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Proposed amendments to UN ST/SG/AC.10/11: transport of dangerous goods—lithium batteries

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Abstract

UN Document ST/SG/AC.10/11 [ST/SG/AC.10/11, The UN recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, 2nd revision] outlines a test plan that is fundamental to the classification for transport of lithium batteries with metallic lithium or lithium alloy anodes. Cells and batteries that fall within its scope are considered dangerous goods. The test plan requires amendment to address many shortcomings. Some tests assess risks that do not exist, other risks are not addressed. This paper outlines the issues we have identified with the test plan, the proposed amendments, the rationale behind the proposed amendments, and issues we have not addressed in the current round of amendments. Transport of lithium batteries has an excellent record. Packaging requirements are essential to continued safe transport. Tests that address known risks relevant to conditions normal to transport are discussed. It is for consideration that non-metallic anode systems such as some polymer and lithium-ion systems should be treated as distinctly different technologies with their own set of transportation risks. The use of the marketing term *lithium battery* when applied to lithium polymer and lithium-ion products has erroneously lead to the suggestion that they be included in the scope of UN Document ST/SG/AC.10/11. A recommendation to classify such systems under a new UN number is presented. It is suggested that UN 3090 or UN 3091 should be reserved for lithium metal or lithium metal alloy products.

Keywords: Specifications; Lithium batteries; Safety

1. Introduction

Primary and rechargeable lithium batteries that contain lithium metal and lithium alloy anodes were originally introduced over twenty years ago. Their unique qualities of high energy density and excellent low temperature performance assured interest in the new technology. Lithium primary cells were quickly adopted for use in a variety of critical applications. ELT search and rescue beacons in aircraft were one example. Accidents inevitably occurred in the absence of a thorough understanding of the fledgling technology. These incidents resulted in a backlash that included bans on the use of lithium primary batteries for a long period of time. The problems associated with lithium primary cells and batteries were investigated over a long period and the safety record of these systems gradually improved.

Approximately ten years ago, Canada began drafting a test plan that would *prove* (a term we prefer not to use) if lithium metal and lithium alloy anode cells and batteries were safe to transport. Canadian regulators were clearly motivated by the safety incidents of primary lithium batteries. Canada's draft found its way into the United States. There it was reviewed and amended by representatives of two major alkaline cell manufacturers who were introducing small lithium primary cells: one company had developed a 3 V, 2/3 A size of Li–MnO_2 cell and the other a 1.5 V, AA size Li–FeS_2 cell.

After many years, the resulting document was adopted by the United Nations Committee of Experts on the Transport of Dangerous Goods in Geneva and first published in the Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria, second revised edition in 1995. By the time the member states of the UN and the international transportation organizations, such as IATA, had adopted the UN recommendations, approximately eight years had gone by. The commercial lithium products on the market eight years later were substantially different in size and chemistry from the 3-V 2/3 A Li–MnO_2 and the 1.5-V AA Li–FeS_2 primary cells which so greatly influenced the design of the UN tests.

Finally, in July 1998, the US, France and Germany, in joint papers to the UN [1,2] succeeded in amending the UN tests to add 'large' batteries to the scope of the lithium

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battery tests. The large batteries were electric vehicle batteries. Some EV batteries use lithium metal anodes and while others have intercalated anodes (lithium-ion) No distinction between the two different types of batteries was proffered in the amendment. One result of the amendment was probably unintentional. Lithium-ion cells and batteries for portable electronics such as cell phones and laptop computers were now *lithium batteries* under the Dangerous Goods regulations. This amendment also introduced the official terms ‘small’ and ‘large’ lithium cells and batteries. This was completely unnecessary. Defining the amount of lithium in a product is sufficient to categorize it. Now it is difficult to discuss products without confusing the official use of the words ‘small’ and ‘large’ with casual, descriptive use. For example, it would now be correct but hopelessly confusing to say ‘‘Small cells are exempt from testing’’. What has now been categorized ‘small’ were considered large fifteen years ago.

