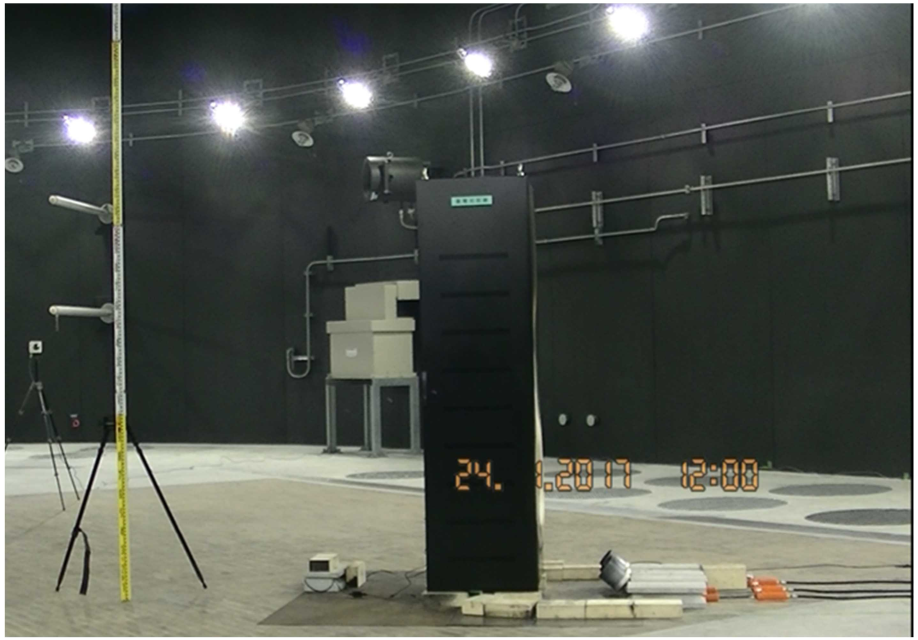

Fig. 8 Rack image after 90-minutes burning

(Gas valves shut off)

4．3　Temperature Measurement

Temperature measurement results are provided in Figs. 9 and 10.

Temperatures of top-side and back-side of battery modules (TC 2, TC 3, TC 6 and TC 7) kept increasing after ignition, dropped gradually after the end of the test. Compared to temperatures of top of battery modules, The temperature of the battery module 10 (TC 3) closest to fire was the highest at up to about 148 ℃. On the other hand, that of the battery module 16 (TC 7) farthest from fire was the lowest at up to about 88 ℃. The interior temperature of battery module 10 (TC 1) also increased for 40 minutes after the end time of the test, and dropped gradually after it reached at about 100 ℃. The interior temperature of battery module 10 (TC 1) dropped to less than 50 ℃, in 6 hours after the sample extinguishment.

Because the temperature TC 5 which the thermocouple placed inside wall of rack on burners side was measured with fluctuating at the early stage of the test, it can be thought the thermocouple was out of place from inside wall at this time and measured the temperature of the space between inside wall and battery module 10. The maximum temperature of the space was exceeded 400 ℃.

