EI Research report: Investigation into the possible risks arising from the presence and operation of button cell energised devices in potentially flammable atmospheres associated with transport fuels, 1st Edition.

Addendum September 2018

Investigation conducted by Terry Hedgeland

INTRODUCTION

Further to the April 2014 publication of the Energy Institute Research Report: Investigation into the possible risks arising from the presence and operation of button cell energised devices in potentially flammable atmospheres associated with transport fuels (Known as EI 2014 Button Batteries Research report), in February 2017 the International Electrotechnical Commission (IEC) published a new Standard IEC 62133-2. The document relates to secondary, rechargeable, cells and batteries containing alkaline or other non-acid electrolytes and gives safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications. This Part 2 of the Standard applies to lithium systems.

The EI 2014 Button Batteries Research report relates to primary, non-rechargeable, button cells, specifically excluded secondary, rechargeable, lithium-ion button cells. Investigation of the latter cells has subsequently taken place and a related Research report is in the process of publication by the EI. The requirements of IEC 62133-2 were considered during preparation of this later report. A particular requirement of IEC 62133-2 is that cells containing lithium should be subjected to short-circuit testing at elevated temperature.

Cells energising electrical/electronic devices in locations having high ambient temperatures, or otherwise being at raised temperatures, absorb heat from their surroundings, thus increasing their internal stored energy. Tests subjecting cells to elevated temperatures in the range 55 oC ± 5 oC, as prescribed in IEC 62133-2, demonstrate whether or not the increased internal energy stored at that temperature can result in sparks or other adverse effects being produced under short-circuit conditions.

In the EI 2014 Button Batteries Research report relating to primary, non-rechargeable, button cells the range of cells tested and reported on included an assortment of lithium-manganese dioxide primary cells. In common with all the other types of cell tested, the lithium-manganese dioxide cells were subjected to abnormal conditions by imposing a variety of abuses. These included different modes of short-circuit testing, but not at elevated temperatures.

Further to the publication of IEC 62133-2 it was considered to be prudent to carry out additional, elevated temperature, short-circuit tests on specimen primary lithium-manganese dioxide cells. The related investigations are the subject of this report.

Cells selected for testing

The lithium-manganese dioxide (lithium/MnO2) cells subjected to testing in the EI 2014 Button Batteries Research report were identified by the cell references CR2016, CR2025 and CR2032, where the 'CR' designates lithium/MnO2. The first two numerals indicate the nominal diameter of the cell in millimetres (i.e. 20 mm) and the third and fourth numerals indicate the nominal height of the cell (i.e. 1.6, 2.5 and 3.2 mm). Reference should be made to the EI 2014 Button Batteries Research report for data relating to these cells.

As to be expected, and confirmed by the following table, the largest cell size, CR2032, has the largest energy capacity:

Cell	Cell type	Cell chemistry	Nominal rated voltage V	Typical capacity mAh
CR2016	Primary	Lithium/MnO2	3	90
CR2025	Primary	Lithium/MnO2	3	160-165
CR2032	Primary	Lithium/MnO2	3	225

Again, as to be expected, the larger the cell capacity, the greater the probability that an ignitive spark will be produced when short-circuiting a cell. Samples of the largest, CR2032 cells were therefore subjected to testing with the results to determine whether or not smaller capacity cells should also be tested. Quantities of the following cells were subjected to testing:

Tests undertaken

The purpose of the tests was to investigate how the button cells performed under, and reacted to, abnormal conditions representing reasonably foreseeable misuse by imposing a variety of short-circuit tests to cells within the temperature range of 55 oC ± 5 oC. The following tests were applied:

(1) Short-circuit spark test using short length of 0.066 mm2 csa brass wire
(2) Short-circuit spark test using short length of 1 mm2 csa copper wire
(3) Spark test applying 150 Ω across cells
(4) Short-circuit by wrapping cells in metal foil and checking for adverse effects within 30 min
(5) Short-circuit by wrapping cells in metal foil for 24 h & checking for adverse effects

Additionally,

(6) Cells preheated within the temperature range of 55 oC ± 5 oC were immersed in boiling water and allowed to cool, then air dried and checked for adverse effects.

Short-circuit spark tests (1), (2) and (3) – for test results see Annex A, tables 1, 2 & 3
These tests were carried out in a totally darkened room with the objective of visually observing any sparks produced by short-circuiting a quantity of new and unused CR2032 lithium/MnO2 cells. Prior to spark testing the cells were raised to and maintained at a temperature in the range 55 oC ± 5 oC for 3 h.

