MOTOROLA
Product Testing Services

Lithium Battery Transportation Considerations

Purpose:

To provide the reader a basic understanding of the testing called out in the amendments to the UN Manual of Test and Criteria, section 38.3 Lithium Batteries, and the related Dangerous Goods Regulations as published by the International Air Transport Association (IATA).

Notices to Reader:

This primer is for guidance purposes only and is not intended as either legal advice or a guarantee of compliance. Confirmation of the reader's specific circumstances should be validated through available legal and logistics resources.

The testing referenced and described herein is potentially very dangerous. It is critical that those conducting such testing have both the requisite knowledge and proper equipment before conducting any such testing.

Executive Summary:

On January 1, 2003, a new revision of regulations went into affect governing the shipment of cells and batteries containing lithium. These new regulations are the result of world events concerning the safety aspects of lithium battery shipments. The regulations are found in two main documents:

- UN Manual of Tests and Criteria, Part III, Sub-Section 38.3 Lithium Batteries
- International Air Transport Association (IATA) 2004 Dangerous Goods Regulations, 45th Edition

These new regulations have been adopted and implemented by the International Air Transport Association (IATA). Many countries in Europe and Asia have also adopted the regulations by their respective transportation directorates. The United States Department of Transportation (US DOT) has yet to produce a final ruling while it considers the economic impacts of such requirements on American small business. Despite this delay, a ruling is expected soon. However, the transportation of primary and rechargeable lithium cells and batteries is regulated in the United States in accordance with Part 49 Code of Federal Regulations of the US Hazardous Materials Regulations (HMR).

The regulations address the following main areas:

- Cell and battery testing
- Design similarity (Does a new design require retesting?)
- Package testing
- Labeling
- Emergency contacts & procedures

- Packaging requirements
- Prototype shipments
- Temporary exclusions for products shipping before January 1, 2003
- Exclusions for batteries shipping in or with equipment

US REGULATIONS:

Part 49 Code of Federal Regulations of the US Hazardous Materials Regulations (49 CFR Sections 100-185)

In the United States, lithium primary and rechargeable cells and batteries are regulated in accordance by Part 49 Code of Federal Regulations of the Hazardous Materials Regulations. Under the HMR, 49 CFR parts 171-180, most lithium batteries and equipment packed with lithium batteries are regulated as Class 9 materials. Lithium batteries have to be tested in accordance with the UN Manual of Tests and Criteria, and, amongst other things, must be equipped with an effective means of preventing short circuits, packaged in Packing Group II performance level packaging, and identified on shipping papers and package marking and labels. However, 49 CFR 173.185 contains two significant exceptions for lithium batteries, which is noted in the tables below. We have broken out the exceptions based on the battery type (primary or rechargeable), whether they are assembled or single cells (cell or battery) and if the type of cathode for primary cells (liquid or solid):

Primary Cell, Liquid Cathode

Type	Maximum Lithium Content	Shipping Classification	Testing Required	Packaging Requirements
Cell, Liquid Cathode	Up to 0.5 gram	Exception, Not Class 9	None	No
Cell, Liquid Cathode	0.51 to 5.0 grams	Exception, Not Class 9	UN T1-T8	No
Cell, Liquid Cathode	5.01 grams & greater	Class 9	UN T1-T8	Yes

Primary Cell, Solid Cathode

Type	Maximum Lithium Content	Shipping Classification	Testing Required	Packaging Requirements
Cell, Solid Cathode	Up to 1.0 gram	Exception, Not Class 9	None	No
Cell, Solid cathode	1.01 to 5.0 grams	Exception, Not Class 9	UN T1-T8	No
Cell, Liquid Cathode	5.01 grams & greater	Class 9	UN T1-T8	Yes

Primary Battery, Liquid & Solid Cathode

Type	Maximum Lithium Content	Shipping Classification	Testing Required	Packaging Requirements
Primary Battery	Up to 1.0 gram	Exception, Not Class 9	None	No
Primary Battery	1.01 to 25.0 grams	Exception, Not Class 9	UN T1-T8	No
Primary Battery	25.01 grams or greater	Class 9	UN T1-T8	Yes

Rechargeable Cell

Type	Maximum Lithium Content	Shipping Classification	Testing Required	Packaging Requirements
Rechargeable Cell	Up to 1.5 grams	Exception, Not Class 9	None	No
Rechargeable Cell	1.51 to 5.0 grams	Exception, Not Class 9	UN T1-T8	No
Rechargeable Cell	5.01 grams or greater	Class 9	UN T1-T8	Yes

