JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL 1973:2022

STANDARD FOR SAFETY

Batteries for Use in Stationary and Motive Auxiliary Power Applications

ANSI/UL 1973-2022

Annex E (Normative)

Cell Test Program

E1 General

E1.1 The following shall be used to evaluate lithium ion cells or other secondary lithium cells.

E1.2 Samples used for testing shall be representative of production. The number of samples used for each test and the pass/fail criteria for testing is outlined in Table E.1. As an alternate, the lithium ion cell test program outlined in Sections E10 – E11 may be used.

E1.3 Prior to conditioning in E1.4, two samples from the total set of samples as representative samples shall be subjected to the capacity check per E2.2 to confirm the capacity of the samples is correct.

E1.4 Prior to testing, the samples shall be conditioned by first discharging them down to the manufacturer's specified end point voltage and then charging them to the manufacturer's specified upper limit charging voltage using the manufacturer's specified maximum charging current. Samples shall be charged at the upper temperature limit of the charging operating region and the lower limit of the charging operating region for those tests as identified in Table E.1. During charging, a minimum of one temperature is measured on the surface of the cell centered on the cell. For prismatic cells, this would be on the largest flat surface.

Table E.1
Test Samples and Results Criteria

Test	Section	Number of samples conditioned at upper limit temperature per E1.4[a]	Number of samples conditioned at lower limit temperature per E1.4[a]	Total samples tested	Compliance[c]
Short Circuit	E3	1	1	2	No: fire or explosion
Cell Impact	E4	1	1	2	No: fire or explosion
Drop Impact	E5	–	–	2	No: fire or explosion
Heating	E6	1	1	2	No: fire or explosion
Overcharge	E7	1	1	2	No: fire or explosion
Forced Discharge	E8	–	–	2	No: fire or explosion
Projectile	E9	–	–	2 (4)	No: projectiles in accordance with E9.2.

[a] The upper limit temperature, lower limit temperature, upper limit charging voltage, maximum charging current, discharge current and end point voltage parameters used for conditioning of cell samples are specified by the cell manufacturer.

[b] Those cells not complying with the Projectile Test of E9 can be used in batteries that comply with the Thermal Exposure for Explosion Hazards Test of Section 41.

[c] Test results for compliance criteria is defined in E12.2.

E1.5 Some lithium cells are capable of exploding when the tests described in this Annex are conducted. It is important that personnel be protected from the flying fragments, explosive force, sudden release of heat, and noise that results from such explosions. The test area shall be well ventilated to protect personnel from possible harmful fumes or gases.

E1.6 As an additional precaution, the temperatures on the surface of the cell casings shall be monitored in accordance with E1.7 during the tests described in this Annex. All personnel involved in the testing of lithium cells shall be instructed never to approach a lithium cell while the surface temperature exceeds 90 °C (194 °F) and not to touch the lithium cell while the surface temperature exceeds 45 °C (113 °F).

E1.7 In accordance with E1.6, the surface temperatures of the cell casing shall be measured as follows:

a) By thermocouples consisting of wires not larger than 0.21 mm^2 (24 AWG) and not smaller than 0.05 mm^2 (30 AWG) and a potentiometer-type instrument; and

b) The temperature measurements on the cells shall be made with the measuring junction of the thermocouple held tightly against the metal casing of the cell.

Exception: Placing the thermocouple on a thin piece of paper or label is an acceptable practice.

E1.8 For protection, the Projectile Test in E9 shall be conducted in a room separate from the observer or within an appropriate containment chamber.

E2 Preconditioning and Capacity Check

E2.1 Preconditioning

E2.1.1 The charge/discharge cycling preconditioning in E2.1.2 shall be done before testing and conducted on secondary lithium metal (i.e. lithium metal anode) cells. Lithium ion cells need not be subjected to charge/discharge cycle preconditioning.

E2.1.2 Secondary lithium metal (i.e. lithium metal anode) cells shall be conditioned at 25 °C ±5 °C (77 °F ±9 °F). The cells shall be continuously cycled as specified by the manufacturer. The specification shall be such that the full rated capacity of the cell is utilized and the number of cycles accumulated shall be at least equal to 25 % of the advertised cycle life of the cell or cycled continuously for 90 days, whichever is shorter. Cycling shall be done either individually or in groups. Cells shall be recharged prior to testing.

E2.2 Capacity check

E2.2.1 Prior to conducting testing, the capacity of the lithium ion and lithium metal cells to be tested shall be checked in accordance with E2.2.2 – E2.2.5 by selecting two samples from the total set of samples.