It appears there has been very little consideration of the appropriateness of the existing UN tests in evaluating the hazard of transporting EV lithium batteries. Instead, in the rush to regulate them, the majority of activity has focused on amending the tests to make them suitable for the larger cells and batteries. All the shortcomings of the tests have been ignored in the process. All the faults and loopholes still exist. Just as in the earlier drafting of the tests, no risk assessment appears to have been carried out.

2. A review of the existing regulations

Special Provisions are found in Chapter 3.3 of the UN document *Recommendations on the Transport of Dangerous Goods, Model Regulations, 10th Revised Edition*. Special Provisions (SP) define the scope of the regulations. For example, SP188 defines the size and other conditions in order for cells to be exempt from Class 9 Dangerous Goods classification. SP230 defines the size and circumstances for classification of cells and batteries as Class 9. SP231 sets out rules for shipping Class 9 lithium batteries in or with equipment. Under both SP188 and SP230, some cells and batteries are required to pass the UN tests described in the Manual of Tests and Criteria.

The following is a brief description of the UN tests for lithium cells and batteries as they appeared in the summer of 1998. The use of the words ‘cell’ and ‘battery’ are deliberate and specific in the test prescriptions. The Series T tests:

T.1 Altitude Simulation, Extreme Temperature Exposure and Short-circuit
T.2 Vibration, Shock, and Short-circuit
T.3 Vibration, Shock and Charge
T.4 Internal Short-circuit
T.5 Vibration, Shock and Low Capacity Cell
T.6 Forced Discharge

The Series-T test prescriptions are summarized as follows.

T.1: The altitude test is simply exposure for 6 h to 11.6 kPa. The extreme temperature exposure is 48 h at 75°C, followed within 5 min of 6 h at -20°C, then 24 h at 20°C. The short-circuit test is conducted at a chamber temperature of 55°C. A conductor of less than 50 mΩ is placed across the terminals of a cell or battery and the temperature of the cell or battery is monitored until the battery temperature has fallen to 55°C or below for at least 1 h.

T.2: The vibration test is a simple harmonic motion of 0.8 mm amplitude. The frequency is swept from 10 Hz to 55 Hz and back to 10 Hz over a 95 ± 5 min period. The shock test calls for three shocks of 75 g acceleration during the first three milliseconds with a peak acceleration of between 125 and 175 g. For both vibration and shock tests, the samples are tested in 3 axes. The short-circuit test is the same as in T.1.

T.3: The vibration and shock are the same as in T.2. The charge test for cells begins with a classification of nominal cell voltage—being either above or below 2 V. The sample is placed in series with other undischarged cells or batteries that act as the power supply providing the charge. If the cell, when undischarged, is below 2 V, the number of cells used to charge it are calculated by the formula: 18 V divided by the nominal voltage of one cell. If the cell is over 2 V, the formula is: 12 V divided by the nominal voltage of one cell. The battery is discharged on a resistive load chosen so that the maximum current of discharge is within 10% of the protective device rating or the manufacturers maximum discharge current specification if there are no protective devices. The charge test runs until the voltage of the series string of cells drops to 10% of its starting voltage or until 24 h has elapsed, whichever is longer.

T.3 is only conducted on batteries up to 4 V if the component cell voltages are over 2 and on batteries up to 6 V if the component cell voltages are under 2.

T.4: The internal short-circuit test calls for either cells or the component cells from a battery to be crushed with a 6 mm rod until an internal short-circuit is detected. Two means of detecting the short-circuit are identified: the voltage of the cell drops abruptly or the cell voltage drops to one-third of its initial value.

T.5: The vibration and shock tests are conducted as described in T.1. The low capacity cell test is only conducted if the samples are batteries. Specially modified batteries are tested, each being assembled with one cell in each series string having been fully discharged prior to assembly. The battery is discharged on a resistive load chosen so that the maximum current of discharge is within 10% of the protective device rating or the manufacturers maximum discharge current specification if there are no protective devices. The charge test runs until the string voltage drops to 10% of its starting voltage or 24 h has elapsed, whichever is longer.

T.6: The forced discharge test is conducted in a similar fashion as the T.3 charge test. It uses the same formulae to determine how to establish the series string. The battery is discharged on a resistive load chosen so that the maximum current of discharge is within 10% of the protective device rating or the manufacturers maximum discharge current specification if there are no protective devices. The charge test runs until the string voltage drops to 10% of its starting voltage or 24 h has elapsed, whichever is longer. T.6 is only conducted on batteries up to 6 V if the component cell voltages are over 2 and on batteries up to 9 V if the component cell voltages are under 2.

