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Sub-Committee of Experts on the Transport of Dangerous Goods
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MISCELLANEOUS DRAFT AMENDMENTS TO THE MODEL REGULATIONS ON THE TRANSPORT OF DANGEROUS GOODS

Lithium batteries

Transmitted by the experts from Canada and Japan

Introductory Note: At the 16th session of the subcommittee of Experts on the Transport of Dangerous Goods, which was held in Geneva, 5 – 14 July 1999, the following documents were considered:

ST/SG/AC10/C3/1999/8	(South Africa)
ST/SG/AC10/C3/1999/29	(Japan)
ST/SG/AC10/C3/1999/36	(Canada)
UN/SCETDG/16/INF21	(Canada)

After the discussion of these documents under agenda item 5(b) Lithium batteries, it was agreed that a joint Canada/Japan proposal should be submitted at the 17th session in Geneva in December 1999. In addition, Canada and Japan advised they would invite comments through a Correspondence Working Group.

Although a Correspondence Working Group is not a fully satisfactory process, comments were received. This INF paper is offered as an advance over ST/SG/AC.10/C.3/1999/73 in that it has taken into account all comments received and contains no text in square brackets. The more significant changes are the inclusion of tests on short circuit, overcharge and forced discharge.

This paper contains the result of the intersessional work. It includes revisions to the testing requirements. In addition, a new proposal on a 'quarantine' period has been added to address cases in which there has been severe abuse in handling of a shipment of lithium cells or batteries.

Overview of Proposal: The model regulations establish restrictions on the transport of a substance or article if the substance or article possesses sufficient potential to cause harm to people, property or the environment during normal conditions of transport. The process of determining which restrictions to impose requires an understanding of the potential for harm and of the possible restrictions.

For the case of lithium cells or batteries, an analysis of the potential for harm is set out in Part A of this paper. It includes a listing of credible possible causes or conditions which could lead to a realization of the potential for harm. Tests relative to the identified conditions are described in Part B. The proposition in this paper is that cells or batteries which satisfy appropriate tests and requirements are safe to transport.

Part C of this paper contains the text of the formal proposal being set before the Sub-Committee.

The distinction between lithium-ion and lithium which was introduced in the eleventh revised edition of the Model Regulations has been retained. Primary lithium cells or batteries that contain lithium metal anodes were introduced commercially over twenty years ago and were soon followed by primary lithium cells or batteries that contain lithium alloy anodes. Recent technologies include lithium-ion and lithium polymer cells or batteries that use lithium-ion chemistries. Lithium-ion battery technologies are distinct from lithium metal and lithium alloy technologies in design and in reactivity. Lithium metal and lithium alloy technologies use metallic lithium and lithium alloy as the negative electrode. In contrast, lithium-ion technologies use a lithiated carbon material for the negative electrode and another intercalation compound for the positive electrode. Lithium-ion technologies are less reactive with water and are more thermally stable.

The history of transporting lithium cells and batteries is worth noting. Since the 1970's, over ten billion primary lithium cells/batteries have been transported, and since the early 1990's, over one billion rechargeable lithium cells/batteries utilizing lithium-ion chemistries have been transported.

Part A: Analysis

The potential for harm associated with lithium cells or batteries can be divided into two general groupings. The first is the generation of heat and the second is the release of dangerous substances directly or as a by-product of the burning of substances making up the cell or battery. The substances of concern which could be released directly, or exposed to the prevailing atmospheric conditions, are lithium, lithium-ion, or a flammable or corrosive electrolyte. The substances which could be released indirectly, i.e., as a result of a fire or a release into water, could include hydrogen or the corrosive gases lithium monoxide, lithium hydroxide, or lithium carbonate.

The first goal of this analysis is to identify the conditions whereby one or both of the potentials for harm could be realized. For example, in considering how heat may be generated, one condition whereby this might be realized is through a short circuit.

The second goal of this analysis is to determine what steps could be taken to ensure such conditions were not present and would not arise. Continuing on with the example from the last paragraph, testing could be proposed to determine if a cell or battery has a potential to short circuit during transport. How the result of such a test would be used is set out in Part C.

1. Generation of heat:

Heat may be generated from an intact lithium cell or battery through an internal short circuit, an external short circuit, forced discharging (overdischarge), voltage reversal, charging (a primary cell or battery) or overcharging (a rechargeable cell or battery). Heat may additionally be generated from a cell or battery which is no longer intact by the burning of substances which had been in the cell or battery.