E2.2.2 For secondary lithium metal (i.e. lithium metal anode) cells, this capacity check shall be conducted on preconditioned secondary lithium metal cells per E2.1.

Exception : For secondary lithium metal cells subjected to preconditioning per E2.1, the capacity check may be conducted during the preconditioning of these secondary lithium metal cells by checking the discharged capacity during the first few cycles. This capacity confirmation may be done in the manufacturer shipping inspection by checking the capacity discharge curve shipped with the samples.

E2.2.3 The cell shall be discharged at 25 °C ±5 °C (77 °F ±9 °F) at a constant current of 0.2C rate, down to a specified end of discharge voltage. The cell shall then be charged in a room ambient temperature, 25 °C ±5 °C (77 °F ±9 °F), at charging parameters specified by the manufacturer until fully charged. The cell shall then be allowed to stabilize at room ambient per 6.52.

E2.2.4 With the cell in the fully charged condition, the cell shall be discharged at a constant current discharge in accordance with the cell manufacturer's specifications down to the end of discharge voltage. The duration of the discharge shall be monitored and the measured capacity of the cell shall be calculated to three significant figures.

E2.2.5 For cells to be used for the test program outlined in this Annex, their measured capacity shall equal or exceed the rated specifications. All samples shall be subjected to the capacity check test if any representative sample does not meet this criteria. The cells not meeting this criteria shall be excluded from testing.

E3 Short Circuit

E3.1 Fully charged, conditioned cells are stored in an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) until their casing reaches ambient temperature, and then subjected to a short circuit condition using an external resistance of ≤ 20 mΩ.

E3.2 The external resistance shall be applied to the cell terminals for 7 h or until temperatures on the cell cool to within ±10 °C (18 °F) of ambient conditions.

E3.3 The sample and compliance criteria shall be in accordance with Table E.1.

E4 Cell Impact

E4.1 Fully charged, conditioned cells shall be subjected to an impact test as outlined in E11.4. The cells shall be at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) prior to testing.

E4.2 The sample and compliance criteria shall be in accordance with Table E.1.

E5 Drop Impact

E5.1 Fully charged cells shall be dropped three times from a height of 1 m (3.3 ft) onto a flat concrete or metal surface. The cells shall be at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) prior to testing.

E5.2 The cells shall be dropped in a manner that the impacts occur in random orientations.

E5.3 After completion of the impacts, the cells shall be subjected to a minimum one hour observation period before being examined.

E5.4 The sample and compliance criteria shall be in accordance with Table E.1.

E6 Heating

E6.1 Fully charged, conditioned cells shall be subjected to a heating test as outlined in E11.7.

E6.2 The sample and compliance criteria shall be in accordance with Table E.1.

E7 Overcharge

E7.1 Fully charged conditioned cells shall be discharged in accordance to manufacturer's specifications down to the specified end point voltage. The test is conducted in an ambient of 25 °C ±5 °C (77 °F ±9 °F) and with the cell casing at an ambient of 25 °C ±5 °C (77 °F ±9 °F) at the start of the test. The voltage and temperature of the cell shall be monitored during the test.

E7.2 The cells are charged with a constant current at the maximum specified charge current until the voltage of the cell reaches 120 % of the maximum specified charge voltage value or 130 % State of Charge (SOC), whichever is reached first. The charge is then terminated while the cell temperature continues to be monitored. The test is concluded when the cell temperature drops and returns to ±10 °C (18 °F) of the test ambient.

E7.3 The sample and compliance criteria shall be in accordance with Table E.1.

E8 Forced Discharge

E8.1 Fully charged cells shall be discharged in accordance to manufacturer's specifications down to the specified end point voltage. The test is conducted in an ambient of 25 °C ±5 °C (77 °F ±9 °F).

E8.2 The discharged cells are subjected to a forced discharge at a constant current 1.0 I_t A for 90 min with the discharge voltage limit not to exceed the numerical value of the upper limit charging voltage specified for the cell. If the discharge voltage limit is reached before the 90 min, the cell shall be discharged at a constant voltage discharge equal to the manufacturer's determined low voltage cutoff, with the current decreasing as necessary until the 90 min time period is reached.

E8.3 The sample and compliance criteria shall be in accordance with Table E.1.

E9 Projectile

E9.1 Two fully charged cells shall be subjected to the projectile test criteria as outlined in E11.10.

E9.2 As a result of the projectile test, the cells there shall not be an explosion of the cells resulting in projectiles with sufficient force to penetrate the test cage screen.

