9/18/2023

Nanoracks Test Requirements for Lithium-ion Batteries

Applicable to CubeSats & Small Satellites on the ISS

Nanoracks
VOYAGER SPACE

Doc No:	NR-SRD-139
Revision:	F

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.
E	11/1/2021	Maggie Ahern	Updated template for clarity
F	8/11/2023	Brenden Swanik	Removed Open Circuit Voltage (OCV) 14-Day test, added Charge Cycling process figure, added Pre-Vibration, added Post-Vacuum Test, and Pre/Post-Vibration & Vacuum Test Deviation Analysis, added Appendix C, added a figure for the intended flow of testing REQ ID 5 and REQ ID 7. Switched order of Sec. 5,6

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 80Wh, 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
A	Ampere
Ah	Ampere Hour
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)
COTS	Commercial Off the Shelf
DAC	Digital to Analogue Converter
ISS	International Space Station
OCV	Open Circuit Voltage
PD	Payload Developer
PSIA	Pounds per Square Inch Absolute
SDT	Safety Data Template
SOC	State of Charge
TR	Thermal Runaway
Wh	Watt Hour

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	Pack/Cell	Inspection	Battery Test Report
4.4	Physical Properties	Physical	Acceptance	Flight	Pack/Cell	Inspection, Testing	Battery Test Report
5.1	Cell Over-Discharge	Electrochemical	Qualification	Non-flight	Pack	Inspection, Testing	Battery Test Report
5.2	External Short Protection	Electrochemical	Qualification	Non-flight	Pack/Cell	Inspection, Testing	Battery Test Report
6.1	Measurement of Open Circuit Voltage	Electrochemical	Acceptance	Flight	Pack/Cell	Testing	Battery Test Report
6.2	Measurement of Closed-Circuit Voltage	Electrochemical	Acceptance	Flight	Pack/Cell	Testing	Battery Test Report
6.3	Charge Cycling	Electrochemical	Acceptance	Flight	Pack/Cell	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 Battery Testing Flow Process

The 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.

In the instance of this specific battery test report, there are two types of testing: acceptance and qualification. Acceptance testing is performed on flight batteries, while qualification testing is done on flight-like batteries from the same lot due to its destructive tendencies. "Batteries from the same lot" implies the batteries were produced together with similar performance characteristics. For that reason, flight batteries are called acceptance batteries, and flight-like batteries from the same lot are qualification batteries.