3. Specific criticisms of the T-series of tests

T.1: The extreme temperature test does not agree with the temperature range of air transport which is stated by IATA as −40°C to 55°C. Short-circuits have not occurred in transport and will not if packaging instructions found in the Special Provisions are followed. Therefore a short-circuit test is not needed. Prevention is more valuable than testing.

T.2: The vibration test does not cover the entire frequency range of air transport which is stated by IATA as 7 Hz, 1 g to 200 Hz, 8 g. The shock test does not call for both positive and negative shocks in each axis. It is not a very forceful shock.

T.3: When the packaging instructions and other requirements of the Special Provisions are followed, cells cannot be charged. The use of formulae is inappropriate to modern cell and battery designs. Only the smallest, safest batteries are tested. Otherwise, most modern battery designs are exempt from this charge test. The charge test assesses a cell's ability to withstand a charge. Many lithium cells can be dangerous when charged. Safe transport of lithium metal and lithium alloy anode cells and batteries is only assured if charging cannot occur. The risk of charging is eliminated if the cell or battery being transported is non-operating, packed so as to prevent short-circuiting, and diode protected if called for in the Special Provisions.

T.4: This test is often confused with a crush test. It clearly is not a crush test as the test is terminated when an internal short-circuit is created. A crush test would cite a percent deformation or a crushing force as the termination criterion. Internal short-circuits are rare but plausible risks. They can initiate an uncontrolled current flow in cells and batteries that could lead to unacceptable, perhaps hazardous, behaviour. The existing T.4 test is not designed to screen for the likelihood of internal short-circuits. It tries to identify designs of cells that behave safely when an internal short-circuit arises. However, it forces only one kind of internal short-circuit, and one that is completely artificial and not likely to arise in transport. It has also been criticised for its likelihood to change the safety performance of the cell by deforming the cell casing and therefore modifying the behaviour of the vent mechanism. But beyond these issues, this test completely ignores short-circuits within battery packs that are known to occur with unsafe consequences. As written, failure to induce an internal short-circuit would be considered non-compliance. Cells with low pressure vents are at an unfair disadvantage in this test.

T.5: A battery that is diode protected, as called for in the Special Provisions, and non-operating, should be safe to transport, even if it contains a low capacity cell.

T.6: If packaging instructions and Special Provisions are followed, forced discharge of cells or batteries is not a risk. The use of existing formulae does not cater for modern batteries. Anything other than the smallest, safest batteries are not tested.

4. General criticism of the T-series of tests

Lithium cells and batteries contain significant energy, a fact that must be given due weight. However, the UN tests are weak on assessing real transport conditions and instead dwell on unrelated performance issues. In the T.1 and T.2 tests, external short-circuits are performed. Safe transport of lithium metal and lithium-alloy cells and batteries is only assured if short-circuits are effectively prevented and cannot occur. Years of safe transport have proven this point.

The UN tests are unfair. For example, the T.4 test assumes that an internal short-circuit will occur and must be proven to not be a hazard; a case of guilty until proven innocent. Better to assess the likelihood of an internal short-circuit occurring in the transportation environment.

Cell level and battery level tests should be considered separately. There are different risks associated with each. In particular, poorly designed or poorly assembled batteries made from high quality, well designed, cells pose unique risks. It is now common to find battery assemblers manufacturing lithium batteries from cells not made by them but purchased from cell manufacturers and distributors. This was rare when the existing tests were drafted. Less experience and knowledge at the battery assembly level manifests itself in design or assembly weaknesses that are battery pack problems, not cell problems. There is no test that assesses this liability in the existing UN test plan.

