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Nanoracks Test Requirements for Lithium-ion Batteries

Applicable to CubeSats & Small Satellites on the ISS

Nanoracks

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List of Revisions

Revision	Revision Date	Revised By	Revision Description
-	Pre-2017	Dana Gomez	Initial Release
A	3/29/2017	Bob Alexander	Updated per NASA comments
B	5/08/2017	Bob Alexander	Revised Sections 5 & 6
C	6/28/2017	Kirk Woellert	Minor revision to document caveats
D	5/11/2021	Maggie Ahern	Added Battery Test Report Template, removed Cell Over-charge Testing, and reformatted each requirement into a shall statement.

Table of Contents

List of Tables and Figures

1 Introduction

This document describes the acceptance/screening tests required for Lithium-Ion/Lithium-Ion Polymer cells and battery packs to determine if they are acceptable for flight for NASA crewed space vehicles. The requirements stated in this document are based on JSC 20793 'Crewed Space Vehicle Battery Safety Requirements' with additional guidance from the NASA Johnson Space Center Power and Propulsion Division.

1.1 Scope

The scope of this cell/battery acceptance testing is to screen the flight items wherever possible to discover indications of defects or design that may become a hazard to the ISS or Crew. The acceptance criteria documented herein is applicable to the majority of Lithium-ion cells/batteries for CubeSats and small satellites. The criteria apply to battery applications for spacecrafts launched pressurized or externally mounted on a Resupply Vehicle but does not apply to designs that are charged or discharged while a hazard potential is present to the ISS or Crew.

For battery applications where the total energy is at or above 80Whr, additional criteria are imposed and discussed in Appendix A of this document.

For battery applications that are charged while onboard the ISS, additional criteria are imposed and discussed in Appendix B of this document.

2 Acronyms and Definitions

Table 2-1: Acronyms

Terms/Acronym	Definition
Battery Pack	A set of cells either in series and/or parallel
C	The discharge rate that is equal to the maximum capacity of the battery in amp-hours divided by 1 hour. e.g., for a battery with a maximum capacity of 1Ah, a 1C discharge will provide 1A for 1 hour, a 2C discharge will provide 2A for 30 minutes, or at C/3 it will provide 0.33A for 3 hours
CCV	Closed Circuit Voltage
Cell	A single Lithium-Ion cell (e.g., 18650)
DPA	Destructive Physical Analysis
ISS	International Space Station
OCV	Open Circuit Voltage
PD	Payload Developer
SDT	Safety Data Template
TR	Thermal Runaway

3 Battery Test Matrix and Flow Process

3.1 Battery Test Requirement Matrix

The Battery Test Requirement Matrix (Shown in Table 3.1-1) outlines the required tests and documentation for CubeSats and small satellites that plan to launch to the ISS with Lithium-Ion Batteries. The matrix identifies whether a test is required to be completed at a pack level, cell level, or a choice of pack or cell level testing. When a test qualifies for pack/cell level testing, ensure that the testing level remains consistent throughout this process.