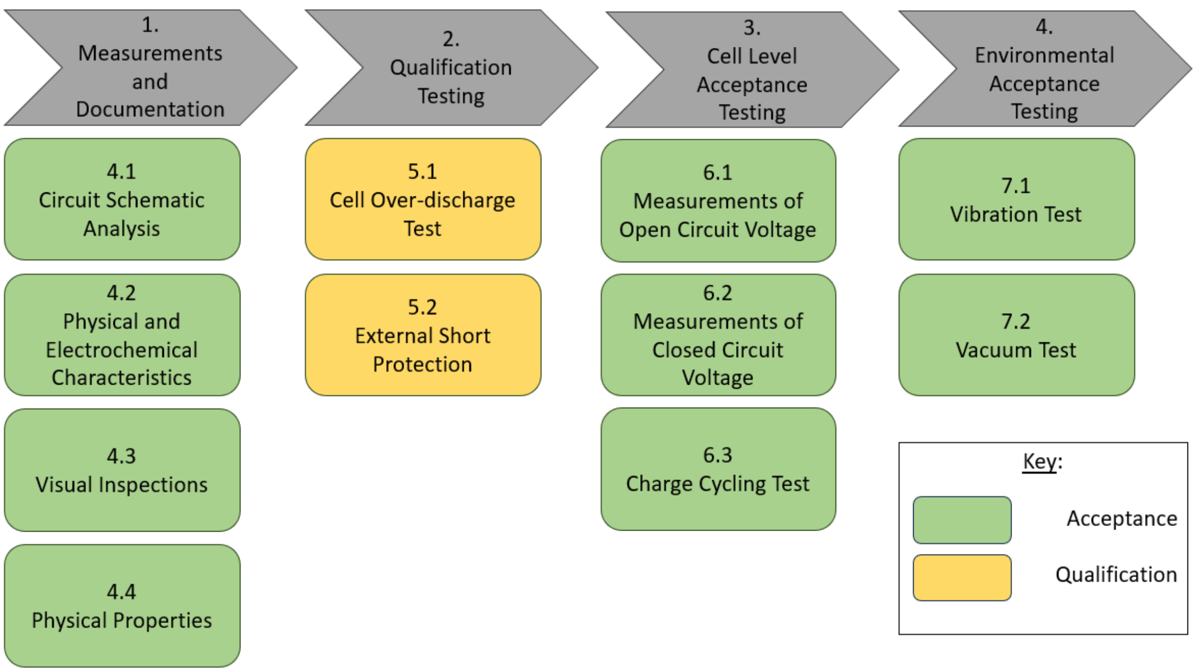


Figure 3.2-1: Battery Testing Flow Process

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 the circuit operates 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 damage or deformations such as scrapes, bulges, dents, etc. The PD shall record all findings and include pictures. Pictures should entail everything, not just defects.

4.4 Physical Properties (REQ ID: 4.4)

The PD shall record the following depending on what they have available:

For a cylindrical cell, record the length and width (diameter of cylindrical cells) with 0.1mm precision of each cell. The PD shall record the mass of each cell with 0.1g precision.

For a battery pack or pouch, record the length, width and height with 0.1mm precision. The PD shall record the mass of each cell with 0.1g precision. The PD must consult a Nanoracks mission manager for this option.

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 Qualification Tests

For all qualification tests, PDs shall verify that all qualification cells/battery packs come from the same lot as the acceptance cells/battery packs. The qualification batteries shall be in the same configuration as the acceptance batteries for flight. They shall also contain identical cell protection circuitry. Consult a mission manager if PD is unable to obtain the same configuration.

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

5.1 Over-discharge Test (REQ ID: 5.1)

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

The PD shall over-discharge battery packs at a rate defined by the manufacturer. The PD shall record the voltage at which the protection circuitry opens. The PD shall charge the pack at the standard rate defined by the manufacturer. The PD shall record the voltage at which the protection circuit closes/resets the circuit.

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

5.2 External Short Protection (REQ ID: 5.2)

Perform an external short test to assure that the battery protection system will open the circuit and remain open should an external short occur. The qualification cells/battery shall be used with the identical protection circuitry utilized in the previous test. If it is not possible to use the flight-like configuration, contact a Nanoracks mission manager.

The qualification battery pack from the over-discharge test (Section 5.1 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 for this test. The battery shall be short-circuited through a 50 mΩ ±10% load. A 1 kHz data collection rate shall be used for the first 3 seconds. Afterwards, the short shall be held for a minimum of 3 hours to ensure the protection circuity remains active.

This test shall show that the battery protection circuitry can be expected to function within 100ms. If not, the PD shall contact a Nanoracks mission manager to justify why that does not pose a hazard.

Pass/Fail criteria is defined by whether the protection circuitry opens within 100ms and remains open for the duration of the short.

6 Cell Level Acceptance Tests

As it will be discussed in the next following sections, Measurement of Open Circuit Voltage (REQ ID: 6.1) and Charge Cycling Test (REQ ID: 6.3) are the baselines for the pass/fail criteria of the Environmental Acceptance Tests. The PD is not required to perform the Environmental Acceptance Tests more than once. Refer to Figure 6-1 below for the intended testing flow.

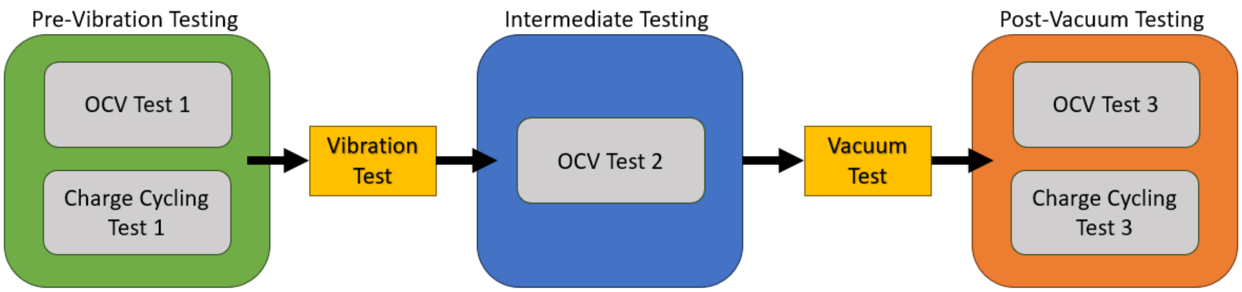


Figure 6-1: Intended Flow for Cell Level (REQ ID 5) and Environmental (REQ ID 7) Acceptance Testing