The inappropriateness of the UN tests to the modern lithium battery is most apparent in use of formulae in T.3 and T.6. These formulae determine how many additional cells or batteries must be used to create a power supply to charge or force-discharge the test sample. Cells under 2 V must be charged or force-discharged with up to 16.5 V. Three-volt cells must be charged or force-discharged by only 9 V. The explanation lies in the history of the development of the tests. These formulae were only designed to test the 1.5 V $Li–FeS_2$ cells and 2/3A 3-V $Li–MnO_2$ cells. The company manufacturing the 1.5-V cell could foresee batteries up to 18 V. The 3-V cell manufacturer could only foresee battery packs up to 12 V. Neither assumption is valid today. An exemption for batteries over 6 V exists, if component cells are over 2 V, results in this test not being conducted on most modern battery packs. For example, two or more $Li–SOCl_2$ cells in a battery pack are exempt from this test even if they are high rate, R20 sized, cells or larger. If the risks of charging (T.3) or forced discharging (T.6) during transport were real,both small packs and larger ones should be tested. These regulations now apply to all lithium products including EV batteries. The continued use of these formulae is counter to the evaluation of the safety of lithium cells and batteries for transport.

The undue influence of the manufacturers making the two original batteries in the drafting of the original test plan led to another serious problem encountered today many in the industry. When defining the number of cells and batteries to be tested, the cost of each cell in these original batteries was only a fraction of a dollar. Today, cells can cost over US$25 each. One hundred and thirty cells are required by the test plan. The UN tests also apply to very sophisticated battery packs used in aerospace applications where only 5 or 6 battery packs are manufactured each year and cost over US$2000 each. For a test plan that calls for a minimum of 20 batteries, the expense incurred can be a great incentive to avoid the UN tests.

5. A proposal for amending the UN tests

An amended test plan was prepared under contract by Farrington, Lockwood and submitted to the appropriate Canadian Government department, Transport Canada. Transport Canada officials reworked the proposal drafting it into a Canadian proposal [3] for amending the UN regulations. The Canadian proposal was scheduled to be discussed and voted on at the December 1998 UN Committee of Experts on the Transport of Dangerous Goods meeting in Geneva.

Each of the existing tests was assessed for its appropriateness in evaluating the unique risks posed by lithium cells and batteries. No test plan provisions would ever protect against the liabilities of cells and batteries shipped without regard for the regulations, therefore only the safety of cells and batteries that are compliant with the instructions contained in the Special Provisions was considered.

Conditions normal to transport were reviewed and adopted as the standard conditions to be used when assessing the risks posed by a cell or battery. The UN tests are not intended to prove a cell or battery's ability to withstand abusive conditions beyond the limits encountered in shipping and handling. As stated earlier, the existing test plan does not adequately cover the conditions normal to transport in some areas. The conditions appropriate to air transport, as published in the IATA Dangerous Goods Regulations [4], were the most severe of the land, maritime and air transport modes therefore they were adopted as a basis for test amendments. Briefly they are: temperature range: $-40°C$ to $55°C$, minimum pressure: 68 kPa, and vibrations of 5 mm amplitude at 7 Hz to 0.05 mm amplitude at 200 Hz.

Some consideration was given to Special Provision 188 and Special Provision 230. Table 1 shows the changes proposed to the scope of the UN regulations. A call for the prohibition from operation during transport of cells containing over 1 g of lithium per cell and 2 g per battery (lithium metal anode) is proposed. Exempting cells and batteries containing a minimum amount of lithium from testing has not led to transportation safety problems and should be continued.

The reference to liquid and solid cathodes should be removed to simplify and modernize the UN regulations.

The proposal includes the unfortunate but necessary addition of lithium-ion cells and batteries. Since lithium-ion

Table 1
Proposed changes to the scope of UN tests

	Grams of lithium or lithium alloy per cell	Grams of lithium or lithium alloy per battery	Equivalent grams of lithium per cell	Equivalent grams of lithium per battery
Small lithium cells or batteries				
Subject to provisions of SP188. UN Tests not required.	1.0	2.0	1.5[a]	8.0[a]
Subject to provisions of SP188. Must pass UN Tests 38.4.	5.0	25	8[a]	40[a]
Subject to provisions of SP230. Must pass UN Tests 38.4. Class 9 DG	15[b]	750[c]	25[d]	1000[d]
Large lithium cells or batteries				
Subject to provisions of SP230. Must pass UN Tests 38.3. Class 9 DG	> 15	> 750	> 25	> 1000