Rechargeable Battery

Type	Maximum Lithium Content	Shipping Classification	Testing Required	Packaging Requirements
Rechargeable Battery	Up to 8.0 grams	Exception, Not Class 9	None	No
Rechargeable Battery	8.01 to 25.0 grams	Exception, Not Class 9	UN T1-T8	No
Rechargeable Battery	25.01 grams or greater	Class 9	UN T1-T8	Yes

For the purpose of this document, “lithium content” means the mass of lithium in the anode of a lithium metal or lithium alloy cell. An exception is in the case of a lithium-ion cell where the “equivalent lithium content” in grams is to be calculated to be 0.3 times the rated capacity in ampere-hours. The lithium equivalent-content of a battery equals the sum of grams of equivalent-lithium content contained in the component cells of the battery.

Please refer to the Portable Battery Rechargeable Association's Web site for details on 49 CFR Sections 100-185 for Lithium Cell and Battery regulations (http://www.prba.org/docs/Li_Battery_Proposed_Rule.pdf).

INTERNATIONAL REGULATIONS:

International Air Transport Association (IATA), 2004 Dangerous Goods Regulations 45th Edition

This is an excellent reference. It covers all aspects of shipment of dangerous goods by air and is available directly from IATA: www.iataonline.com

Beginning with section 4, Identification, lithium batteries fall under UN ID numbers 3090 and 3091. Reviewing the 3090 Lithium batteries entry:

- It is to be treated as Class 9 (Dangerous Goods) Miscellaneous
- Packaging must meet the requirements of PG II (Packaging Group II). This involves a more heavy-duty package
- For passenger aircraft, the shipment must meet the requirements of packaging instruction 903 and must not exceed 5 kg gross weight
- For cargo only aircraft, the shipment must also meet the requirements of packaging instruction 903, but up to 35 kg gross weight
- The shipment must meet special provisions A45, A88, and A99. These will be discussed in detail in the following sections as they represent the heart of the requirements

Special Provision A45; specific requirements

Type	Maximum Lithium Content	Shipping Classification	Testing Required	Packaging Requirements
Primary Cell	Up to 1.0 gram	Exception, Not Class 9	UN T1-T8	Yes
Primary Cell	1.01 grams & greater	Class 9	UN T1-T8	Yes
Primary Battery	Up to 2.0 grams	Exception, Not Class 9	UN T1-T8	Yes
Primary Battery	2.01 grams or greater	Class 9	UN T1-T8	Yes
Rechargeable Cell	Up to 1.5 grams	Exception, Not Class 9	UN T1-T8	Yes
Rechargeable Cell	1.51 grams or greater	Class 9	UN T1-T8	Yes
Rechargeable Battery	Up to 8.0 grams	Exception, Not Class 9	UN T1-T8	Yes
Rechargeable Battery	8.01 grams or greater	Class 9	UN T1-T8	Yes

1. Lithium metal cells must contain no more than 1 gram of lithium. Lithium-ion cells must contain no more than 1.5 grams of equivalent lithium.
2. Lithium metal batteries must contain no more than 2 grams of lithium. Lithium-ion batteries must contain not more than 8 grams of equivalent lithium.
3. Each cell or battery must meet the test requirements as specified in the UN Manual of Tests and Criteria, Part III, sub-section 38.3 (Lithium batteries). The requirements of this document will be covered in detail in a subsequent section.
4. Cells and batteries must be separated to prevent shorting (for example, in a case where they are installed in equipment), must also be packaged in “strong” packaging.
5. For bulk shipments defined as greater than 24 lithium batteries The following additional requirements must be met:
    a. The package must be marked indicating that it contains lithium batteries and that special emergency procedures must be followed should the package be damaged
    b. Each shipment must include documentation indicating that it contains lithium batteries and that special emergency procedures must be followed in case the package is damaged.
    c. Each package must be of sufficient robustness to tolerate a 1.2 meter drop in any on any side:

- without damage to the contents
- and/or shifting of the contents so as to permit batteries to come in contact with each other
- release of the contents.

d. The package must not exceed 30 kg gross mass, except in the circumstance of lithium batteries packaged with equipment,

6. There is a grandfather clause for batteries and cells that were manufactured before January 1, 2003 and have not completed UN testing requirements. They may continue to be shipped untested until December 31, 2004 provided that the other regulations noted above are met.