6.1 Measurement of Open Circuit Voltage (REQ ID: 6.1)

The Open Circuit Voltage (OCV) test will be one of the baselines for the pass/fail criteria of future environmental acceptance tests outlined in the following sections. The OCV shall be recorded **before** and **after** vibrational and vacuum testing.

The PD shall record the Open Circuit Voltage on the fully charged acceptance 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**.**

6.2 Measurement of Closed-Circuit Voltage (REQ ID: 6.2)

The PD shall record the Closed-Circuit Voltage (CCV) on an acceptance cell/battery pack that is fully charged to the manufacturer's recommended level before proceeding. An electronic load shall be setup to a standard discharge rate defined by the manufacturer's data sheet, the battery shall be loaded, and the CCV shall be recorded 30 seconds after the battery is loaded.

Note: it is recommended to capture and record all battery monitoring and power supply data with a DAC system at 1Hz.

6.3 Charge Cycling Test (REQ ID: 6.3)

The Charge Cycling test will be one of the baselines for the pass/fail criteria of future environmental acceptance tests outlined in the following sections. It shall be recorded **before** vibrational testing and **after** vacuum testing.

The PD shall fully charge the acceptance cell or battery pack following the manufacture's recommended charging procedure. The PD shall discharge the acceptance battery pack at a rate defined by the manufacturer until the voltage drops to the minimum manufacturer recommended cell/battery pack voltage.

The PD shall allow the battery to rest for 10 minutes between the charge and discharge cycles to allow the battery temperature to stabilize. The PD shall repeat charge cycling procedures until the charge cycling order is complete, as shown below.

The process follows three cycles:

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

The PD shall complete the Charge Cycling Test on all acceptance cells and battery packs before completion of the vibration test and vacuum test. The PD shall preform this test again after the vibration test and vacuum test.

The Charge Cycling Data Procedures include the following cycle order:

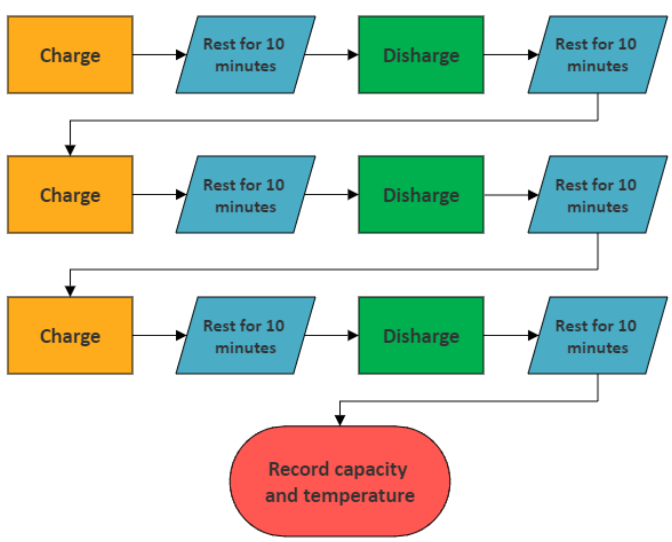


Figure 6.3-1: Charge Cycling Flow Process

7 Environmental Acceptance Tests

7.1 Vibration Test (REQ ID: 7.1)

The PD shall record the OCV for each acceptance cell/battery pack **before** and **after** vibration testing. The PD shall record charge cycling test for each acceptance cell/battery pack **before** vibration testing. The cells/battery pack shall be discharged to less than 10% SOC prior to vibration testing. The pass/fail criteria requires that there shall be less than 0.1% change in the OCV before and after vibration testing and less than 5% change in capacity before 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 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