The US Department of Transport published an Advisory Guidance (page 36742 of Volume 64 of the US Federal Register) advising of several cases of fires which started due to sparks or heat generated from cells or batteries of all types including lithium cells or batteries and other than lithium cells or batteries.

In July of 1999 in Edmonton, Canada, a drum which was used to contain used lithium batteries for transport was found to be warm to the touch several days after it had been closed and sealed for transport. The drum had been stored inside a warehouse at a temperature of approximately 22 degrees Celsius during that time. When opened there was a clear indication of the release of internal pressure. Of 107 rectangular shaped lithium batteries ten were visibly deformed from melting, two were split open (one on an edge and one on a flat surface) and another had electrolyte on it. Of 90 cylindrical shaped lithium batteries four were deformed at the ends with one of these opened. The batteries had been removed from service based on time in use. Two adjacent drums with non-lithium batteries, also removed from service based on time in use, showed no problems. It is not known if each of the eleven batteries failed on its own or if some were affected by the actions of others. It is also not known when the initial reaction began but it is believed it developed over a period of days. At the time the drum was opened, approximately one week after it was closed and sealed, some batteries were still generating heat. This incident may indicate a need to develop appropriate provisions pertaining to the transportation of lithium cells and batteries for the purpose of waste disposal and/or recycling.

The Edmonton incident is similar in some respects to the incident in March, 1999 in Los Angeles involving a large number of new lithium cells. After handling abuse and a passage of hours a fire broke out. The incident is under investigation and it is not currently known how many cells contributed to the fire or if there was a propagation from one or more cells to another. Each cell was exempted from regulation due to its small size and consequently each package (containing 1,000 distinct cells) and the pallet load of packages were also exempt from regulation. Nevertheless, the consignor had marked the pallet loads as containing lithium batteries, which alerted the fire department to the proper response to follow.

2. Release of dangerous substances directly or as a by-product of the burning of substances making up the cell or battery:

Lithium, lithium-ion or a flammable or corrosive electrolyte could be released (lithium or electrolyte), or exposed to the prevailing atmosphere (lithium, lithium-ion or electrolyte), if the cell or battery were to be opened from without, e.g., punctured, or were to be opened from within, e.g., ruptured. A special case to consider is the potential for a cell or battery to be opened due to the activity of an adjacent cell or battery which may have ruptured violently or be burning (propagation effect).

The two general problems are summarized in Table 1. Potential causes and possible mitigating conditions are contained in Table 2.

TABLE 1:

Problems	**Consequences**	**Potential Enabling Conditions**
Generation of Heat	Sufficient heat or sparks can be produced to start a fire in nearby combustible material or to burn a person holding the cell or battery. Should the lithium or lithium-ion burn, the fire could attain a very high temperature.	- internal short circuit - external short circuit - forced discharging (over-discharge) - voltage reversal - re-charging (charging and overcharging problems) - burning of substances making up the battery following their release
Release of dangerous substances directly or as a by-product of the burning of substances making up the cell or battery.	Substances that can be directly or indirectly released include an explosive gas, corrosive gases and a flammable or corrosive electrolyte. In addition these materials or parts of the cell or battery can be thrown if the rupture is violent.	cell or battery opened from without due to - puncture - abrasion - tearing or splitting - heat cell or battery opened from within due to - pressure differential (altitude) - pressure differential (heat) - internal pressure due to crushing Note: If the contents of a cell or battery become exposed, a heat source or fire may be generated up to several days after the exposure.

TABLE 2:

Item	Potential Enabling Conditions	Potential Causes	Mitigation For Transport	Related Test (See Part B)
1	internal short circuit	vibration	test to withstand vibration	Test 1
		shock	test to withstand shock	Test 2
		poor internal connections	test connections through expansion and contraction induced by temperature changes, and by alterations in the ratio of internal pressure to external presssure	Tests 3, 4
		deformation of the cell or battery	ability to withstand crush expected in normal conditions of transport; or specify packaging characteristics and handling requirements, including quarantine	Tests 6
2	external short circuit	connection made across the anode and cathode	if transported with any level of charge, specify appropriate packaging to protect against connection of positive and negative electrodes	Test 5
3	forced discharging	not likely during transport	residual effects of this may cause harm during transport	st 8
4	voltage reversal	not likely during transport	not required	nil
5	re-charging	not likely during transport	residual effects of this may cause harm during transport	Test 7
6	burning, external to the cell or battery, of substances making up the cell or battery	possible	protect cell or battery from opening through packaging requirements and handling requirements, including quarantine	Tests 1-6
7	cell or battery opened from without, other than from heat	possible	require ability to withstand puncture, abrasion, tearing, or splitting conditions normal in transport; or specify packaging conditions and handling requirements, including quarantine	Test 4
8	cell or battery opened from without due to heat	possible	require ability to withstand heat arising during normal conditions of transport or from burning or heat associated with an adjacent cell or battery; or specify packaging conditions and handling requirements, including quarantine	Test 3
9	cell or battery opened from within due to pressure differential (altitude)	depressurization of cargo space containing the cell or battery during air transport	require ability to withstand pressure differential of 0.6 bar arising during depressurization of cargo space.	Test 4

10	general abuse	possible	cell or battery not allowed in transport within seven days of involvement in any unusual shock, vibration, abrasion, crushing or heat unless inspected and approved for release.	Quarantine

Part B: Tests

Test No	Name	Comment	Purpose	Pass Requirement
1	Vibration	induce vibrations in each of three mutually perpendicular directions	verify that internal connections are stable and verify the integrity of the cell or battery 'case'	no weight loss, no leakage, no venting, no rupture, no explosion, no fire and no short circuit
2	Shock	induce shock in each of three mutually perpendicular directions	verify that internal connections are stable and verify the integrity of the cell or battery 'case'	no weight loss, no leakage, no venting, no rupture, no explosion, no fire and no short circuit
3	Expansion and contraction	expand and contract the cell or battery by altering its temperature	verify that internal connections are stable and verify the integrity of the cell or battery 'case'	no weight loss, no leakage, no venting, no rupture, no explosion, no fire and no short circuit
4	Pressure differential	induce a relatively high internal pressure.	verify that internal connections are stable and verify the integrity of the cell or battery 'case'	no weight loss, no leakage, no venting, no rupture, no explosion, no fire and no short circuit
5	External Short Circuit	connect the anode with the cathode	verify that the cell or battery can survive an eternal short circuit	no rupture, no fire, and the external temperature of the cell or battery does not exceed 150^0 C
6	Internal Short Circuit	gradually compress the cell or battery up to a pressure limit or until a short circuit occurs	verify that if an internal short circuit is induced that no fire develops	no explosion and no fire
7	Overcharge	simulate overcharge	to determine latent effects of overcharge	no fire or explosion within seven days.

8	Discharge	simulate forced discharge	to determine latent effects of forced discharge	no fire or explosion within seven days.

In addition to the above tests, a Quarantine Condition would be used to ensure an intact but abused cell or battery would not allowed in transport within seven days of involvement in any unusual shock, vibration, abrasion, crushing or heat unless inspected and approved for release.

Tests 1, 2, 3, 4 and 5 would be conducted in sequence on the same cell or battery.
Tests 6, 7 and 8 would be conducted using not otherwise tested cells or batteries.

Part C: The Proposal

Recommendation 1: It is recommended that the Recommendations on the Transport of Dangerous Goods Model Regulations, eleventh revised edition, be amended as follows:

Replace Special Provisions 188, 230 and 287 with:

"Special Provision 188

This entry on lithium cells and batteries applies to cells and batteries containing lithium in any form, including lithium metal and lithium alloy chemistries and lithium-ion chemistries. Lithium metal and lithium alloy chemistries use metallic lithium and lithium alloy, respectively, as the negative electrode. Lithium-ion chemistries use intercalation compounds (intercalated lithium exists in an ionic or quasi-atomic form within the lattice of the electrode material) in the positive and negative electrodes. This entry also applies to lithium polymer cells and batteries, which are regulated either as lithium metal or as lithium-ion cells and batteries, depending on the nature of the material used in the negative electrode.

1. Each lithium cell or battery with a non-zero charge must be designed or packaged in such a way as to prevent an external short circuit under normal conditions of transport.

2. To preclude a violent rupture under normal conditions of transport each lithium cell or battery must incorporate a safety venting device or be designed to preclude such a rupture.

3. Each lithium cell or battery must be packed in strong packagings or be contained in an equivalent case or device (e.g., installed in electronic devices) so as to prevent, under normal conditions of transport, a rupture of the cell or battery or a crushing of the cell or battery sufficient to induce a rupture or an internal short circuit.