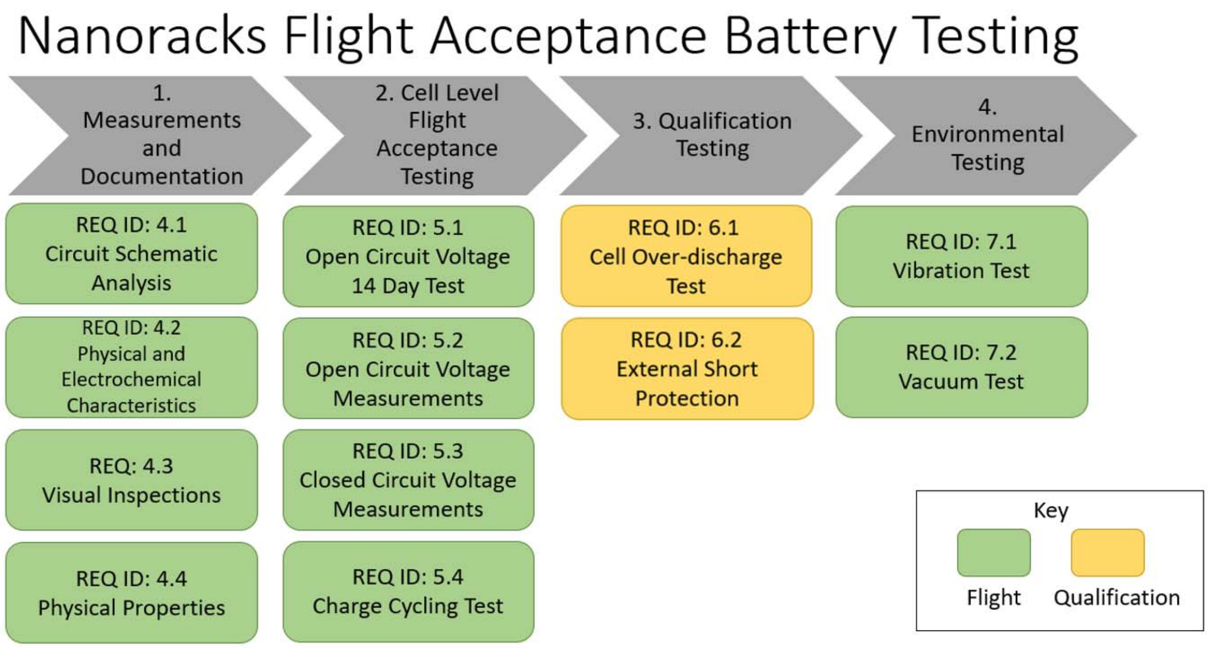
Table 3.1-1: Battery Test Requirement Matrix

Req ID	Requirement Name	Req Type	Testing Type	Flight/Non-flight	Pack/Cell	Verification Method	Data Located
4.1	Circuit Schematic Analysis	Physical	Acceptance	N/A	N/A	Inspection	SDT
4.2	Physical and Electrochemical Characteristics	Electrochemical	Acceptance	N/A	N/A	No Verification Required	SDT
4.3	Visual Inspection	Physical	Acceptance	Flight	Cell	Inspection	Battery Test Report
4.4	Physical Properties	Physical	Acceptance	Flight	Cell	Inspection, Testing	Battery Test Report
5.1	Open Circuit Voltage 14-day test	Electrochemical	Acceptance	Flight	Cell	Testing	Battery Test Report
5.2	Measurement of Open Circuit Voltage	Electrochemical	Acceptance	Flight	Pack/Cell	Testing	Battery Test Report
5.3	Measurement of Closed-Circuit Voltage	Electrochemical	Acceptance	Flight	Pack/Cell	Testing	Battery Test Report
5.4	Charge Cycling	Electrochemical	Acceptance	Flight	Pack/Cell	Testing	Battery Test Report
6.1	Cell Over-Discharge	Electrochemical	Qualification	Non-flight	Pack	Inspection, Testing	Battery Test Report
6.2	External Short Protection	Electrochemical	Qualification	Non-flight	Pack/Cell	Inspection, Testing	Battery Test Report
7.1	Vibration Test	Physical	Acceptance	Flight	Pack/Cell	Inspection, Testing	Battery Test Report
7.2	Vacuum Test	Physical	Acceptance	Flight	Pack/Cell	Inspection, Testing	Battery Test Report

3.2 Flight Acceptance Battery Testing Flow Process

The Flight Acceptance Battery Testing Flow Process (Shown in Figure 3.2-1) summarizes chronologically the requirements outlined in this document. Payload developers should follow this order of operations to reduce the risk of failing any given requirement. Should a Payload Developer care to perform the operations in a different order, please consult a Nanoracks Mission Manager to ensure the requirements will still be met.

Figure 3.2-1: Flight Acceptance Battery Testing Flow Process



4 Measurements and Documentation

4.1 Circuit Schematic Analysis (REQ ID: 4.1)

The PD shall provide the protection circuitry schematic and a description of how it works in the Safety Data Template (SDT).