ALTERNATIVE TEST PROGRAM FOR SECONDARY LITHIUM CELLS

E10 General

E10.1 This cell test program may be used to evaluate secondary lithium cells for use in battery systems that comply with this standard instead of the test program outlined in Sections E1 – E9. Samples used for testing shall be representative of production. The number of samples used for each test and the pass/fail criteria for testing shall be as outlined in Table E.2.

E10.2 Some lithium cells are capable of exploding when the tests described below are conducted. It is important that personnel be protected from the flying fragments, explosive force, sudden release of heat, and noise that results from such explosions. The test area shall be well ventilated to protect personnel from possible harmful fumes or gases.

E10.3 As an additional precaution, the temperatures on the surface of the cell casings shall be monitored in accordance with E10.4 during the tests described below. All personnel involved in the testing of lithium cells shall be instructed never to approach a lithium cell while the surface temperature exceeds 90 °C (194 °F) and not to touch the lithium cell while the surface temperature exceeds 45 °C (113 °F).

E10.4 In accordance with E10.3, the surface temperatures of the cell casing shall be measured as follows:

a) By thermocouples consisting of wires not larger than 0.21 mm^2 (24 AWG) and not smaller than 0.05 mm^2 (30 AWG) and a potentiometer-type instrument; and

b) With the measuring junction of the thermocouple held tightly against the metal casing of the cell.

Exception: Placing the thermocouple on a thin piece of paper or label is an acceptable practice.

E10.5 For protection, the Projectile Test in E11.10 shall be conducted in a room separate from the observer or within an appropriate containment chamber.

E10.6 Secondary lithium metal (i.e. lithium metal anode) cells shall be conditioned in accordance with E2.1 prior to the testing.

E10.7 The capacity of the samples for all lithium chemistries shall be confirmed in accordance with E2.2 prior to testing.

E11 Tests

E11.1 Short-circuit test

E11.1.1 Each test cell shall be short-circuited by connecting the positive and negative terminals with a resistance load of less than or equal to 20 mΩ. The temperature of the cell case shall be recorded during the test. The short circuit shall be applied until the cell case temperature has returned to ±10 °C (±18 °F) of ambient temperature.

E11.1.2 Tests shall be conducted at 55 ±5 °C (131 ±9 °F). The samples shall reach equilibrium at 55 ±5 °C (131 ±9 °F), as applicable, before the terminals are connected.

E11.1.3 The sample and compliance criteria shall be as noted in Table E.2.

E11.2 Overcharge test

E11.2.1 The cell shall be subjected to the overcharge test as outlined in E11.2.2.

E11.2.2 A cell shall be subjected to a constant current charge at the maximum specified charging current until the cell reaches 120 % of its maximum specified charge voltage limit or it reaches 130 % SOC, whichever comes first.

E11.2.3 The sample and compliance criteria shall be in accordance with Table E.2.

E11.3 Crush test

E11.3.1 A cell shall be subjected to a bar crush using a bar with a 15-cm (5.9-in) diameter. The force for the crushing shall be applied by a hydraulic ram or similar force mechanism. The force shall be applied until one of the following in (a) – (c) occurs. Once the maximum force has been obtained, the force shall be released.

a) A voltage (OCV) drop of one-third of the original cell voltage occurs;

b) A deformation of 15 % or more (in the direction of the crush) of initial cell dimension occurs; or

c) A force of 1000 times the weight of cell is reached.

E11.3.2 A cylindrical, pouch or prismatic cell shall be crushed with its longitudinal axis parallel to the crushing apparatus. Each sample shall be subjected to a crushing force in only one direction and the crush shall be conducted only on the wide side of a pouch or prismatic cell. Separate samples shall be used for each test. See also, E11.3.3 and E11.3.4.

E11.3.3 With reference to E11.3.2, for other than pouch cells, the crush shall be applied in the center of the cells.

E11.3.4 With reference to E11.3.2, for pouch type cells, the crushing force shall be applied on the casing near where the cell tabs exit. If the positive and negative tabs are on opposite sides, the crush force shall be applied on the casing near where the negative tab exits.

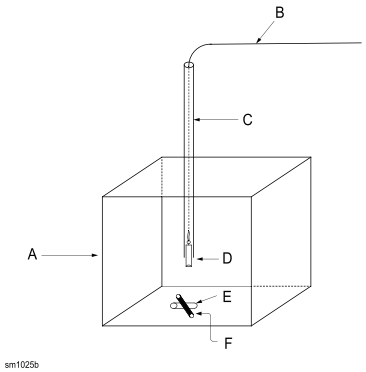
E11.3.5 sample and compliance criteria shall be in accordance with Table E.2.