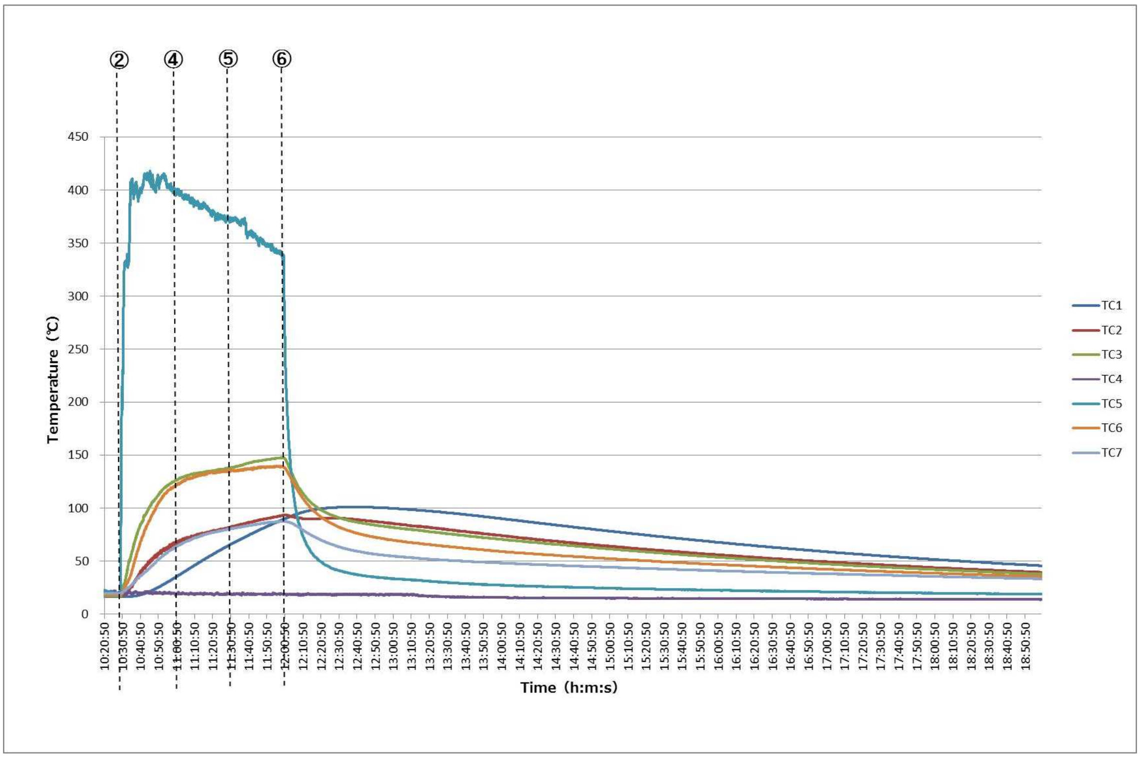

Fig. 9 Temperature measurement results. The numbers on the broken line correspond to those in Table 4.