4.2 Physical and Electrochemical Characteristics (REQ ID: 4.2)

The PD shall provide a detailed description of each cell and/or battery pack and how they interact in the SDT.

4.3 Visual Inspections (REQ ID: 4.3)

The PD shall inspect cells/battery packs for any deformations such as scrapes, bulges, dents, etc. The PD shall record all findings and include pictures.

4.4 Physical Properties (REQ ID: 4.4)

The PD shall record the length and width (diameter for cylindrical cells) with 0.1mm precision of each cell. The PD shall record the mass of each cell with 0.1g precision. If inspections are completed on a battery pack or pouch cell, then the PD shall record the height, contact Nanoracks, and consult the manufacturer for cell level data.

Length: The horizontal length of the battery with the serial number upright.

Width: The vertical length of the battery with the serial number upright.

Height: The smallest dimension (pack level only).

5 Cell Level Flight Acceptance Tests

5.1 Open Circuit Voltage (OCV) 14-day test (REQ ID: 5.1)

The OCV 14-day test is used to verify that cells with declining voltages (>2.0mV) from the original voltage at any point during the 14-day period shall be rejected. The PD shall record the largest decline in voltage from the original OCV and indicate whether the cell is rejected. This test shall be completed at the cell level.

The PD shall discharge each cell at a constant current to the minimum allowable voltage specified by the manufacturer's data sheet. The PD shall continue the discharge at a constant voltage until the current tapers below the manufacturer's recommended termination current (e.g., C/100). The PD shall record the OCV at discharge termination for each cell. Finally, the PD shall rest cells for 14 days while monitoring and recording the OCV for each cell on days 1, 3, 7, 10 and 14.

If using COTS at a pack level, please contact Nanoracks for further instructions and request OCV 14-day test data from manufacturer.

5.2 Measurement of Open Circuit Voltage (REQ ID: 5.2)

The PD shall record the Open Circuit Voltage (OCV) on the fully charged flight cells/battery pack using a multi-meter, oscilloscope, or other measuring device, and record the value for each of the cells/battery packs. Measurements shall be recorded with 0.1 V precision**.**

The OCV shall be recorded before vibrational and vacuum testing. The OCV is used as a baseline for the pass/fail criteria of future environmental tests outlined below.

5.3 Measurement of Closed-Circuit Voltage (REQ ID: 5.3)

The PD shall record the Closed-Circuit Voltage (CCV) on a flight cell/battery pack that is at least charged to the manufacturer's recommended level before proceeding. The programmable load shall be setup to a constant current defined by the manufacturer's data sheet (e.g., C/2), the battery shall be loaded, and the CCV shall be recorded 30 seconds after the battery is loaded.

5.4 Charge Cycling Test (REQ ID: 5.4)

The Charge Cycling test will be a baseline for the pass/fail criteria of future environmental tests outlined in the following sections. The Charge Cycling Data Procedures include the following cycle order:

1. Charge
2. Discharge
3. Charge
4. Discharge
5. Charge
6. Discharge

The PD shall record Capacity and Temperature of the cells throughout the following procedures. The PD shall charge the flight cell or battery pack to the manufacture's recommended level using a current defined by the manufacturer (e.g., C/2). The PD shall hold the batteries at a constant charge voltage until the charge current drops below the manufacturer's recommended charge termination current (e.g., 50mA). The PD shall wait 10 minutes for temperature to stabilize.

The PD shall discharge the flight battery pack at a rate defined by the manufacturer (e.g., C/2) until the voltage drops to the minimum manufacturer recommended cell/battery pack voltage. The PD shall repeat charge cycling procedures until the charge cycling order is complete, as shown above.

The PD shall complete the Charge Cycling Test on all flight cells and battery packs before completion of the vibration test and vacuum test.