4. Each lithium cell or battery is assigned to Category A, B, C or D according to the following table, where Q is the maximum amount of lithium or lithium equivalent content which is expected to be in the cell or battery at some point during its lifetime. Lithium content means the mass of lithium in the cell or battery. Lithium equivalent content means, for a lithium-ion cell or battery, 0.3 times the rated capacity of the cell or battery in ampere-hours, with the result expressed as grams.

	Li content		**Li equivalent content**	
	Cell	**Battery**	**Cell**	**Battery**
Category A			0 g < Q # 1.5 g	0 g < Q # 8 g
Category B			1.5 g < Q # 8 g	8 g < Q # 40 g
Category C	5 g < Q # 15 g	25 g < Q # 750 g	8 g < Q # 25 g	40 g < Q #1000 g
Category D	15 g < Q	750 g < Q	25 g < Q	1 000 g < Q

5. A lithium cell or battery in Category A may be transported without meeting any requirements of these regulations other than paragraphs 1, 2, 3 and 10 of this special provision.

6. A lithium cell or battery in Category B may be transported without meeting any requirements of these regulations other than paragraphs 1, 2, 3 and 10 of this special provision provided its cell or battery type has been tested according to sub-section 38.3 of the Manual of Tests and Criteria and has passed the tests.

7. A lithium cell or battery in Category C or in Category D may be transported provided its cell or battery type has been tested according to sub-section 38.3 of the Manual of Tests and Criteria and has

passed the tests. In this case the primary class is Class 9.

8. New, uncycled and fully discharged lithium ion cells or batteries are not subject to these Regulations if:

(a) the electrolyte does not meet the definition of any class or division in these Regulations; or

(b) the electrolyte meets the definition of a class or division in these Regulations but the electrolyte will not flow from a ruptured or cracked case and there is no free liquid to flow.

9. No cells or batteries may be transported within seven days of an event which may have damaged the cell or battery or its protective features unless the cell or battery is visually inspected and its voltage is verified as not having changed due to the event.

10. A consignment of lithium or lithium-ion cells or batteries in Category A or B which exceeds 500 kg and is to be delivered to one destination may be transported provided that the shipping pallet containing the consignment is marked on all four sides with a label that contains the words "Lithium Batteries" and appropriate safety warnings in English and Japanese. The dimensions of the label shall be the size of A4 or A5 paper. The typeface of each word in the label shall be 3-5 cm in height.

11. A lithium cell or battery which does not satisfy the provisions of paragraph 5, 6, 7, 8, 9 or 10 may only be transported with special authorization granted by the competent authority.

12. A cell or battery type may be exempted by the competent authority from having to satisfy the requirements of testing provided the cell or battery type will be transported under conditions which will provide, in the opinion of the competent authority, a level of safety equivalent to that which would be attained had the tests been passed."

Recommendation 2 :

Amend sub-section 38.3 of the Manual of Tests and Criteria to read:

" **38.3.1** This section presents the tests required under special provision 188 of the Model Regulations.

38.3.2 This section presents definitions for special provision 188.

Battery means two or more cells, including case, terminals, and marking.

Cell means a single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across its two terminals. Under these Regulations, to the extent the encased electrochemical unit meets the definition of "cell" herein, it is a "cell," not a "battery," regardless of whether the unit is termed a "battery" or a "single cell battery" outside of these Regulations.

Component cell means a cell contained in a battery.

Cycle means one sequence of fully charging and fully discharging a rechargeable cell or battery.

Effluent means a liquid or gas released when a cell or battery vents or leaks.

Explosion means an instantaneous release wherein solid matter from any part of the cell or battery is propelled to a distance greater than 25 cm away from the cell or battery.

Fire means combustion of cell or battery components with emission of flame.

First cycle means the initial cycle following completion of all manufacturing processes.

Fully charged means a rechargeable cell or battery which has been electrically charged to its rated capacity.

Fully discharged means either: (a) a primary cell or battery which has been electrically discharged to remove 100% of its rated capacity; or (b) a rechargeable cell or battery which has been electrically discharged to a load voltage of less than 2/3 of its starting open circuit voltage.

Leakage means the unplanned escape of electrolyte, gas, or other flowable material from a cell or battery.

Lithium content is applied to lithium metal and lithium alloy cells and batteries, and for a cell means the mass of lithium in the negative electrode of a lithium metal or lithium alloy cell when undischarged or fully charged. The lithium content of a battery equals the sum of the grams of lithium content contained in the component cells of the battery.

