Cellular Phones in Class I, Division 2/Zone 2 Hazardous Locations

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Allan Bozek P.Eng, MBA
Member IEEE
EngWorks Inc.
Calgary, Canada
abozek@engworks.ca

Ken Martin
Member IEEE
Brodwell Industrial Sales Ltd.
Calgary, Canada
kmartin@brodwell.com

Marty Cole
Senior Member IEEE
Hubbell Canada
Toronto, Canada
mcole@hubbell-canada.com

Abstract - The risk associated with using a portable cellular phone in a Class I, Division 2 or Zone 2 hazardous location is evaluated. Experimental trials were performed on a representative sample of commercial grade cellular phones using the guidelines provided in ISA-RP12.12.03-2002 *"Recommended Practice for Portable Electronic Products Suitable for Use in Class I and II, Division 2, Class I Zone 2 and Class III, Division 1 and 2 Hazardous (Classified) Locations"* [1]. The ignition risks are subsequently classified according to a framework ranking system for ignition sources developed by Rew and Spenser (1997)[2]. The results are used to construct a probability model that estimates the risk of a cell phone igniting a flammable atmosphere in a Class I, Division 2 or Class I, Zone 2 hazardous location.

All cell phones evaluated did not meet the ISA-RP12.12.03-2002 requirements for a PEP 2 (Portable Electronic Product) device and therefore could not be considered "*incapable of causing an ignition under normal operating conditions*" as per the PEP definition. Additional testing and analysis of the high risk cell phone components indicated a very low probability of ignition even under ideal conditions. A Monte Carlo simulation of the probability model estimated the odds of a cell phone causing a fire or explosion in a Class I, Division 2 or Class I Zone 2 hazardous location as being 1.16E-06; or one in a million.

Index Terms – Cellular mobile cell phones, Hazardous locations, Ignition probability model.

I. INTRODUCTION

In recent years, the cell phone has become the most widely used technology media for voice communications. In North America alone, there are estimated to be 180 million mobile phones in use; with on average 1 mobile phone for every two persons. Their convenience and portability make it an ideal means of communication within a petrochemical facility. This convenience must be weighed against the risk of a fire or explosion inadvertently caused by the use of a cell phone within a hazardous location.

The purpose of this paper is to estimate the risk associated with using a standard commercial grade cellular phone in a Class I, Division 2 or Class I, Zone 2 hazardous location. Class I, Division 2 and Zone 2 locations were selected as the basis for the study since 95% of all hazardous locations within North America are assigned this classification. It should be cautioned that the risk of using commercial grade cell phones in a Class I, Division 1 or Class I, Zone 1 hazardous location is an order of magnitude higher and is not addressed within the scope of this paper.

Results from previous research studies are examined and the current industry regulations related to cell phone use in hazardous locations is reviewed. An industrial user survey is conducted to determine the extent of cell phone use by petrochemical operations and how their use is monitored in hazardous locations.

To estimate the probability of a cell phone igniting a flammable atmosphere, a series of tests are performed on a sample cross section of cellular phones. The results are summarized and incorporated into a probability model that approximates the risk of a cell phone igniting a flammable mixture within a Class I Division 2/Zone 2 hazardous location.

II. OVERVIEW OF CELL PHONE TECHNOLOGY

A cell phone is essentially a radio transmitter/receiver operating in the 800 Mhz and 1900 Mhz frequency spectrum. A cell phone communicates to a network of base stations which in turn are linked to the telephone network.

Cell phone technology has evolved over a number of product generations to where it is today. In 1981, the 1st generation mobile phone began operation with the introduction of analog cellular service called AMPS (Advanced Mobile Phone Service). The 1G cell technology allowed users to place calls and converse seamlessly as they moved from cell to cell locations. A typical 1G handheld mobile phone was large, heavy and expensive and required 6 watts of power to transmit and receive.

The 1G was rendered obsolete in the early 1990's with the introduction of the 2nd generation based on digital cellular technology. Digital cellular technology increased the number of simultaneous phone conversations for the same range of radio spectrum and allowed for services beyond simple voice communications. As cellular phones incorporated additional features such as personal digital assistants, text messaging, cameras, internet browsers and email capability, a 2.5G generation of mobile phone technology emerged. The majority of mobile phones in use today are 2.5G.