Special Provision A88; specific requirements

Special provision A88 covers the shipment of "prototypes," cells or batteries that have not been tested per the UN requirements.

1. Prototype cells are limited to a maximum of 24 units per package.
2. Prototype batteries are limited to a maximum of 12 units per package.
3. Approval from the appropriate authority in the state (country) of origin is required.
4. The cells or batteries must be shipped in a packaging that is a metal, plastic, or plywood and meet the requirements of packaging group 1.
5. Each cell or battery must be individually packed in a two-layer package (unit is put inside the first layer, then that sub-package put inside another layer). The outer package must then be cushioned (non-conductive, non-combustible material).
6. Cells and batteries must be protected against short-circuiting.

Special Provision A99; specific requirements

Special provision A99 covers large shipments. It states that any cell or battery that has passed testing under the UN Manual of Test and Criteria and that meets the requirements of packaging 903 may have a mass greater than 35 kg provided the appropriate authority within the state (country) of origin approves the shipment. To comply with this regulation, a copy of that authorization must accompany the shipment.

Special Provision A48; specific requirements

This special provision only applies to batteries shipped in a piece of equipment. It states that packaging tests are not considered necessary.

UN Manual of Tests and Criteria, Part III, Sub-Section 38.3 (Lithium Batteries)

This document specifies the testing required for lithium cells and batteries. It begins by categorizing such devices as follows:

- Cell or Battery
- Primary or Secondary: Non-rechargeable or rechargeable.
- Large or Small: Large cells are those with a lithium content (or equivalent lithium content) when fully charged is greater than 12 grams. For the case of batteries, the threshold for large is an aggregate lithium content greater than 500 grams.
- Prismatic or Non-Prismatic (Cells Only)

Sample Quantities

Summary of Sample Quantities by Product Category

	Primary (Non-Rechargeable)	**Secondary** (Rechargeable)
Non-Prismatic Cells	40 New	35 New 15 Cycled (50X)
Prismatic Cells	50 New	40 New 20 Cycled (50X)
Battery Packs	8 New	12 New Charged 12 Cycled (50X)

Note the requirement that cells and batteries must have a defined state of charge for each test. Additionally in the case of secondary product, some of the samples will be fresh, while others will be exercised though fifty charge-discharge cycles per the manufactures specifications. It is recommended where possible, rates of 1C for both charge and discharge be employed as the intent is simply to exercise the pack and not to achieve an optimal capacity.

Quantities Per Test

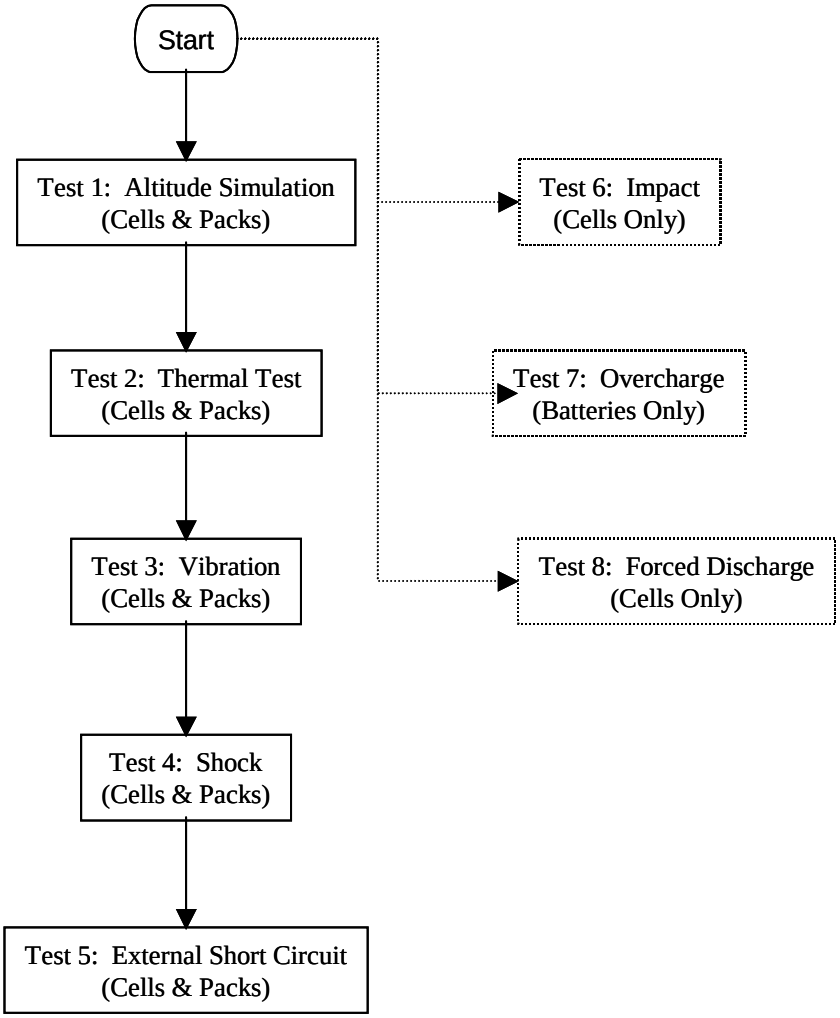
Based upon the category, the guidelines note the required tests and quantities of samples for each test:

		Primary (Non-Rechargeable)	Secondary (Rechargeable)
Cells	Test 1-5	10 Undischarged 10 Discharged	10 New Charged 10 New Discharged
	Test 6	*5/10 Undischarged *5/10 Discharged	*5/10 New @ 50% Charge *5/10 Cycled Discharged
	Test 8	10 Discharged	10 New Discharged 10 Cycled Discharged
Battery Packs	Test 1-5	4 Undischarged 4 Discharged	4 New Charged 4 New Discharged 4 Cycled Charged 4 Cycled Discharged
	Test 7	Not Applicable	**4 New Charged **4 Cycled Charged

** For prismatic cells, ten test cells are required for each state of charge for Test 6.*
*** The portion of test 7 that requires cycled battery packs may be conducted using undamaged cycled battery packs from tests 1-5.*

Test Flow

The heart of the guidelines is the specifications and criteria for the actual tests. These tests are commonly referred to as “T1-T8” as there are a total of eight tests in the regime. Tests 1 through 5 are sequential, e.g. the same group of cells or batteries is exposed to the series of stresses in order. Conversely, test 6 and test 8 are for cells only and are done on independent groups of cells. Test 7 is also done on an independent group of product, but is specific only to battery packs.



For tests 1 through 5, the samples are checked for open-circuit voltage (does not apply to those fully discharged samples), mass, and physical condition. Voltage after testing must be within 90% of the pre-test value. Mass must remain within a specified tolerance based on the weight of the sample.

Test Time
Completion of all aspects of this test regime takes approximately 4 to 6 weeks.

Test Descriptions

The following test descriptions are paraphrased from the UN Guidelines and are included for general reference. Some notes have been added on test implementation for clarification to the reader. As some details have been omitted, the reader is encouraged to refer back to the UN Guidelines.

T1: Altitude Simulation

This test simulates a reduced pressure environment approximately equivalent to an altitude of 50,000 feet. Samples are placed in a vacuum chamber at ambient temperature (20 ± 5°C). The pressure is reduced to 11.6 kPa or less and held for a period of at least 6 hours. Passing criteria for this test is defined as no mass loss (as defined by the required mass tolerance), no leakage, no venting, no disassembly, no rupture, and no fire, and if the open circuit voltage remains 90% or higher of the pre-test voltage (again, the voltage requirement does not apply to fully discharged samples).

T2: Thermal Test

This test is a thermal cycling regime and is conducted in a temperature or temperature/humidity chamber (note that in the case of the latter, the guidelines do not specify any given humidity for conducting the test). Samples are loaded into the chamber, which is programmatically controlled to cycle between –40 degrees C and +75 degrees C (each temperature extreme must be maintained within a ±2°C tolerance). Each temperature extreme is held for a period of 6 hours for small cells or batteries or 12 hours in the case of large cells or batteries. Temperature transitions between the two extremes must be accomplished within a maximum of 30 minutes. The cycle of hot and cold is repeated for a total of 10 times for a total of 130 hours for small cells and batteries. For large batteries, the corresponding exposure time is 250 hours. Additionally for both the large and small case, an additional 24-hour rest period at ambient temperature is specified at the end of the test. Passing criteria is identical to that defined for T1.