Lithium-equivalent content is applied to lithium-ion cells and batteries, and for a cell is measured as 0.3 times the rated capacity of the cell in ampere-hours, with the result expressed in grams. The lithium-equivalent content of a battery equals the sum of the grams of lithium-equivalent content contained in the component cells of the battery.

Lithium-ion cell or battery means a rechargeable electrochemical cell or battery in which the positive and negative electrodes are both intercalation compounds (intercalated lithium exists in an ionic or quasi-atomic form within the lattice of the electrode material) constructed with no metallic lithium in either electrode. A lithium polymer cell or battery that uses lithium-ion chemistries, as described herein, is regulated as a lithium-ion cell or battery.

Primary means a cell or battery which is not designed to be electrically charged or recharged.

Protective devices means devices such as fuses, diodes and current limiters which interrupt the current flow, block the current flow in one direction or limit the current flow in an electrical circuit.

Rated capacity means the capacity, in ampere-hours, of a cell or battery as measured by subjecting it to a load, temperature and voltage cutoff point specified by the manufacturer.

Rechargeable means a cell or battery which is designed to be electrically recharged.

Rupture means the mechanical failure of a cell container or battery case induced by an internal or external cause, resulting in exposure or spillage but not ejection of solid materials.

Series ST tests are the particular series of tests for cells and batteries set forth in section 38.3.4, below.

Short circuit means a direct connection between positive and negative terminals of a cell or battery that provides a virtual zero resistance path for current flow.

Type means a particular electrochemical system and physical design of cells or batteries.

Undischarged means the cell or battery is at the maximum electrical potential it will experience during normal usage.

Venting means the release of excessive internal pressure from a cell or battery in a manner intended by design to preclude rupture or explosion.

Weight loss means a loss of weight that exceed the values in Table 1, below. In order to quantify the weight loss, the following procedure is provided. Weight loss = $(W_1 - W_2)/W_1$ x 100% where W_1 is the weight before the test and W_2 is the weight after the test. When weight loss does not exceed the values in Table 1, it shall be considered as "no weight loss."

Table 1 – Weight loss limits

Weight *W* of cell or battery	**Weight loss limit**
W # 1 g	0.5 %
1 g < W # 5 g	0.2 %
W > 5 g	0.1%

38.3.3 When a cell or battery type is to be tested under this sub-section, the number and condition of cells and batteries of each type to be tested are as follows:

(a) When testing primary cells and batteries under Tests ST.1 to ST.5 the following shall be tested:

(i) ten cells in undischarged states,

(ii) ten cells in fully discharged states,

(iii) four batteries in undischarged states, and

(iv) four batteries in fully discharged states;

(b) When testing rechargeable cells and batteries under Tests ST.1 to ST.5 the following shall

be tested:

(i) ten cells, at first cycle, in fully charged states,

(ii) ten cells, at first cycle, in fully discharged states,

(iii) four batteries, at first cycle, in fully charged states,

(iv) four batteries, at first cycle, in fully discharged states,

(v) four batteries after fifty deep cycles ending in fully charged states, and

(vi) four batteries after fifty deep cycles ending in fully discharged states.

(c) When testing primary and rechargeable cells under the ST.6 test, the following shall be tested:

(i) for primary cells, five cells in undischarged states and five cells in fully discharged states,

(ii) for component cells of primary batteries, five cells in undischarged states and five cells in fully discharged states,

(iii) for rechargeable cells, five cells at first cycle in the state of charge when transported (normally less than 50%) and five cells after 50 deep cycles ending in fully discharged states, and

(iv) for component cells of rechargeable batteries, five cells at first cycle in the state of charge when transported (normally less than 50%) and five cells after 50 deep cycles ending in fully discharged states.

In the case of prismatic cells, ten test cells are required for each of the states of charge being tested, instead of the five described above, in order that the procedure can be carried out on five cells along the longitudinal axes and, separately, five cells along the other axes. In every case, the test cell is only subjected to one crush.

(d) When testing rechargeable batteries under the ST.7 test, the following shall be tested:

(i) four rechargeable batteries, at first cycle, in fully charged states, and

(ii) four rechargeable batteries after fifty deep cycles, ending in fully charged states.