E11.4 Impact test

E11.4.1 A cell shall be placed on a flat surface. A 15.8 ±0.1-mm (5/8 ±0.004-in) diameter bar shall be placed across the center of the sample. A 9.1 ±0.46-kg (20 ±1-lb) weight shall be dropped from a height of 610 ±25 mm (24 ±1 in) onto the sample. See Figure E.1.

Figure E.1

Impact test



A – Steel impact chamber (hinged door not shown)

B – Weight support rope

C – Containment tube

D – 9 kg (20 lb) weight

E – Cell

F – 16-mm (5/8-in) diameter bar

E11.4.2 The cell shall be impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8-mm (5/8-in) diameter curved surface lying across the center of the test sample. For prismatic and pouch cells, only the wide side shall be impacted. Each sample shall be subjected to only a single impact. Separate samples shall be used for each test.

E11.4.3 The sample and compliance criteria shall be in accordance with Table E.2.

E11.5 Shock test

E11.5.1 The cell shall be secured to the testing machine by means of a rigid mount which supports all mounting surfaces of the cell. Each cell shall be subjected to a total of three shocks of equal magnitude. The shocks shall be applied in each of three mutually perpendicular directions unless it has only two axes of symmetry in which case only two directions shall be tested. Each shock shall be applied in a direction normal to the face of the cell.

E11.5.2 For each shock, the cell shall be accelerated in such a manner that during the initial 3 ms the minimum average acceleration is 75 g (where g is the local acceleration due to gravity). The peak acceleration shall be between 125 and 175 g. Cells shall be tested at a temperature of 25 ±5 °C (77 ±9 °F).

E11.5.3 The sample and compliance criteria shall be in accordance with Table E.2.

E11.6 Vibration test

E11.6.1 A cell shall be subjected to simple harmonic motion with an amplitude of 0.8 mm (0.03 in) [1.6 mm (0.06 in) total maximum excursion].

E11.6.2 The frequency shall be varied at the rate of 1 Hz/min between 10 and 55 Hz, and return in not less than 90 nor more than 100 min. The cell shall be tested in three mutually perpendicular directions. For a cell that has only two axes of symmetry, the cell shall be tested perpendicular to each axis.

E11.6.3 At the end of the vibration conditioning, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.

E11.6.4 The sample and compliance criteria shall be in accordance with Table E.2.

E11.7 Heating test

E11.7.1 A cell shall be heated in a gravity convection or circulating air oven with an initial temperature of 25 ±5 °C (77 ±9 °F). The temperature of the oven shall be raised at a rate of 5 ±2 °C (9 ±3.6 °F) per minute to a temperature of 130 ±2 °C (266 ±3.6 °F) and remain for 10 min. For cells specified for temperatures above 100 °C (212 °F), the conditioning temperature shall be increased from 130 ±2 °C (266 ±3.6 °F), to 30 ±2 °C (86 ±3.6 °F) above the manufacturers maximum specified temperature.

Exception: For cells whose weight is greater than 500 g (1.1 lbs), the maximum temperature of the heating test shall be held for 30 min rather than 10 min.

E11.7.2 The sample shall return to room temperature, 25 ±5 °C (77 ±9 °F), and then be examined.

E11.7.3 The sample and compliance criteria shall be in accordance with Table E.2.

E11.8 Temperature cycling test

E11.8.1 The cells shall be placed in a test chamber and subjected to the following cycles:

a) Raising the chamber-temperature to 85 ±2 °C (185 ±3.6 °F) or T_{max} + 10 °C (T_{max} is the manufacturer's maximum specified temperature) within 30 min and maintaining this temperature for 4 h;

b) Reducing the chamber temperature to 25 ±5 °C (77 ±9 °F) within 30 min and maintaining this temperature for 2 h;

c) Reducing the chamber temperature to minus 40 ±2 °C (minus 40 ±3.6 °F) within 30 min and maintaining this temperature for 4 h;

d) Raising the chamber temperature to 25 ±5 °C (77 ±9 °F) within 30 min;

e) Repeating the sequence for a further 9 cycles; and

f) After the 10th cycle, storing the cells for a minimum of 24 h, at a temperature of 25 ±5 °C (77 ±9 °F) prior to examination.

E11.8.2 At the end of the cycling, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.