6 Qualification Tests

For all qualification tests, PDs shall verify in the final battery test report that all non-flight cells/battery packs come from the same lot as the intended flight cells/battery packs and contain identical cell protection circuitry.

WARNING: Do not perform qualification testing on flight cells/pack as the batteries will incur damage. Ensure that the non-flight cells/pack contains a battery protection system before performing any qualification testing.

6.1 Cell Over-discharge Test (REQ ID: 6.1)

Over-discharge tests are to be performed on non-flight battery packs, from the same lot as flight battery packs, in order to establish protection characteristics.

The PD shall over-discharge battery packs at a rate defined by the manufacturer (e.g., 1C). The PD shall record the voltage at which the protection circuit opens. The PD shall charge the pack at the rate defined by the manufacturer (e.g., C/5). The PD shall record the voltage at which the protection circuit opens the circuit.

If the PD desires to use a non-flight cell instead of a battery pack for the Cell Over-discharge Test, then consult a Nanoracks Mission Manager.

6.2 External Short Protection (REQ ID: 6.2)

Perform an external short test to assure that the battery protection system will open the circuit and remain open should an external short occur. Identical flight battery protection system and non-flight cells/battery packs shall be used for this test. The non-flight battery pack from the over-discharge test (Section 6.1 above) may be used for this test provided that the battery pack is shown to still be acceptable for testing by demonstrating that they have retained capacity within 5% of the previously run cycle.

The PD shall use a fully charged battery to be short-circuited using a 50 mΩ +/-5 mΩ load. The short shall be held for a minimum of 3 hours. A 1 kHz data collection rate shall be used for the first 3 seconds. The current at which the safety MOSFET activates shall be recorded.

This test shall show that the flight protection circuitry can be expected to function within 100ms or alternatively function fast enough to prevent damaging the cells.

Pass/Fail criteria is defined by whether the protection circuitry opens within 100ms and/or cells/battery pack are not damaged.

7 Environmental Tests

7.1 Vibration Test Procedure (REQ ID: 7.1)

The PD shall record the OCV for each flight cell/battery pack before and after vibration testing. In addition, the PD shall ensure Section 5.4 charge cycling has been completed and recorded before vibration testing. The cells/battery pack shall be discharged to less than 10% SOC prior to vibration testing. The pass/fail criteria require that there shall be less than 0.1% change in the OCV and less than 5% change in capacity before and after vibration tests and throughout the remainder of the test procedures.

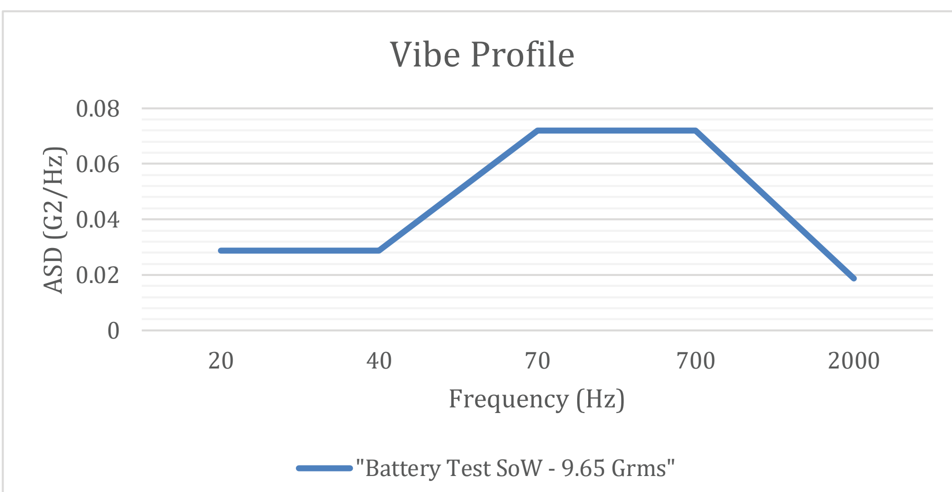
Vibration testing shall follow the spectrum as specified in Table 7.1-1 for one minute on each axis. The PD shall measure at least one accelerometer response channel and provide pictures of the test set up on each axis for the final battery test report.