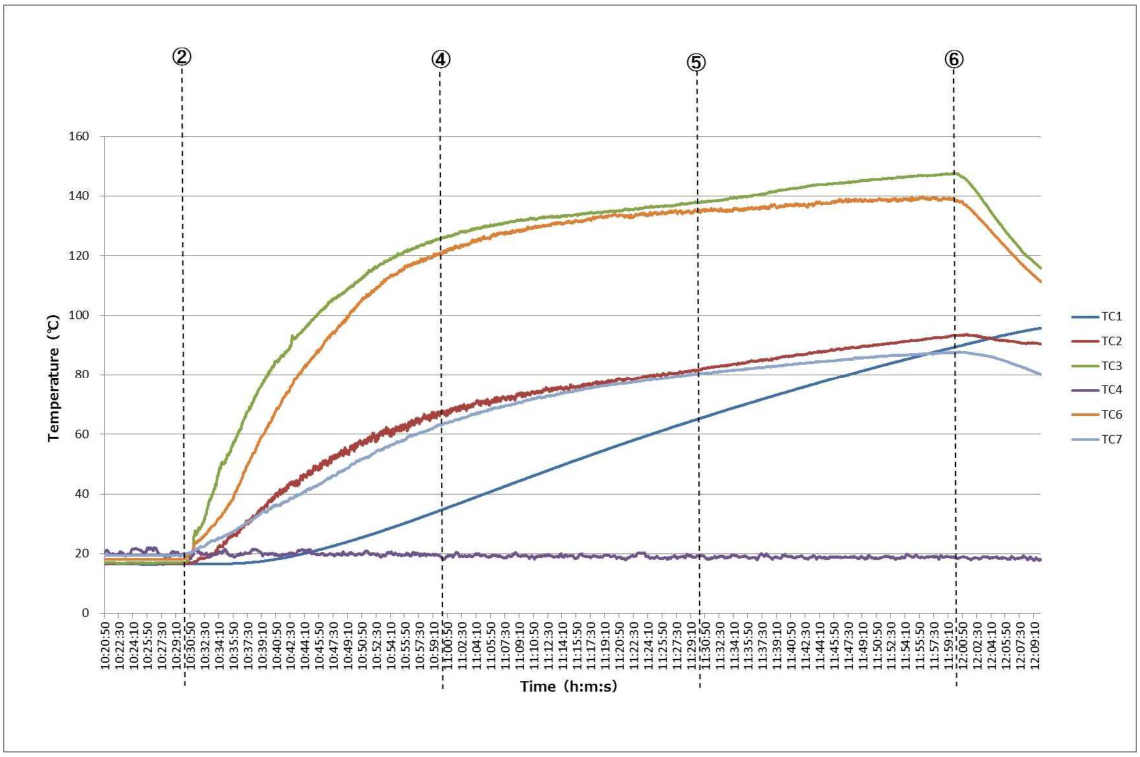

Fig. 10 Enlarged figure of the red frame part in Fig. 9. The numbers on the broken line correspond to those in Table 4.

4.4 Generated-Gas Concentration Measurement

During the test, concentrations of CO, CO_2, O_2, SO_2, HF, and HCl did not change at all. The concentration of NO_x fluctuated between 0.0 ppm and 2.7 ppm, and reached 3.2 ppm after 25 minutes from later after extinguishment. It can be thought NO_x wasn't also detected, because the concentration of NO_x also fluctuated between 0.0 ppm and 2.5 ppm in the usual time when a test wasn't performed. Measurement result of the concentration of NO_x is provided in Fig. 11.

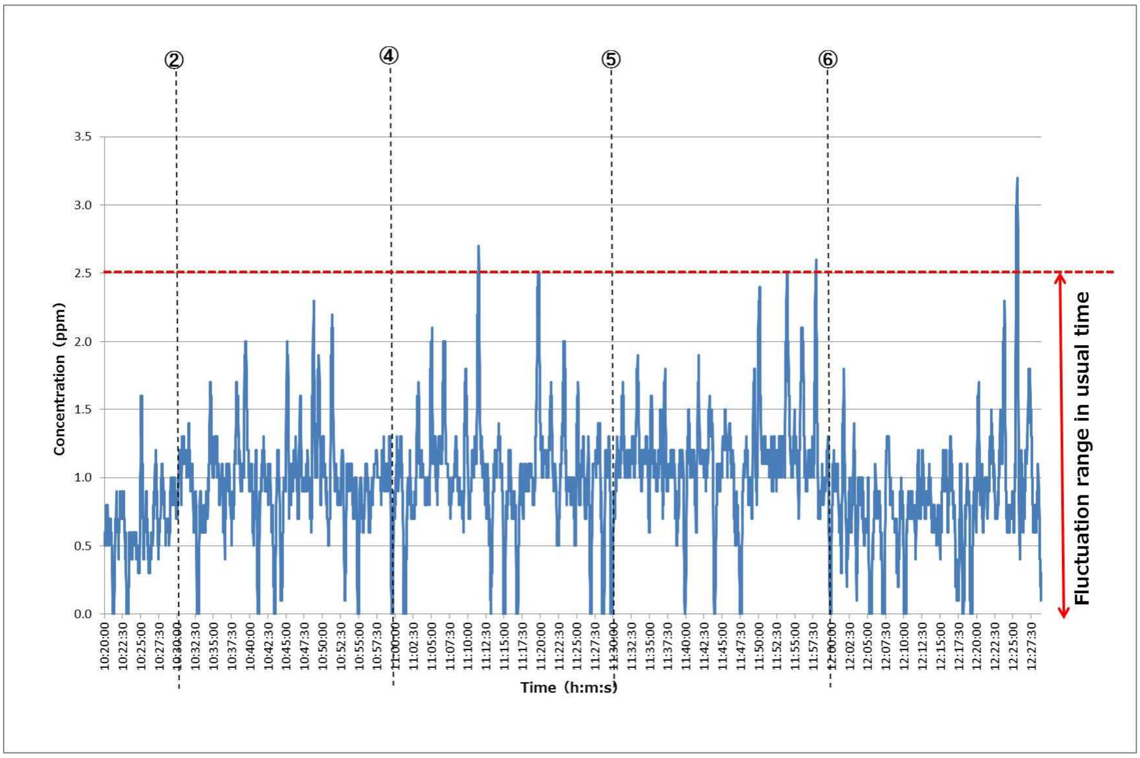

Fig. 11 Generated gas concentration measurement results for NO_x

4.5 Sample Images after Fire-exposure Test

Images of the sample after the fire exposure test are provided in Figs. 12, 13, 14 and 15.