[a] Proposed by NEMA and PRBA.
[b] Increased from 12 g. Several lithium primary cell manufacturers have products available now or in the near future that will contain up to 15 g.
[c] Increased from 500 g. Several lithium primary cell manufacturers have products available now or in the near future that will contain up to 750 g.
[d] Set arbitrarily. To our knowledge there are no commercial products in this range.

products do not have lithium metal anodes, the abstract value of *equivalent grams of lithium* is borrowed from the EV battery amendments. A lithium-ion cell or battery is assigned an equivalent grams of lithium by the formula *rated capacity in A h times 0.3 g*. The proposed amendment to SP188 goes on to recognize the greater inherent safety of lithium-ion products by allowing more equivalent grams of lithium per cell or battery in each category.

Special Provision 230 defines the size of cells and batteries that are subject to the regulations. Proposed amendments now delineate between small cells and batteries and large ones. New emphasis on packaging and non-operation during transport was recommended for the small cells and batteries portion of 230. See Table 1. An increase in the upper limits for small cells and batteries under SP230 is included as new products are available or in development that exceeded the old limits.

6. Reorganizing the UN test plan

A study of the amendments by France, Germany and the United States [1,2] which added EV batteries to the UN test plan revealed that the structure of the test plan was clumsy. Attempts to accommodate EV batteries were proposed that adversely affected small cells and batteries, presumably unintentionally. Descriptions of the cell and battery types and the conditions of their testing are long and tortured for each test prescription. A simple remedy was conceived to clarify the test plan. Instead of one series of tests for all cells and batteries, a series appropriate to each logical family of cells and batteries is proposed. Amendments could be made to one group by experts in that group's technology without affecting another. Adding new groups such as EV batteries is simple and uncomplicated with this approach. A series T.1 for small cells, T.2 for small batteries, and T.3 for large (EV) batteries is proposed. Such a change would make the tests less difficult to understand for those attempting to comply with them.

7. Refocusing the test plan on transport issues

The purpose of the UN tests is to determine the safety of lithium cells and batteries offered for transport. Transport Canada provided guidelines for drafting amendments to the test plan. They insisted that language and style of the new test plan had to remain the same as the existing UN tests. Therefore much of the structure and many definitions were simply adopted from the existing UN tests.

There was a strong sense that simplifying the tests would encourage compliance and this became a goal. Reducing the cost of the tests would have the same effect. Therefore, where possible, proposed amendments were drafted to allow the use of data collected from other more stringent test plans, such as airworthiness qualifications, to save the redundant cost of performing these Dangerous Goods tests.

It was concluded that several of the most contentious and problematic aspects of the existing test plan could be addressed by enhancing the instructions in the Special Provisions prohibiting operation of a cell or battery during transportation. Therefore those existing tests that evaluated performance issues are eliminated. Non-operation during transport is the status quo for most lithium cells and batteries being transported. The one exception to the non-operating rule has been very small lithium cells operating in air transports for keep-alive memory duties on circuit boards and other similar applications. These applications are usually diode-protected from charging and, through the design of circuitry, only operate at microamp levels. Such applications do not appear to have posed a risk during transportation in the past twenty years, therefore small cells and batteries should continue to be permitted to operate in such roles.

Performance standards from respectable organizations such as UL, IEC and ANSI now exist to evaluate the safety of lithium products in their intended applications. Such test plans did not exist or were only in their infancy when the existing UN tests were drafted. The UN tests do not need to perform this double duty: read-across should be adequate.

The transportation of lithium cells and batteries for disposal was also deemed to be outside the responsibility of the UN tests. Unlike the excellent record that new or in service cells and batteries have when shipped as dangerous goods, some safety incidents have occurred when transporting lithium cells and batteries as hazardous waste. Nothing in the existing tests determines the safety of a cell or battery for transportation to a disposal site. Simply testing a few new, discharged, cells or batteries does not simulate the nearly infinite charge states of a cell or battery when ready for disposal. Disposal is a separate issue, as much concerned with the ultimate environmental impact of the disposal of the products as it is the safety of transportation.