(e) When testing primary cells, primary batteries and rechargeable batteries under the ST.8 test, the following shall be tested:

(i) ten primary cells in fully discharged states;

(ii) four primary batteries in fully discharged states;

(iii) four rechargeable batteries, at first cycle, in fully discharged states, and

(iv) four rechargeable batteries after fifty deep cycles ending in fully discharged states.

38.3.4 Procedure and General Pass Conditions

(a) Each cell and battery type must be subjected to tests ST.1 to ST.5 in sequence.

(b) (i) If the cell or battery ruptures or a short circuit develops before Test ST.5 is commenced that type of cell or battery fails the tests. A short circuit is deemed to have occurred during one of Test ST.1 to ST.4 if the open circuit voltage of the cell or battery after the test is less than 90% of its voltage immediately prior to the test. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

(ii) If the mass of the cell or battery declines, from the commencement of test ST.1 to the conclusion of test ST.5 by more than the weight loss limit shown in Table 1, that type of cell or battery fails the tests.

38.3.4.1 Test ST.1: Vibration

38.3.4.1.1 *Purpose*

This test simulates vibration during transportation.

38.3.4.1.2 *Test procedure*

Test cells and batteries shall be subjected to simple harmonic motion with an amplitude of 0.8 mm (1.6 mm total maximum excursion). The frequency shall be varied at a rate of 1 Hz/minute between 10 Hz and 55 Hz, and return in no less than 90 minutes and no more than 100 minutes. Each test cell and battery shall be tested in three mutually perpendicular directions.

38.3.4.1.3 *Requirement*

Cells and batteries meet this requirement if they satisfy the general pass conditions of 38.3.4 and there is no weight loss, no leakage, no venting, no explosion, and no fire, and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.2 Test ST.2: Shock

38.3.4.2.1 *Purpose*

This test simulates rough handling during transportation.

38.3.4.2.2 *Test procedure*

Test cells and batteries shall be secured to the testing machine by means of a rigid mount which will support all mounting surfaces of each test battery. Each test cell and battery shall be subjected to a total of three shocks of equal magnitude. The shocks shall be applied in each of three mutually perpendicular axes. For each shock, the test cell and battery shall be accelerated in such a manner that during the first three milliseconds the minimum average acceleration is 75 g_n. The peak acceleration shall be between 125 g_n and 175 g_n.

However, for Category D cells exceeding 750 g and Category D batteries, there is no three millisecond requirement, the peak acceleration shall be not less than 50 g_n and the peak acceleration shall be attained within 11 milliseconds.

38.3.4.2.3 *Requirement*

Cells and batteries meet this requirement if they satisfy the general pass conditions of 38.3.4 and there is no weight loss, no leakage, no venting, no explosion, and no fire, and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.3 Test ST.3: Expansion and Contraction

38.3.4.3.1 *Purpose*

This test assesses cell and battery seal integrity, and internal electrical connections. The test is conducted using rapid and extreme temperature changes.

38.3.4.3.2 *Test procedure*

Test cells and batteries shall be stored for six hours at a temperature of (75 ± 2)E C, followed by storage for six hours at a temperature of (-20 ± 2)E C, followed by storage for at least 24 hours at ambient temperature. The maximum time for transfer to each temperature shall be ten minutes. Each test cell and battery must undergo this procedure five times.

In the case of Category D cells or batteries, the maximum time for transfer to each temperature shall be 120 minutes.

38.3.4.3.3 *Requirement*

Cells and batteries meet this requirement if they satisfy the general pass conditions of 38.3.4 and there is no leakage, no venting, no explosion, and no fire, and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.4 Test ST.4: Pressure Differential

38.3.4.4.1 *Purpose*

This test simulates air transportation under low pressure conditions.

38.3.4.4.2 *Test procedure*

Test cells and batteries shall be stored at a pressure of 11.6 kPa or less for at least six hours and at an ambient temperature.

38.3.4.4.3 *Requirement*

Cells and batteries meet this requirement if they satisfy the general pass conditions of 38.3.4 and there is no weight loss, no leakage, no venting, no explosion, and no fire, and if the open circuit voltage of each test cell or battery after testing is not less than 90% of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

38.3.4.5 Test ST.5: External Short Circuit

38.3.4.5.1 *Purpose*

This test simulates an external short circuit.

38.3.4.5.2 *Test procedure*

The cell or battery to be tested shall be stabilized at 55 ± 2E C and then subjected to a short circuit condition with a total external resistance of less than 0.1 ohm at 55 ± 2E C. This short-circuit condition is continued for at least one hour after the cell or battery case temperature has returned to 55 ± 2E C. The cell or battery must be observed for a further six hours for the test to be concluded.