E11.8.3 The sample and compliance criteria shall be in accordance with Table E.2.

E11.9 Low pressure (altitude simulation) test

E11.9.1 Sample cells shall be stored for 6 h at an absolute pressure of 11.6 kPa (1.68 psi) and a temperature of 25 ±5 °C (77 ±9 °F).

E11.9.2 At the end of the conditioning, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.

E11.9.3 The sample and compliance criteria shall be in accordance with Table E.2.

E11.10 Projectile test

E11.10.1 Each test sample cell shall be placed on a flat screen that covers a 102-mm (4-in) diameter hole in the center of a platform table. The flat screen cover shall be constructed of steel wire mesh having 20 openings per square 25.4 mm (1 in) area and a wire diameter of 0.43 mm (0.017 in).

E11.10.2 The screen shall be mounted 38 mm (1-1/2 in) above a Meker type burner. The fuel and air flow rates shall be set to provide a bright blue flame that causes the supporting screen to glow a bright red.

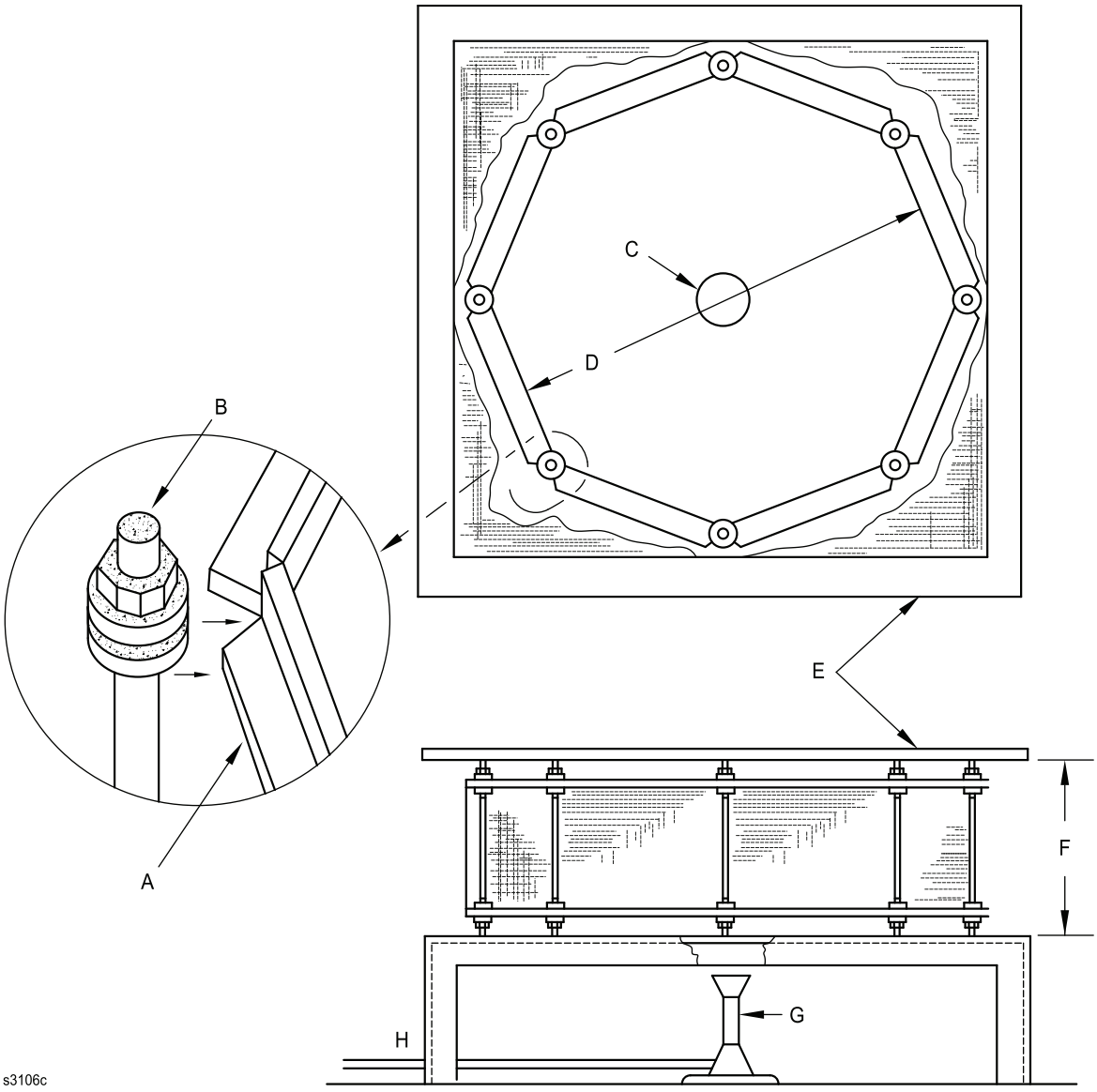
E11.10.3 An eight-sided covered wire cage, 610-mm (24-in) across and 305-mm (12-in) high, made from metal screening shall be placed over the test sample. See Figure E.2. The metal screening shall be constructed from 0.25-mm (0.010-in) diameter aluminum wire with 16 – 18 wires per square 25.4 mm (1 in) in each direction.