For each brand of button cells 5 samples were then subjected, singly, to a short-circuit using a short length of 0,066 mm2 csa brass conductor, resistance < 75 mΩ. After a recovery period to allow the cell voltages to rise near to their pre-test values (above nominal voltage) the samples were subjected, singly, to a short-circuit using a short length of 1 mm2 csa copper conductor, resistance < 1,5 mΩ. Another 5 samples of each brand of cell were subjected, singly, to a spark test when applying 150 Ω across the cells.

For each cell a short-circuit was applied three times in succession seeking to observe a spark at make and break on each occasion. The contact time for each make/break was estimated to be within 100 mS. Tabulated results of these tests are shown in Annex 1. Cell voltage was measured immediately before and after the short-circuiting.

In all cases the voltage before the spark test exceeded the nominal voltage of the cell and in all cases the voltage after the spark tests was lower than the nominal voltage of the cell. Maintaining a voltmeter connection showed the voltage slowly recovering and in most cases it was close to its pre-test value within one h.

As a 'control' for observing sparks, unheated samples of alkaline 1,5 volt type 'AA' batteries and nickel cadmium 1,2 volt rechargeable type 'AAA' batteries were employed to positively produce visible sparks.

Findings (i): As shown in Annex 1, tables 1, 2 and 3, no sparks were observed on make or break of contact for any of the single button cells short-circuited by either of the short-circuit conductors or the 150 Ω resistor. Neither were sparks observed on make or break of contact when applying the tests to single AA or AAA type batteries.

As a consequence, unused button cells were then stacked (i.e. in series) 2,3,4 and 5 high, heated as prescribed, with short-circuits being applied across each stack size in turn.

Findings (ii): As shown in Annex 1, no sparks were observed on make or break of contact for any of the 2, 3 or 4 high button cell stacks short-circuited by either of the short-circuit conductors or the 150 Ω resistance. Sparks were observed on break of contact for one stack of 5 cells short-circuited by both of the short-circuit conductors, but not by the 150 Ω resistor. Sparks were readily produced when short-circuiting 2 or more stacked AA batteries.

Short-circuit 'wrap' tests (4) and (5)
The purpose of these tests was to try to produce dangerous heat levels and/or catastrophic failure of deliberately abused button cells by totally wrapping each cell in metal (aluminium) foil so as to create a total short-circuit between anode and cathode around the rim of the cell.

(4) Wrap test at 55 oC ± 5 oC for 30 min:
Prior to wrap testing, three cells of each brand were raised to and maintained at a temperature in the range 55 oC ± 5 oC for 3 h. The cells were then individually quickly wrapped in aluminium foil and maintained at the elevated temperature for 30 min, during which time they were checked for any rise in temperature at 5 min intervals.

Findings (i): For all cells tested, a temperature rise in the range 4 oC - 6 oC was observed after a time of 10-15 min. The temperatures then commenced dropping back towards their initial elevated temperature. None of the cells caught fire, exploded, ruptured, or showed signs of leakage.

As a consequence of these findings a stack of 5 Ultra Max cells was raised to and maintained at a temperature in the range 55 oC ± 5 oC for 3 h. The stack was then quickly wrapped in aluminium foil and maintained at the elevated temperature for 30 min, during which time it was checked for any rise in temperature at 5 min intervals. Temperature measurements were repeatedly made at different points on the exterior of the wrapped stack.

Findings (ii): The maximum temperature rise observed was about 8oC above the initial elevated temperature, occurring within 10 min of the wrapping. The temperature then commenced dropping back towards the initial elevated temperature. None of the cells caught fire exploded, ruptured, or showed signs of leakage.

(5) Wrap test at 55 oC ± 5 oC for 24 h:
Further to the previous tests for 30 min the single wrapped cells and the wrapped stack of 5 cells were maintained at a temperature in the range 55 oC ± 5 oC for 24 h to observe the effects of the abuse.
Findings: The single cells showed slight bulging of the anodes and cathodes. The stacked cells had more marked bulging of anodes and cathodes, each having an increase in height of approximately 10%. None of the cells caught fire exploded, ruptured, or showed signs of leakage.

(6) Immersion in boiling water test:
In order to subject sample cells to more extreme abuse than that applied in the foregoing tests, 2 cells (designated as A and B) were subjected to immersion in boiling water. Prior to immersion the cells were raised to and maintained at a temperature in the range 55 oC ± 5 oC for 3 h. They were then immersed in boiling water to depth of approximately 4 cm which was then allowed to cool down to local ambient temperature of 15oC. The initial temperature at immersion was 53 oC and at 1 h it was 53.2 oC. During this period the condition of the cells was observed at regular intervals. The cells were removed from the cooled water after 24 h their condition was as shown below:

Cell A (left) and cell B (centre) were immersed in boiling water. The cell on the right was new and un-used

Findings: At about 20 min after immersion a brownish rust colouration appeared in the water surrounding the cells. As the cells cooled the colouration 'halo' surrounding each cell increased in density. After removal from the cooled water after 24 h, and air drying, the cell anodes were discoloured as shown above.