T3: Vibration

Best characterized as a relatively long duration, low frequency, sine sweep, this profile is significantly intense for battery products. It is typically executed on an electrodynamic vibration table. The frequency is swept bi-directionally from 7 Hz to 200 Hz, and back to 7 Hz. The rate of change in frequency is logarithmically controlled and is set such that each bi-directional cycle is completed in 15 minutes. Intensity control is done in stages:

Starting Freq	Ending Freq	Method of Control	Value	Units
7 Hz	18 Hz	Acceleration	1	g_n
18 Hz	~ 50 Hz	Displacement	1.6	mm_{pk-pk}
~ 50 Hz	200 Hz	Acceleration	8	g_n

Units are run on a total of twelve bi-directional cycles (three hours) in each of three cardinal axes (x, y, and z). Note that one of the axes must be perpendicular to the terminal face. Passing criteria for T3 is identical to that defined for T1.

T4: Shock

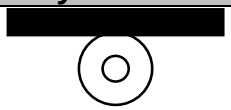
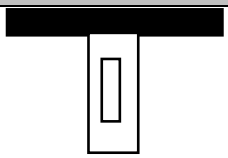
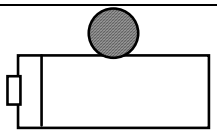
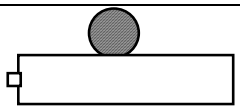
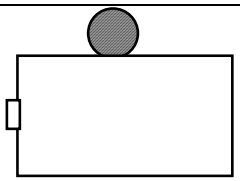
The mechanical shock profile is typically executed using a falling weight shock table. Product is rigidly attached to the top of the table. In the case of small cells and batteries, the system is programmed to generate a half sine pulse with a peak acceleration of 150 g_n and a pulse width of 6 milliseconds. For large cells and batteries, the peak acceleration is reduced to 50 g_n while the pulse width is increased to 11 milliseconds. Samples are subjected to three shocks in each of six cardinal orientations (±x, ±y, ±z). Passing criteria is identical to that defined for T1.

T5: External Short Circuit

In this test, the samples are heated until their case temperature has stabilized to 55 ± 2°C. Once heated, an electrical short circuit (< 0.1 ohms at the test temperature) is applied across the positive and negative terminals of the device while temperature is monitored (or preferably logged). The short is held for 1 hour after the external case temperature re-stabilizes to 55 ± 2°C. Additionally, the unit must be monitored for an additional six hours after the short has been removed. Passing criteria for this test is that the case temperature does not exceed 170°C and there is no disassembly, no rupture, and no fire within the six hours observation period.

T6: Impact (Cells Only)

Cylindrical and prismatic cells are treated differently for this test. Each cell is placed on a stable flat surface. A 15.8 mm diameter curved bar is placed across the center of the cell under testing. A 9.1 kg is dropped from a height of 61 ± 2.5 cm onto the sample. In the case of cylindrical cells, only a single drop is applicable and is done with the long side of the cell parallel to the flat surface. In the case of prismatic cells, a second drop is done on a fresh cell (hence the reason for twice the number samples required for prismatic testing). For this drop, the cell is rotated 90 degrees about it longitudinal axis such that the bar is now placed on the narrow side of the cell. Coin or button cells are laid flat on the surface with the bar placed across their center.

	Cylindrical	Prismatic 1 of 2	Prismatic 2 of 2
Front View			
Side View			

Passing criteria for this test is that the temperature of the cells under test does not exceed 170°C and that there is no disassembly and no fire within six hours of this test.

T7: Overcharge (Battery Packs Only)

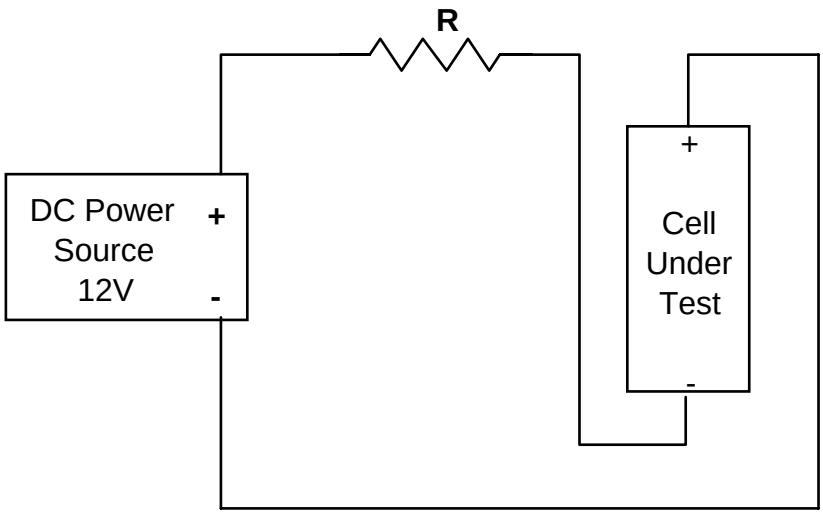
A DC source is used for this test. The charge current is set to a value twice that specified by the battery manufacturer. The voltage is set based on the recommended charge voltage of the pack. If it is not more than 18 Volts, then the lesser of twice the maximum charge voltage or 22 Volts is used as the minimum voltage. If the recommended charge voltage is more than 18 Volts, a minimum voltage of 1.2 times the maximum charge voltage is used.