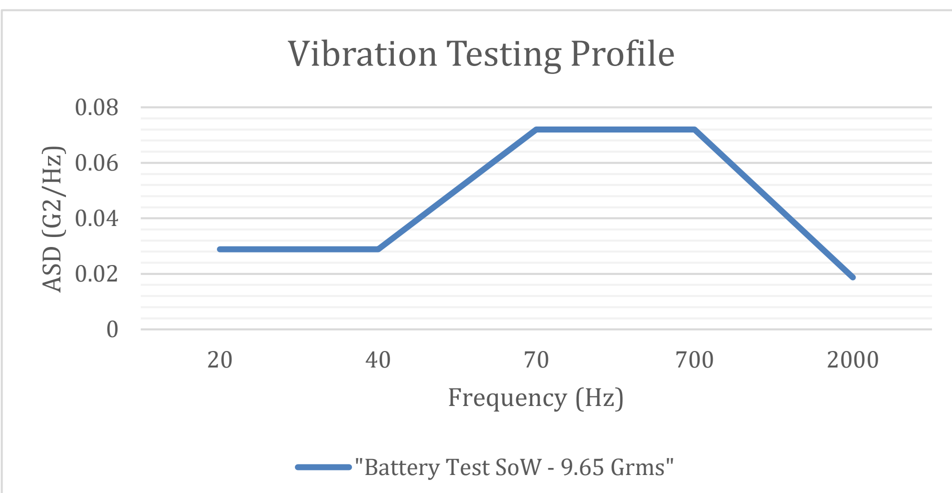


Figure 7.1-1: Vibration Testing Spectrum Profile

7.2 Vacuum Test (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 the OCV test **before** and **after** the vacuum test. The PD shall complete a charge cycling test **after** the vacuum test. The pass/fail criteria requires that there shall be less than 0.1% change in the OCV before and after vacuum testing and less than 5% change in the capacity after vacuum testing.

The PD shall ensure the voltage of all cells/battery pack is nominal 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 a rate of 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. Provide pictures for all, not just damages.

For 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 damages such as bulges/dents/leakages.

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 80Wh

Large capacity battery systems may present extreme hazard to the ISS or Crew. Systems which have energy capacity above 80Wh 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 80Wh should be divided into smaller isolated battery enclosures each of which are below 80Wh. 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 80Wh.

B. Where battery designs are above 80Wh 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 80Wh, 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 qualification cells/battery packs, from the same lot as acceptance cells, in order to establish protection characteristics.

The PD shall over-charge cells/battery packs beyond the manufacturer's recommended voltage per cell using the manufacturer's recommended current. 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. The PD shall record the voltage at which the protection circuit opens the circuit.

Appendix C

Requirement for batteries of a shelf life of 5 years or greater

The PD shall perform an additional Charge Cycling Test for batteries of shelf lives 5+ years to verify the robustness of the batteries. The test is to be performed on a sample of the acceptance batteries. The PD must state the manufacturing date of the batteries.

The PD shall perform five charge cycle, and record precent of the required performance. If the percent of the required performance is at least 80%, the life can be extended for 1 year. If it is at least 90%, it results in a 2 year extension.

Appendix D

Battery Test Report Template

Overview

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

Battery Pack or Cell Level Testing Designation

The below tests may be performed on either the **battery pack** or **cell level.** Please indicate in the table below which was tested on for each section of the report:

Battery Pack or Cell Level Testing Designation Table			
REQ ID	Requirement Name	CHECK if Battery Pack	CHECK if Cell Level
4.3	Visual Inspection	☐	☐
4.4	Physical Properties	☐	☐
5.1	Cell Over-Discharge	☐	**N/A (Pack Only)**
5.2	External Short Protection	☐	☐
6.1	Measurement of Open Circuit Voltage	☐	☐
6.2	Measurement of Closed Circuit Voltage	☐	☐
6.3	Charge Cycling	☐	☐
7.1	Vibration Test	☐	☐
7.2	Vacuum Test	☐	☐

Circuit Schematic Analysis (REQ ID 4.1)

Details documented in STD

Physical and Electrochemical Characteristics (REQ ID 4.2)

Details documented in STD

Visual Inspections (REQ ID 4.3)

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

STEP 1: Inspect the acceptance cell/battery packs for any damage or deformations such as scrapes, bulges, dents, etc. If it does not apply, say N/A.