Nanoracks also recommends recording the OCV between each axis of vibration, but this is not required. If the PD desires to use this battery vibration test profile for the CubeSat flight acceptance vibration test, then consult a Nanoracks Mission Manager.

Table 7.1-1: Vibration Testing Spectrum

Frequency (Hz)	ASD (G2/Hz)	dB/OCT	Grms
20.00	0.028800	*	*
40.00	0.028800	0.00	0.76
70.00	0.072000	4.93	1.43
700.00	0.072000	0.00	6.89
2000.00	0.018720	-3.86	9.65

Figure 7.1-1: Vibration Testing Spectrum Profile



7.2 Vacuum Test Procedure (REQ ID: 7.2)

The PD shall perform the Vacuum test and record pictures of the test set up in order to verify that the batteries do not produce leaks, deformations, or bulges.

The PD shall complete a charge cycling test as specified in Section 5.4 and record the capacity. The pass/fail criteria requires that there shall be less than 0.1% change in the OCV and less than 5% change in the capacity before and after vacuum testing.

The PD shall ensure the voltage of all cells/battery pack and record the values in the battery test report template. If any batteries are not fully charged, charge before continuing.

The PD shall place fully charged batteries into the vacuum chamber at atmospheric pressure and pull vacuum at approximately 8 psi/minute.

For lithium-ion pouch cells, the PD shall pull vacuum until 10 psia is reached. Nanoracks recommends testing pouch-cells in a restrained configuration (with support structures installed on the wide faces of the cells) to prevent damage due to pouch expansion.

For all other types of cells and battery packs, the PD shall pull vacuum until 0.1 psia is reached.

The PD shall maintain vacuum for 6 hours. The PD shall re-pressurize the chamber to ambient at a rate of 9 psi/minute. The PD shall visually inspect the batteries for leaks, deformations, or bulges and record any findings and provide pictures.

If lithium-ion pouch cells, the PD shall obtain measurements of the length, width, height, and mass of the post-vacuum tested cells/battery packs and record them in the battery test report template. The PD shall compare these measurements against the measurements obtained in Section 4.3. The pass/fail criteria require that there be less than 0.1% change in mass and no significant changes in dimensions.

8 Reporting

Prepare a Battery Acceptance Test Report to document the acceptability of the cells/battery pack to be flown. Provide all the above data including test set-up details and all results. Additionally, include photo documentation which accurately displays the test activity. The report should be dated, signed, and approved by the appropriate program authority. A blank battery test report template is provided in Appendix C if desired.

Appendix A

Requirements for battery systems at or above 80Whr

Large capacity battery systems may present extreme hazard to the ISS or Crew. Systems which have energy capacity above 80Whr necessitate the application of additional requirements to reduce or control this hazard level. Options listed below are to be considered for these designs per EP-19-001, Interpretation Memo for the Battery TR Propagation Requirements in JSC 20793 Rev D.

A. Wherever possible, designs above 80Whr should be divided into smaller isolated battery enclosures each of which are below 80Whr. The enclosures shall be physically and electrically separated/isolated to preclude any thermal runaway (TR) event in one enclosure from propagating to the other enclosure(s). Thermal runaway testing will not be required for enclosures having less than 80Whr.

B. Where battery designs are above 80Whr in a single non-isolated enclosure (e.g., single battery box), thermal runaway cell-to-cell propagation testing must be performed. Design features shall be incorporated to preclude cell-to-cell propagation. Testing is required to demonstrate that design features preclude cell-to-cell propagation. Examples are given, but not limited to, those listed below.

    a. Cell isolation such that a TR event will not propagate to from cell to cell. This option must be supported by test results.

    b. Overall cell state of charge reduced to preclude any TR event. This option must be supported by test results.

    c. Other designs which preclude a TR event will be considered on a case-by-case basis.