Samples are mounted in an appropriate safety enclosure at ambient temperature. The overcharge condition is applied for 24 hours. Passing criteria for this test is that no disassembly or fire within seven days of the test.

T8: Forced Discharge (Cells Only)

The cell under test is connected in series with a 12 Volt source. The current of the system has been limited to the maximum discharge current specified by the cell manufacturer using a resistive load. The duration of the discharge is calculated by dividing the rated capacity divided by the initial test discharge current (e.g. the cell's specified maximum discharge current).

The passing criteria for this test are that there is no disassembly and no fire within seven days of the test.



Forced Discharge Test Setup

Observations of effects (Design Considerations)

T1: Altitude Simulation

Soft pack cells (such as lithium polymer) or batteries made from cells of this construction are susceptible to leaks due to swelling stress from the low pressure environment. Such leaks are most common at the area where the contacts protrude through the package.

Battery packs made with soft pack cells may experience stress to the overall package again due to the swelling noted above. If the swelling causes the cells or other components to gain undesired mobility within the package, subsequent mechanically intense stresses will likely cause mechanical breakage of the foil contact material.

Sealed battery packs must be sufficiently robust to pressure. An example of this was a battery package where the end cap popped off during testing due to insufficient adhesive.

T2: Thermal Test

Soft pack cells and batteries made from soft pack cells are again vulnerable due to swelling. The thermal cycling causes repeated inflation and deflation of the package inducing stress on itself and surrounding components in the case of batteries.

The temperature extremes of this test are outside the typical lithium battery specifications (typically –20°C to +60°C). Depending upon the quality of the cells, permanent damage may result and affect either the electrical performance or mechanical integrity of the samples.

Shrink-wrap batteries can also be susceptible to mechanical problems, if a low-temperature shrink-wrap is used that can be degraded by the temperature extremes.

Residual contamination of printed circuit boards can develop into ionic shorts (dendrites) between critical components. This has been seen on safety circuits in lithium-ion batteries resulting in a partial shutdown of the safety circuit and loss of voltage.

T3: Vibration

As noted previously, this is a relatively intense profile. Its test levels and duration are commensurate with military-grade vibration profiles. Marginal quality components and electrical interconnects are extremely vulnerable. Mechanical design is also critical. There are basically two strategies. Critical components may either be rigidly fixed, or they may be permitted to move, but in a design-controlled manner. Both options have advantages and disadvantages, but a discussion of this topic is outside the scope of this article.

T4: Shock

Same comments as T3.

T5: External Short Circuit

It is important to note that the units subjected to this stress have already endured altitude simulation, thermal cycling, vibration, and mechanical shock. This last test is a final check of the electronics or other safety devices. If all works as it should, the safety devices should activate and shut down the pack immediately after the short is applied. Design considerations for this test are simply an effective design to survive the first four tests and a solid safety apparatus that will operate as expected.

T6: Impact

During this test the cell is subjected to an external force concentrated to a specific area. The force is transferred from the weight through the bar onto the cell. This test causes the layers in the cell to be pressed together. This in turn can create an internal short in the cell. Things to consider for design are; can rigidity, layering of materials and amounts of active material.

T7: Overcharge

As with T5, this is a test of the battery pack's electronics under a very significant overcharge condition. If all works as expected, the safety circuit will activate immediately upon the application of the source and completely close off the flow of current. Issues come with marginal components being utilized in the design. By

marginal, I am referencing the requirements of the test, not the design intent of the product. Such components may permit a leakage current that might increase with time or simply be high enough to overcharge the pack's component cells resulting in catastrophic failure of the pack.

T8: Forced Discharge

In primary cells this test can cause plating and dendrites that can cause fire and high temperatures. In rechargeable cells there is also the risk of fire and high temperatures.