The painting on both outside and inside walls of the fire-exposed face was removed and heat fading was observed on this face. However, abnormalities on other faces of battery rack were not observed. The front resin molded member on the fire exposure side battery module 9 to 14 burned out and deformed by heating, because the interior space of sample rack closest to burners was under a high temperature of over 400 ℃ as described in section 4.3. When battery module 10 was taken out from the rack, a little adhered soot was observed at the surface where battery module 10 was removed. No abnormalities such as explosion or burst were observed in all battery modules.

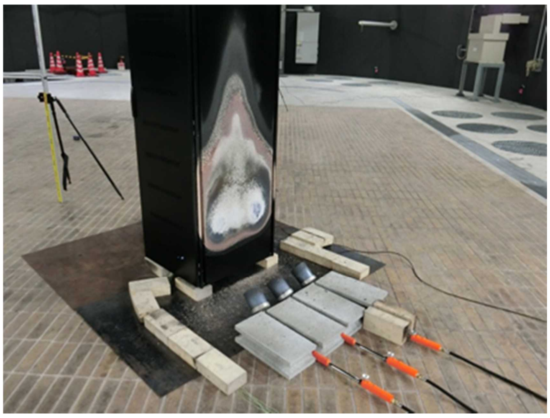

Fig. 12 Sample surface after fire exposure

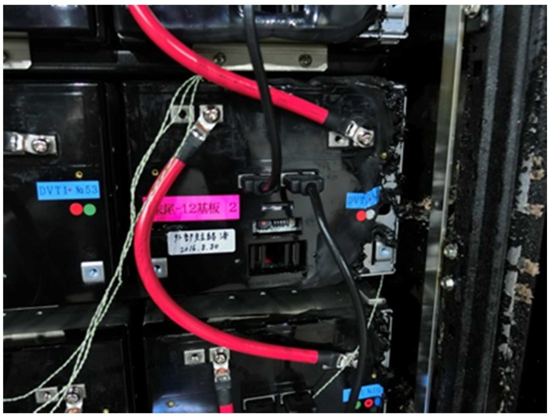

Fig. 13 Battery module 10 after fire-exposure taken out from the rack taken out from the rack (Interior of sample rack)

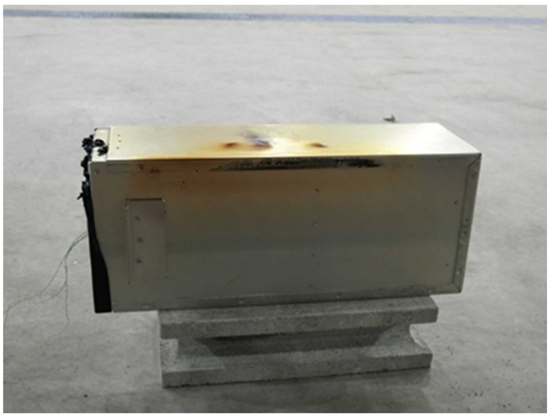

Fig. 14 battery module 10 taken out from the sample rack

Fig. 15 Inside wall of the sample rack after exposure

5. Reference

Andrew F. Blum and R. Thomas Long Jr., Hazard Assessment of Lithium Ion Battery Energy Storage Systems FINAL REPORT, 2016, Fire Protection Research Foundation, http://www.nfpa.org/news-and-research/fire-statistics-and-reports/research-reports/other-research-topics/hazard-assessment-of-lithium-ion-battery-energy-storage-systems, accessed 20, Oct., 2016.