For all systems which meet or exceed 80Whr, design changes (e.g., suggested above or others) must be discussed with Nanoracks to assure that the thermal runaway mitigation approach is acceptable to the ISS program.

Appendix B

Requirements for Cells Charging while Onboard the ISS

The PD shall complete the Cell Over-charge test for qualification and screening if the batteries are intended or capable to be charged on or at the ISS. Over-charge tests are to be performed on non-flight cells/battery packs, from the same lot as flight cells, in order to establish protection characteristics.

The PD shall over-charge cells/battery packs to the manufacturer's recommended voltage (e.g., 5.0V) per cell using the manufacturer's recommended current (e.g., 1C). The PD shall record the voltage at which the battery protection activates to open the charging circuit. The PD shall discharge the cells/batteries at the manufacturer's recommended rate (e.g., C/5). The PD shall record the voltage at which the protection circuit opens the circuit.

Appendix C

Battery Test Report Template

Overview

Payload Name:	
Organization Name:	
Test Facility Details:	
Testing Date(s):	

Visual Inspections (REQ ID 4.3)

Pass/Fail Criteria: Flight cells/battery packs shall not have any deformations such as scrapes, bulges, dents, etc.

STEP 1: Inspect the flight cells/battery packs for any deformations such as scrapes, bulges, dents, etc.

STEP 2: Record any findings and provide pictures in the table below.

Table C-1	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
S/N:					
Visual inspections of leaks, damage, bulges, etc.					
Inspection pictures (S/Ns clearly visible)					
Pass/Fail:					

Physical Property Measurements (REQ ID 4.4)

Measurements and testing can be performed at either the individual cell or the assembled battery pack level. Record the physical properties of the cells/battery packs in the table below.

Cell-level testing:

STEP 1: Measure the length and width (diameter) of each cell with 0.1mm precision.

STEP 2: Measure the mass of each cell with 0.1g precision.

Battery pack-level testing:

STEP 1: Measure the length, width, and height of each battery pack with 0.1mm precision.

STEP 2: Measure the mass of each battery pack with 0.1g precision.

STEP 3: Contact the manufacturer for cell-level data.

Table C-2	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
S/N					
Length [mm]					
Width [mm]					
Height [mm]					
Mass [g]					
Pictures showing dimensions (S/Ns clearly visible)					

Open Circuit Voltage (OCV) 14-day test (REQ ID 5.1)

The OCV 14-day test shall be completed at the **cell level**. If testing a battery pack, contact Nanoracks and request OCV 14-day test data from the cell manufacturer.

STEP 1: Discharge each cell at a constant current to the minimum allowable voltage specified by the manufacturer's data sheet.

STEP 2: Discharge at constant voltage until the current tapers below the manufacturer's recommended termination current (e.g., C/100), then terminate the discharge.

STEP 3: Record the OCV at discharge termination for each cell in Table C-3.

Table C-3	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Discharged OCV [mV]					

STEP 4: Allow the cells to rest for 14 days. Monitor and record the OCV for each cell on days 1, 3, 7, 10 and 14 in Table C-4.

Table C-4	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Day 1 OCV [mV]					
Day 3 OCV [mV]					
Day 7 OCV [mV]					
Day 10 OCV [mV]					
Day 14 OCV [mV]					

STEP 5: Determine the largest change in voltage (ΔOCV) from any point over the 14-day period to the original OCV measurement (from Table C-3). Record the change in voltage in Table C-5. Any cells with a ΔOCV at any point over the 14-day period that is greater than 2.0 mV from the original voltage fail the requirement and shall not be used for flight.

Table C-5	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Largest Δ from original OCV [mV]					
Pass/Fail? (Fail = ΔOCV > 2.0mV)					

Measurement of Open Circuit Voltage (REQ ID 5.2)

STEP 1: Fully charge the flight cells/battery packs to the manufacturer's recommended level.

STEP 2: Measure the Open Circuit Voltage (OCV) of the cells/battery packs.