It deserves a special assessment of the particular risks of transporting lithium cells and batteries. Discharged primary *cells* are not normally shipped other than for disposal, so the requirement to test discharged cells should be eliminated. Shipping discharged *batteries* is, however, a common practice. Many modern lithium batteries are 'technician replaceable' and are shipped to maintenance depots as a regular part of their service life. Therefore testing of discharged batteries is recommended.

Packaging that prevents short-circuiting and crushing of cells and batteries in conditions normal to transport has been and should continue to be required on all sizes of lithium cells and batteries. The excellent transport record of lithium cells and batteries, for more than a decade is most likely due to effective packaging. Packaging has been so effective in preventing short-circuits that not one occurrence of a short-circuit during shipping was identified in our survey of manufacturers. Therefore, the external short-circuit tests should be eliminated. In its place an emphasis on packaging in the Special Provisions is proposed.

In summary, the general concerns for transport that remain once instructions in the Special Provisions are followed, are low pressure exposure in air transport, temperature extremes, and vibration and shock in all modes. Specific lithium cell and battery hazards are the risk of internal short-circuits in cells and short-circuits within the wiring of battery packs.

8. The proposed new test plans for small cells and small batteries

The proposed new test plan as submitted to Transport Canada is far too large to be included here therefore a description of the proposal is outlined herein. The proposed tests are designed to work together to maximize their effectiveness in establishing the safety of a cell or battery offered for transport.

The following are proposed.

For lithium cells (regardless of anode material): altitude, extreme temperature simulation, vibration and shock tests. Ten primary cells are to be tested in the undischarged state. Ten rechargeable cells are to be tested in the state-of-charge in which they are to be transported.

For lithium batteries (regardless of anode material): discharge (half the test samples), altitude, extreme temperature simulation, vibration, shock and discharge (the other half of the test samples). Eight primary batteries or eight rechargeable batteries are to be tested. Four of the batteries must be tested in the fully discharged state. For rechargeables, this is defined as batteries at their lower voltage limit after 50 cycles. The capacities of the four batteries discharged after the tests are complete must agree within 10% with the average capacity of the batteries discharged before the tests began. As some rechargeables will inevitably lose capacity during the 75°C portion of the temperature exposure test, they are allowed to cycle until they recover. The purpose of the capacity test is to determine, in a simple fashion, if there has been a change in the battery pack (such as a failure in one series string) that may not manifest itself in the battery voltage or the assessment methods described in the test plan.

The altitude test can remain unchanged, other than to allow the minimum pressure to be less than 11.6 kPa. This minor wording change allows for the use of data collected from other test specifications that are more stringent.

The extreme temperature test has been changed from one long cycle to ten shorter cycles. The lower temperature extreme should be changed to −40°C to agree with conditions normal to transport. The 75°C upper extreme should be maintained as it is not unreasonable for heating in up to this temperature to occur due to greenhouse effect. This will better simulate the multiple carrier, multiple flight nature of typical transportation. It will also function to stress connections within battery packs by repetitive thermal expansion and contraction. In our experience, lithium cells have had little problem passing either the old or this new extreme temperature test.

The risk of an internal short-circuit in a cell or battery pack can be more effectively evaluated by increasing the vibration and shock test severities and durations. In this way, internal short-circuits of the kind likely to manifest themselves in 'conditions normal to transport', specifically the vibration and shock environment, should be brought out. An internal short-circuit, which is revealed by vibration and shock testing representative of the transport environment is indisputably a risk to transportation. Such an approach should work well for both cells and batteries.

The existing vibration test goes only to 55 Hz and approximately 10 g. While it may be suitable for land transportation, it does not cover the air mode which has a maximum vibration condition (according to IATA) of 200 Hz and 8 g. Therefore, the vibration test should be amended accordingly.

The shock test shock should be redefined as 50 g, 11 milliseconds. An explicit call for three positive and three negative shocks in each perpendicular axis is required. This will stress inter-cell connections in battery packs that have possibly been weakened by the preceding extreme temperature test and vibration test. The combination of extreme temperature test followed by vibration and shock tests will address the void in the existing tests regarding the development of short-circuits within battery packs.

The increased levels of vibration and a change in the shock test should be passable by existing commercial lithium cells. Our experience with lithium battery airworthiness testing has demonstrated that cells can normally withstand vibration and shock levels far greater than what is being proposed.