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

If testing is done on **battery pack**, fill in the first column (Titled: "Cell #1") 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.

STEP 3: Record the measurements and pictures in Table C-2

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.

STEP 4: Record the measurements and pictures in Table C-2

If testing is done on **battery pack**, fill in the first column (Titled: “Cell #1”) in the table below:

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)					

Over-discharge Qualification Test (REQ ID 5.1)

The Over-discharge Test is a qualification test to verify the functionality of the protection circuitry. This test shall be performed on qualification **battery packs** from the same lot as the acceptance battery packs If flight protection circuitry is not available, contact a Nanoracks mission manager. Contact a mission manager if PD is unable to obtain the same configuration.

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

STEP 1: Over-discharge the qualification battery pack at the standard discharge rate specified by the manufacturer.

STEP 2: Record the voltage at which the protection circuit opens in Table C-14.

STEP 3: Charge the qualification battery pack at the manufacturer's standard rate.

STEP 4: Record the voltage at which the protection circuit resets in Table C-14.

Table C-14	Qualification 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 5.2)

Perform an external short test to verify that the protection circuitry will open and remain open if an external short should occur. Qualification cells, or qualification battery packs with flight-like configuration and protection circuitry shall be used for this test. If flight-like configuration or protection circuitry is not available, contact a Nanoracks mission manager.

The qualification battery pack used for the Over-discharge Test (Section 5.1) 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 6.3).

Pass/Fail Criteria: The protection circuitry shall open within 100ms and remain open for the duration of the short.

STEP 1: Ensure the battery is fully charged and that it retained capacity within 5% to proceed.

STEP 2: Short the circuit using a 50 mΩ ± 10% load.

STEP 3: Use 1 kHz data collection rate for the first 3 seconds.

STEP 4: Record the time at which the protection circuit opens in Table C-15.

STEP 5: Short shall be held for a minimum of 3 hours.

If testing is done on **battery pack**, fill in the first column (Titled: "Cell #1") in the table below:

Table C-15	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)					

Measurement of Open Circuit Voltage (REQ ID 6.1)

STEP 1: Fully charge the acceptance 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.

If testing is done on **battery pack**, fill in the first column (Titled: "Cell #1") in the table below:

Test 1: Pre-Vibration Test

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

Test 2: Intermediate Test:

Return to this section after conducting REQ ID 7.1

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

Test 3: Post Vacuum Test:

Return to this section after conducting REQ ID 7.2

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

Pre/Post-Vibration & Vacuum Test Deviation Analysis:

Return to this section after conducting REQ ID 7.1 and REQ ID 7.2

Table C-6	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Percent Change [%]: $\frac{Test\ 1 - Test\ 2}{Test\ 1} \times 100$					
OCV Pass/Fail (Pass = < 0.1% change)					

Table C-7	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Percent Change [%]: $\frac{Test\ 2 - Test\ 3}{Test\ 2} \times 100$					
OCV Pass/Fail (Pass = < 0.1% change)					

Measurement of Closed-Circuit Voltage (REQ ID 6.2)

Note: it is recommended to capture and record all battery monitoring and power supply data with a DAC system at 1Hz.

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

STEP 2: Setup the programmable load to the standard discharge rate defined in the manufacturer's data sheet.

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

STEP 4: Record the Closed-Circuit Voltage.

If testing is done on **battery pack**, fill in the first column (Titled: "Cell #1") in the table below:

Table C-8	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Closed-circuit voltage [mV]					

Charge Cycling Test (REQ ID 6.3)