STEP 3: Record the OCV for each of the cells or battery packs with 0.1 V precision in Table C-6**.**

Table C-6	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Fully charged OCV [mV]					

Measurement of Closed-Circuit Voltage (REQ ID 5.3)

STEP 1: Fully charge the flight cells/battery packs to the manufacturer's recommended level.

STEP 2: Setup the programmable load to a constant current defined in the manufacturer's data sheet (e.g., C/2).

STEP 3: Load the cells/battery packs and wait for 30 seconds.

STEP 4: Record the Closed-Circuit Voltage in Table C-7.

Table C-7	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Closed-circuit voltage [mV]					

Charge Cycling Test (REQ ID 5.4)

Complete the Charge Cycling Test on all flight cells/battery packs before the vibration and vacuum tests. The Charge Cycling capacity data will be used as a baseline for the pass/fail criteria of the vibration and vacuum tests. Ensure the temperature of the cells/battery packs does not exceed the manufacturer's recommended temperature range.

STEP 1: Charge the flight cells/battery packs to the manufacturer's recommended maximum voltage using the manufacturer's recommended current (e.g., C/2).

STEP 2: Maintain the cells/battery packs at a constant charge voltage until the charge current drops below the manufacturer's recommended charge termination current (e.g., 50mA).

STEP 3: Wait 10 minutes for the cell/battery pack temperature to stabilize.

STEP 4: Discharge the cells/battery packs at the manufacturer's recommended rate (e.g., C/2) until the voltage drops to the manufacturer's minimum recommended voltage.

STEP 5: Repeat the Charge Cycling Test procedures (Steps 1-6) as outlined in the order below.

1. Charge
2. Discharge
3. Charge
4. Discharge
5. Charge
6. Discharge

STEP 6: Record the Capacity and Temperature of the cells/battery packs in Table C-8.

Table C-8	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Capacity [mAh]					
Temperature [°C]					

Over-discharge Qualification Test (REQ ID 6.1)

The Over-discharge Test is a qualification test to verify the functionality of the protection circuitry. This test shall be performed on non-flight battery packs from the same lot as the flight battery packs. If possible, the flight protection circuitry shall be used.

Pass/Fail Criteria: The protection circuitry shall properly function to protect the battery pack.

STEP 1: Over-discharge the non-flight battery pack at a rate of 1C.

STEP 2: Record the voltage at which the protection circuit opens in Table C-9.

STEP 3: Charge the non-flight battery pack at the manufacturer's recommended rate (e.g., C/5).

STEP 4: Record the voltage at which the protection circuit resets in Table C-9.

Table C-9	Non-Flight Battery Pack
Voltage when Protection Circuit Opens [mV]	
Voltage when Protection Circuit Resets [V]	
Pass/Fail? (Pass = Protection Circuit Opened)	

External Short Qualification Test (REQ ID 6.2)

Perform an external short test to verify that the protection circuitry will open and remain open if an external short should occur. Non-flight cells/battery packs and flight protection circuitry (if possible) shall be used for this test. The non-flight battery pack used for the Over-discharge Test (Section 6.1) may be used for this test, provided that the battery pack has retained capacity within 5% of the capacity measured in the Charge Cycling Test (Section 5.4).

Pass/Fail Criteria: The protection circuitry shall open within 100ms and/or shall open fast enough to prevent damage to the cells/battery packs.

STEP 1: A fully charged battery shall be short-circuited using a 50 mΩ +/-5 mΩ load and the short shall be held for a minimum of 3 hours. A 1 kHz data collection rate shall be used for the first 3 seconds. The current at which the safety MOSFET activates shall be noted.

STEP 2: Record the time at which the protection circuit opens in Table C-10.

Table C-10	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Time for Protection Circuit to Open [ms]					
Pass/Fail (Pass = Protection Circuit opened within 100 ms)					

Vibration Test (REQ ID 7.1)

Pass/Fail Criteria: Flight cells/battery packs shall have less than 0.1% change in OCV and less than 5% change in capacity.