The existing T.3 charge test, T.5 low capacity cell test, and the T.6 forced discharge test are eliminated for the reasons stated earlier.

It will be a pass/fail requirement that a battery will have to remain functionally identical before and after completing all of its tests.

9. Amendments to acceptance criteria

The new tests were designed to eliminate subjectivity in evaluating the pass/fail criteria. Cells and batteries have to demonstrate a neutral reaction to the test plan. For cells and batteries, no significant weight change, venting, leaking, short-circuit, fire, or disassembly of any kind will be allowed. Additionally, for batteries only, the before and after capacity comparison will demonstrate that the test plan had no negative effect on the internal assembly of the battery. No negative consequences should be allowed. For example, there should no longer be a debate to determine if a disassembly is actually an 'official' disassembly. Any disassembly should be a failure. Distortion of a cell or distortion of a battery due to deterioration of component cells or their interconnections should not be allowed.

10. Follow-up comments and other issues

Others decided to add commercial lithium-ion cells and batteries for portable electronics to the scope of the UN tests. Technically, it is only by a weak and superficial argument that lithium-ion cells and batteries are included as lithium batteries. They may indeed need to be regulated as their materials can produce hydrogen when wet [5], but the amount of hydrogen produced per gram by a lithium-ion intercalation anode is reported to be far less than for lithium metal anode products. This supports the assertion that the two technologies are significantly different in chemistry. The word lithium remains the most common feature of the two technologies. Drafting an effective test plan is more difficult when it must stretch to embrace different technologies. Lithium-ion cells and batteries commonly found in portable electronics should therefore be exempt from testing. The proposed change to Special Provision 188 would accomplish this.

It is unclear if the use of the identification number UN 3090 for lithium cells and UN 3091 for lithium cells or batteries in equipment now applies to lithium-ion products. These numbers inform transport workers what they are carrying and handling. To use the same UN numbers for both lithium and lithium-ion diminishes the value of the UN identification numbers. The numbers should be reserved for cells and batteries that contain lithium metal and lithium alloy, so that handlers will not be confused as to whether or not lithium metal is on their manifest. Proper response to an accident demands an accurate description of items being shipped. If a specific assessment of transportation risks with lithium-ion cells and batteries is warranted, these products should be assigned unique UN numbers in the same way that other rechargeable batteries and battery materials have unique UN numbers.

The need to regulate small lithium-ion cells and batteries designed for use in portable electronics is questionable. 700 million lithium-ion cells, categorized as dry batteries, have been shipped between 1992 and 1998 without incident [6].

The UN tests do not need to distinguish between lithium-ion and lithium polymer cell and battery designs. It is sufficient to identify the anode material for assessment of transport safety.

Representatives of Portable Rechargeable Battery Association (PRBA) and NEMA have argued that portable lithium-ion products should continue to be shipped as dry batteries [7]. That is certainly one option. Until this is resolved, they are included in the scope of the UN tests.

11. Summary

The December 1998 meeting in Geneva of the UN's Committee of Experts on the Transport of Dangerous Goods solved very little. Transport Canada's proposal for amendments to the UN tests was not adopted leaving intact all the flaws described in this paper. A decision to revise Special Provision 188 to add the 1.5 g per cell and 8 g per battery exemption from testing to the existing T-series tests for lithium-ion was undertaken. This will allow portable electronics containing lithium-ion cells and batteries to continue to be shipped, but little change to the status quo.

No amendments were undertaken that affect lithium metal and lithium alloy anode products. Therefore, it will be at least two more years before the UN tests can be amended and several more subsequently before the manufacturers of lithium metal containing products can hope to be relieved from unwarranted burden of the existing tests. As grandfather clauses allowing transport of some products expire within such a time frame, the lithium metal anode industry has a serious problem in the next two years.

The proposals for change to the existing UN tests outlined in this paper, if adopted, would result in a smaller, focused, and more effective test plan that would protect the transportation industry from known liabilities presented by lithium cells and batteries. It would promote compliance within the industry through its clarity, simplicity and low cost. Restructuring the test plan into cell, battery and other groups would simplify the process of future amendments.

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