The cells showed slight bulging of the anodes and cathodes, resulting in approximately 3,6% increase in the height of cell A and approximately 2% increase in the height of cell B. No other degradation was visible. The open-circuit voltages of the cells before and after immersion were: 3,31 V reducing to 2,88 V for cell A and 3,20 V reducing to 2,87 V for cell B.
Neither of the cells exploded or ruptured.

Summary of findings

1) The spark tests carried out at elevated temperature on a quantity of CR2032 lithium-manganese dioxide cells did not result in any observable sparks for single cells or stacks of cells 2, 3 or 4 high (i.e. in series). Sparks were observed for two sets of cells stacked 5 high.

2) Short-circuiting cells by wrapping in metal foil at elevated temperature for 24 h did not result in any explosion, rupturing or leakage of cells. The resultant increased temperature (above the prescribed elevated temperature) due to the metal foil wrapping was well below the T6 rating of 85 oC.

3) Immersing two sample cells, pre-heated to the prescribed elevated temperature, into boiling water did not cause them to explode or rupture. Discoloration of the water indicated the probability of leakage from within the cells.

4) From the foregoing it was concluded that one or two (stacked) CR2032 lithium-manganese dioxide button cells subjected to the elevated temperatures prescribed in IEC 62133-2 are not capable of producing ignition in a hazardous area related to Group II gases. Consequently, it was considered to be unnecessary to investigate the performance of the lower capacity CR2025 and CR2016 cells.

5) This outcome means that there is no change to the Summary of Findings in the EI 2014 Button Batteries Research report and the observations relating to the use of one or two cells in some types of body-worn or hand-held devices remain unaltered.

ANNEX A

Table 1 **Short-circuit spark test – brass wire** **< 0.075 Ω**

Cell reference	Cell configuration																	
	Single cells										Stacked cells							
	Cell 1		Cell 2		Cell 3		Cell 4		Cell 5		2-stack		3-stack		4-stack		5-stack	
	m	b	m	b	m	b	m	b	m	b	m	b	m	b	m	b	m	b
CR2032 Set 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	S
CR2032 Set 2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	S
AA	X	X	X	X	X	X	X	X			X	S	X	S	X	S		
AAA	X	X	X	X	X	X	X	X			X	X	X	X	X	S		
X = No spark produced S = Spark produced m = make b = break																		

Table 2 **Short-circuit spark test – copper wire** **< 0.0015 Ω**

Cell reference	Cell configuration																	
	Single cells										Stacked cells							
	Cell 1		Cell 2		Cell 3		Cell 4		Cell 5		2-stack		3-stack		4-stack		5-stack	
	m	b	m	b	m	b	m	b	m	b	m	b	m	b	m	b	m	b
CR2032 Set 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	S
CR2032 Set 2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	S
AA	X	X	X	X	X	X	X	X			X	S	X	S	X	S		
AAA	X	X	X	X	X	X	X	X			X	X	X	X	X	S		
X = No spark produced S = Spark produced m = make b = break																		

Table 3 **Spark test applying 150 Ω resistor**

Cell reference	Cell configuration																	
	Single cells										Stacked cells							
	Cell 1		Cell 2		Cell 3		Cell 4		Cell 5		2-stack		3-stack		4-stack		5-stack	
	m	b	m	b	m	b	m	b	m	b	m	b	m	b	m	b	m	b
CR2032 Set 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CR2032 Set 2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
AAA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
X = No spark produced S = Spark produced m = make b = break																		

EI Research Report

Investigation of the possible ignition risks arising from the presence and operation of button cell energised devices in potentially flammable atmospheres associated with transport fuels

EI RESEARCH REPORT

INVESTIGATION OF THE POSSIBLE IGNITION RISKS ARISING FROM THE PRESENCE AND OPERATION OF BUTTON CELL ENERGISED DEVICES IN POTENTIALLY FLAMMABLE ATMOSPHERES ASSOCIATED WITH TRANSPORT FUELS

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FOREWORD

This EI Research Report has been prepared under the direction of the EI's Distribution & Marketing Committee and Electrical Committee.

It provides a compilation of EI-funded studies that have been undertaken to assess the possible ignition risks posed by button cell-energised devices in potentially flammable atmospheres associated with transport fuels.