STEP 1: Record the pre-vibe OCV and capacity for each flight cell/battery pack Table C-11. Nanoracks recommends taking additional measurements between each axis of vibration, but this is not required.

STEP 2: Fixture the flight cells/battery packs to a vibration table using standard hard mount fixturing plates & rods, a battery pack casing, or a representative spacecraft structure. Contact Nanoracks if the CubeSat flight unit will be used for cell/battery pack vibration testing.

STEP 3: Apply at least one (1) response accelerometer to the fixture for data output. Ensure the vibration table has a control accelerometer for verifying acceleration spectrum input.

STEP 4: Take pictures of the vibration configuration in each of 3 axes.

STEP 5: Vibration test the flight cells/battery packs according to the acceleration spectrum profile in NR-SRD-139 Rev D Table 7-1 for 60 seconds/axis in each of 3 axes.

STEP 6: Provide the spectrum response plots and configuration picture for each axis in Table C-13 below.

STEP 7: Conduct the OCV and Charge Cycling Tests for each flight cell/battery pack again. Record the post-vibe OCV and capacity in Tables C-11 and C-12.

Table C-11	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Pre-Vibe OCV [mV]					
Post-Vibe OCV [mV]					
% Change in OCV					
OCV Pass/Fail (Pass = < 0.1% change)					

Table C-12	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Pre-Vibe Capacity [mAh]					
Post-Vibe Capacity [mAh]					
% Change in Capacity					
Capacity Pass/Fail (Pass = < 5% change)					

Table C-13	
X-Axis Vibration Response Plot	**X-Axis Configuration Picture**
Y-Axis Vibration Response Plot	**Y-Axis Configuration Picture**
Z-Axis Vibration Response Plot	**Z-Axis Configuration Picture**

Vacuum Test (REQ ID 7.2)

Pass/Fail Criteria: Flight cells/battery packs shall have less than 0.1% change in mass, less than 0.1% change in OCV, and less than 5% change in capacity.

STEP 1: Record the pre-vacuum mass, OCV, and capacity for each flight cell/battery pack in the tables below.

STEP 2: Place the flight cells/battery packs into the vacuum chamber at atmospheric pressure. For pouch-style cells, Nanoracks recommends testing in a restrained configuration (with support structures installed on the wide faces of the cells) to prevent damage due to pouch expansion.

STEP 3: Pull vacuum at approximately 8 psi/minute.

For pouch-style cells: Pull a vacuum to between 8-10 psia.

For all other cells/battery packs: Pull vacuum until at least 0.1 psia is reached.

STEP 4: Maintain vacuum for 6 hours.

STEP 5: Re-pressurize the chamber at a rate of 9 psi/minute until atmospheric pressure is reached.

STEP 6: Visually inspect the cells/battery packs for leaks, deformations, or bulges. Record any findings and provide pictures in the tables below.

STEP 7: Measure the post-vacuum mass, OCV, and capacity of each cell/battery pack and record in the Tables C-14, 15, 16, and 17.

Table C-14	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Visual inspections of leaks, damage, bulges, etc. Provide pictures.					

Table C-15	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Pre-Vacuum Mass [g]					
Post-Vacuum Mass [g]					
% Change in Mass					
Mass Pass/Fail (Pass = < 0.1% change)					

Table C-16	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Pre-Vacuum OCV [mV]					
Post-Vacuum OCV [mV]					
% Change in OCV					
OCV Pass/Fail (Pass = < 0.1% change)					

Table C-17	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Pre-Vacuum Capacity [mAh]					
Post-Vacuum Capacity [mAh]					
% Change in Capacity					
Capacity Pass/Fail (Pass = < 5% change)					

Report Summary and Signature

Based on the results of this testing, I, [Payload Developer], conclude that the [Payload] flight cells/battery packs meet all requirements described in NR-SRD-139. I have personally overseen all stages of testing on the battery module. By my signature below I attest that these results are complete and accurate to the best of my knowledge.

Payload Developer Signature: ________________________________ **Date:** _____________