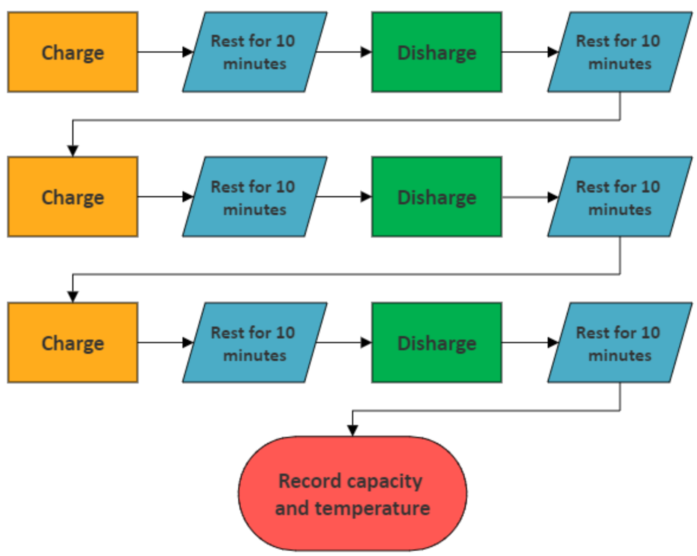
Complete the Charge Cycling Test on all acceptance cells/battery packs **before** the vibration and vacuum test. A **second** charge cycling test should be completed after the vibration and vacuum test. The deviation of data from the second to the first test will be used as a baseline for the pass/fail 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: Fully charge the acceptance cells/battery packs using the manufacturer's recommended charging procedure.

STEP 2: Wait 10 minutes for the cell/battery pack temperature to stabilize.

STEP 3: Discharge the cells/battery packs at the manufacturer's recommended rate until the voltage drops to the manufacturer's minimum recommended voltage.

STEP 4: Record the Capacity and Temperature of the cells/battery packs after 10 minutes from performing all three charge-discharge cycles.



If testing is done on **battery pack**, fill in the first column (Titled: "Cell #1") in the table below:

Test 1: Pre-Vibration Test

Complete this section prior to conducting REQ ID 7.1

Table C-9	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5...
Capacity [mAh]					
Temperature [°C]					

Test 2: Post-Vacuum Test:

Return to this section after conducting REQ ID 7.2

Table C-11	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5...
Capacity [mAh]					
Temperature [°C]					

Pre/Post-Vibration & Vacuum Test Deviation Analysis:

Return to this section after conducting REQ ID 7.1 and REQ ID 7.2

Table C-12	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Percent Change [%]: $\frac{Test\ 1 - Test\ 2}{Test\ 1} \times 100$					
Capacity Pass/Fail (Pass = < 5% change)					

Table C-13	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Percent Change [%]: $\frac{Test\ 2 - Test\ 3}{Test\ 2} \times 100$					
Capacity Pass/Fail (Pass = < 5% change)					

Vibration Test (REQ ID 7.1)

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

STEP 1: Record the pre-vibration OCV (Table C-3 in REQ 6.1) and capacity for each acceptance cell/battery (Table C-9 in REQ 6.3).

STEP 2: Ensure the acceptance battery pack is discharged to less than 10% SOC to proceed.

STEP 3: Fixture the acceptance 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 4: 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 5: Take pictures of the vibration configuration in each of 3 axes.

STEP 6: Vibration test the acceptance cells/battery packs according to the acceleration spectrum profile in Table 7-1 for 60 seconds/axis in each of 3 axes.

STEP 7: Provide the spectrum response plots and configuration picture for each axis in Table C-12 below.

STEP 8: Conduct the OCV and Charge Cycling Tests for each acceptance cell/battery pack again. Record the intermediate OCV and capacity in Tables C-4 and C-10 (Return to REQ 6.1 and 6.3).

Table C-16	
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: Acceptance 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: Ensure the battery is fully charged.

STEP 2: Record the pre-vacuum mass for each acceptance cell/battery pack in the Tables C-17.

STEP 3: Place the acceptance 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 4: 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 5: Maintain vacuum for 6 hours.

STEP 6: Re-pressurize the chamber at a rate of 9 psi/minute until atmospheric pressure is reached.

STEP 7: Visually inspect the cells/battery packs for leaks, deformations, or bulges. Record all findings and provide pictures for both nominal and damages in Table C-18.

STEP 8: Measure the post-vacuum mass, OCV, and capacity of each cell/battery pack and record in the Tables C-17, C-5 and C-11 (Return to REQ 6.1 and 6.3).

If testing is done on **battery pack**, fill in the first column (Titled: "Cell #1") in the table below:

Table C-17	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-18	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5…
Visual inspections of leaks, damage, bulges, etc. Provide pictures.					

Report Summary and Signature

Based on the results of this testing, I, [Payload Developer], conclude that the [Payload] acceptance 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:** ____________