Section A provides an overall assessment of the ignition risk by Mr T. Hedgeland, including data generated from testing, Section B provides a desk study and details of a simplified failure assessment, and Section C provides the original scoping assessment undertaken by Mr T. Hedgeland.

The information provided in this publication is intended to be of use to operators of petroleum distribution installations in their assessments of the use of button cell energised devices. It may also be of use to operators of petroleum road tankers.

The findings of this EI Research Report have been technically endorsed by the EI's Distribution & Marketing Committee and Electrical Committee.

It is likely that this publication will have a wider scope of usage and will encompass differing operating practices and safety and environmental legislation to those that apply in the UK. Therefore, this publication should be read in conjunction with any statutory operating requirements that apply at the point of intended use. It is recommended that if procedures defined in this publication are more stringent than those at the point of use then those in this publication should be followed.

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Suggested revisions are invited and should be submitted to the Technical Department, Energy Institute, 61 New Cavendish Street, London W1G 7AR, UK (e: technical@energyinst.org).

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SECTION A
INVESTIGATION CONDUCTED BY TERRY HEDGELAND

A.1 INTRODUCTION

This project is intended to extend the original investigations carried out by Mr T. Hedgeland (see section C of this EI Research Report), taking into account the desk study and simplified failure assessment (see section B). This report should be read in conjunction with those two sections.

The objective is to produce a document for EI Distribution & Marketing Committee and EI Electrical Committee consideration, detailing an approach to risk assessment relating to the presence and operation of devices energised by single button cells (also called 'coin cells'), that may be carried or worn by persons in potentially explosive atmospheres associated with transport fuels.

In line with the original brief this specifically excludes mobile telephones and devices energised by other than single button cells. Where these further investigations reveal a methodology or approach for dealing with such excluded items, any development of guidance in that respect would be outside the range of the present project.

The intention is to produce guidance that takes into account normal operation and abnormal conditions, the latter covering single jeopardy/first fault conditions, e.g. a device being dropped on the ground in a hazardous area.

The investigations have included researching technical data relating to the various types of devices previously identified, from sources, some non-verifiable, such as Wikipedia, Google Patent and other on-line sites as well as manufacturer/supplier information. Comparisons of characteristics are made with requirements for explosion-protected equipment given in the BS EN 60079 series of Standards.

Section B provides a draft report prepared by a contractor to the EI, and consists mainly of a 'desk study', much of which is information retrieved from internet sources, practical testing not being included in the contractual arrangements. Much of the researched information concerning battery problems is related to lithium-ion batteries with manufacturing imperfections fitted in laptop computers and mobile telephones, resulting in significant product recalls. There does not appear to be much information available 'on-line' concerning problems with the many types of button cells, particularly when used singly. However, there is substantial guidance on correct use, safety precautions and what not to do with button cells. Several button cell manufacturers provide technical specifications, performance characteristics and certification evidence on-line.

Further to the very basic tests detailed in section C, it was considered essential that some more extensive practical testing of button cells was undertaken in order to arrive at a useful outcome for the project, which has been carried out in two phases. The first phase further investigates the behaviour of button cells under adverse conditions, particularly under short-circuit conditions, and the ability of cells to meet the normal operational load requirements of devices energised by them. The second phase investigates devices containing cells.

A.2 FIRST PHASE

A.2.1 Cells incorporated in explosion-protected equipment

The types of cells (by chemical make-up) which may be incorporated in explosion-protected equipment are detailed in BS EN 60079-0, clause 23.3, Table 10 *Primary cells* and Table 11 *Secondary cells* (reproduced with permission of BSI as Tables A.1.1 and A.1.2 in Annex A.1 of this research report). These are mostly based on IEC 60086-1. Although button cell energised devices subject to investigation are not explosion-protected, it seems appropriate to use this reference as a basis for selecting cells for practical testing, with a view to possible acceptance in risk assessment terms.

A.2.2 Cells selected for testing

All cells selected had their nominal voltage and identifiable coding impressed in the outer casing. A table of cell coding is shown in Annex A.2. Where chemical make-up symbols were not shown on the casing it was identifiable via the coding. Some types of cells used are from well-known and established manufacturers, the remainder are marketed under various 'unknown' cover names. The packaging of some of these is marked 'made in China' - those not so marked are assumed to be of similar sourcing.

These cells of 'unknown' brand were selected because they are widely available as affordable options and are used in a wide range of the devices under consideration. Since it was not possible to trace manufacturers' data for the latter cells, their quality is unknown and this is considered to be an important reason for their inclusion for testing. Table A.1 shows the cells (all primary except where stated) that were tested.