38.3.4.5.3 *Requirement*

Cells and batteries meet this requirement if they satisfy the general pass conditions of 38.3.4 and their external temperature does not exceed 150° C and there is no explosion and no fire within six hours of this test.

38.3.4.6 Test ST.6 Internal Short Circuit

38.3.4.6.1 *Purpose*

This test simulates an internal short circuit.

38.3.4.6.2 *Test procedure*

The cell or component cell to be tested shall be crushed between two flat surfaces. The force shall be applied by a vice or by a hydraulic ram with a 32 mm diameter piston. The crushing shall be continued until

(1) the cell or component cell voltage drops abruptly or is reduced to at least one third, or

(2) a pressure reading of either 17 Mpa (an applied force of approximately 13kN) or a maximum force of 1000 times the weight of the cell is attained, whichever is greater.

Once the voltage drops abruptly or is reduced to at least one third, or the maximum pressure has been attained, the pressure shall be released.

A cylindrical cell or component cell shall be crushed with its longitudinal axis parallel to the flat surfaces of the crushing apparatus. A prismatic cell or component cell shall be crushed by applying the force in the direction of one of the two axes perpendicular to its longitudinal axis, and, separately, with another test cell or component cell, by applying the force in the direction of the other one of these two axes. A button/coin cell or component cell shall be crushed by applying force on its flat surfaces.

Each cell or component cell used in the test shall only be crushed once.

38.3.4.6.3 *Requirement*

The type of cell or component cell under test fails the test if any cell or component cell ignites or explodes. Cells and batteries meet this requirement if their external temperature does not exceed 150° C and there is no explosion and no fire within six hours of this test.

38.3.4.7 Test ST.7: Overcharge

38.3.4.7.1 *Purpose*

This test evaluates the ability of a rechargeable battery to withstand an overcharge condition.

38.3.4.7.2 *Test procedure*

The charge current shall be twice the manufacturer's recommended continuous charge current. The maximum voltage of the test shall be two times the maximum charge voltage of the battery, and shall not exceed 20 V.

Tests are to be conducted at an ambient temperature. The duration of the test shall be 24 hours.

38.3.4.7.3 *Requirement*

Rechargeable batteries meet this requirement if there is no explosion and no fire within seven days of the test.

38.3.4.8 Test ST.8: Forced Discharge

38.3.4.8.1 Purpose

The test evaluates the ability of a primary cell and battery, or a rechargeable battery, to withstand a forced discharge condition.

38.3.4.8.2 Test Procedure

For primary cells and batteries, test cells and batteries are connected in a series string with undischarged primary cells and batteries of the same type. For primary cells with nominal voltage of less than 2 volts and primary batteries containing component cells with a nominal voltage of less than 2 volts each, the total number of primary cells and batteries, including the test primary cell or battery, is defined by "18 volts/V", rounded up to the nearest whole number where V is the nominal voltage of one primary cell or battery. For primary cells with nominal voltage of 2 volts or more, and primary batteries containing component cells with nominal voltage of 2 volts or more, the total number of primary cells or batteries in the series string, including the test primary cell or battery, is defined by "12volts/V", rounded up to the nearest whole number, where V is the nominal voltage of one primary cell or battery. A resistive load is added to the series string of primary cells or batteries. The resistive load is such that the average current draw is the same as the maximum discharge current specified by the manufacturer. When this average current draw cannot be achieved employing this test procedure, the current draw required is the maximum current attainable according to this test procedure at the ambient temperature at which the test is performed. However, when it is very difficult to specify the above load resistance, this test can also be performed by the constant current discharge method at the current specified as per the above, by using an external D.C. power source. The current is closed, discharging the test primary cell or battery. The test is continued from the time the circuit is closed until the voltage of the series string reaches 10% of its original open circuit voltage or 24 hours, whichever is longer.

For a primary battery, the battery shall be discharged using a constant current of 0.2 I_t(A) until the battery circuitry terminates discharge or until the battery voltage reaches 0 V at an ambient temperature. (I_t(A) = Capacity (Ah)/1(hr).)

38.3.4.8.3 Requirement

Test primary cells and batteries, and rechargeable batteries, meet this requirement if there is no explosion and no fire within seven days of the test.