Exception No. 1: The overall dimensions of the projectile test aluminum test screen may be increased from those outlined above to accommodate large cells intended for EV applications but the flat panels of the test screen shall not exceed a distance of 305 mm (12 in) from the cell in any direction.

Exception No. 2: The projectile test cage may be replaced by a visible circular perimeter marking on the supporting surface located 0.5 m (19.7 in) from the longest side of the cell. The marking shall be no greater than 5-mm (0.2-in) thick. The test set-up shall be located within a protective enclosure/room with noncombustible surfaces located a distance from the test perimeter marking where any projectiles that fall beyond the test perimeter marking can be safely contained.

Figure E.2

Test apparatus for projectile test



A – 12.7 × 12.7 mm (1/2 × 1/2 in) angle, top and bottom

B – 6.4-mm (1/4-in) diameter rod, 305-mm (12-in) long, threaded both ends, bolted between top and bottom frames

C – 102-mm (4-in) diameter hole in table

D – 610-mm (24-in) or ≤ 305 mm (12 in) from edge of cell

E – Flat screen cover

F – 305 mm (12 in)

G – Burner – Meker type burner

H – Fuel

E11.10.4 The sample shall be heated and shall remain on the screen until it explodes or the cell has ignited and burned out. It is not required to secure the sample in place unless the sample is at risk of falling off the screen before the test is completed. When required, the sample shall be secured to the screen with a single wire tied around the sample.

E11.10.5 The sample and compliance criteria shall be in accordance with Table E.2.

E12 Test Samples and Results Criteria

E12.1 General

E12.1.1 The test samples and results criteria for the tests in this annex shall be in accordance with Table E.2.

Table E.2
Tests Samples and Results Criteria

Test	Reference	Number of samples	Results criteria for total samples tested[c]
Short-Circuit	E11.1	2	No: fire or explosion
Abnormal Charging	E11.2	2	No: fire or explosion
Crush	E11.3	2	No: fire or explosion
Impact	E11.4	2	No: fire or explosion
Shock	E11.5	2	No: venting, leakage, rupture, fire, or explosion
Vibration	E11.6	2	No: venting, leakage, rupture, fire, explosion, or OCV change[a]
Heating	E11.7	2	No: fire or explosion
Temperature Cycling	E11.8	2	No: venting, leakage, rupture, fire, explosion, or OCV change[a]
Low Pressure (Altitude Simulation)	E11.9	2	No: venting, leakage, rupture, fire, explosion, or OCV change[a]
Projectile[b]	E11.10	2 (4)	No: projectiles per E11.10

[a] No "OCV" change would be a drop in the open circuit voltage after testing of less than 10 % of the before test value.

[b] Those cells not complying with the Projectile Test of E11.10 can only be used in batteries that comply with the Thermal Exposure for Explosion Hazards Test of Section 41.

[c] Test results compliance criteria are defined in E12.2.

E12.2 Test results compliance criteria

E12.2.1 Venting is determined by evidence of mass loss as noted in Table E.3 below.

Table E.3
Venting and Leakage Mass Loss Criteria

Mass of cell		Maximum mass percent loss
g	(oz)	%
≤ 1.0	(≤ 0.035)	0.5
> 1.0 ≤ 5.0	(> 0.035 ≤ 0.176)	0.2
> 5.0	(> 0.176)	0.1

E12.2.2 Leakage is determined by evidence of visible liquid electrolyte on the external case of the cell or mass loss criteria as outlined in Table E.3.

E12.2.3 Rupture is determined by a tear in the cell case at a location other than at the designed vent.

E12.2.4 Fire is determine by evidence visible flames or of charging and burning of the cell and its contents.

E12.2.5 Explosion is determined by evidence of disassembly of the cell and its contents beyond a rupture of the case.