A 3rd and 4th generation of cellular phone technology is currently in development. As with all microprocessor technologies, each generation reduces the size, weight, cost and power consumption while improving the features, reliability and the ease of manufacture.

Fig. 1 provides a simplified block diagram of a 2.5G mobile phone.

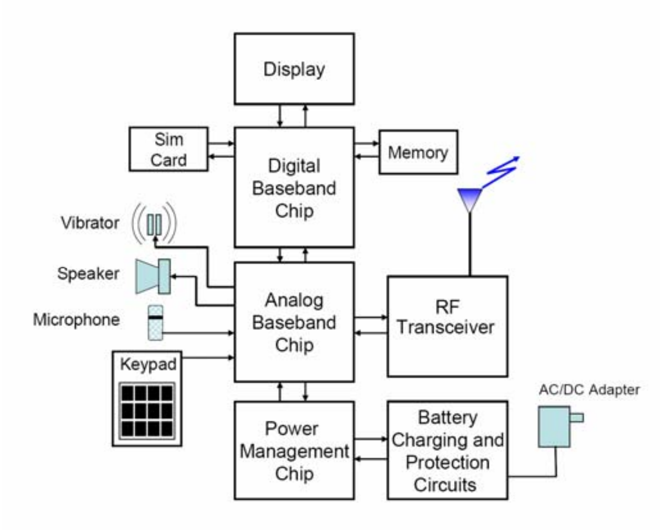

Fig. 1 Mobile Phone Block Diagram

III. SUMMARY OF PREVIOUS RESEARCH STUDIES

The majority of documented cases where a cell phone was identified as a potential ignition source are in retail gasoline operations. Within the petroleum and chemical industry, only one incident was identified where a cell phone was considered a potential source of ignition. The majority of research to date has focused exclusively on retail gasoline operations.

Self-service gasoline pumping operations requires the public (unknowingly or otherwise) to perform activities within a Class 1, Division 2/Zone 2 hazardous location. In several cases where a gasoline fire resulted during filling operations, a cellular phone was identified as possible source of ignition. Widespread media coverage led to the growth of an urban legend where cell phones were quoted as being the primary source of ignition in these events.

In response to public awareness, several retail gas operators issued directives to their staff to post warning signs and monitor the use of cell phones near fuel dispensers. If a customer was observed to be using a cell phone while pumping fuel, the operator was to cease filling operations. Mobile phone manufacturers also responded by incorporating warnings in their user manuals as illustrated in Fig. 2.

Following the accident investigations, a number of formal studies were commissioned to objectively assess the danger of using a cellular phone during filling operations. All studies concluded that it was highly unlikely that a cell phone was the primary source of ignition and that static electricity as the most probable cause. Several formal statements were issued as follows:

> The University of Oklahoma Center for the Study of Wireless Electromagnetic Compatibility study (August 2001); Investigation of the Potential for Wireless Phones to Cause Explosions at Gas Stations, concluded that *"…research into the cell phone – gas station issue provided virtually no evidence to suggest that cell phones pose a hazard at gas stations. …While it may be theoretically possible for a spark from a cell phone battery to ignite gas vapor under very precise conditions, the historical evidence does not support the need for further research."*[3]

> Exponent Failure Analysis Associates, Menlo Park, California (December, 1999) study, Cell Phone Usage at Gasoline Stations, concluded that "*…the use of a cell phone at a gasoline filling station under normal operating conditions presents a negligible hazard and that the likelihood of such an accident under any conditions is very remote." The report also noted "automobiles (which have numerous potential ignition sources) pose a greater hazard… Finally, other potential ignition sources are present, such as static discharge between a person and vehicle."* [4]

> The Institute of Petroleum hosted a technical seminar entitled "Can mobile phone communications ignite petroleum vapour?" (March 2003) issued a press announcement stating *"The seminar showed the findings of research undertaken to date demonstrating that although the majority of mobile phones are not specifically designed and constructed to prevent them igniting a flammable atmosphere (in accordance with standards for 'protected equipment) the risk they present as a source of ignition is negligible."* [5]

Potentially Explosive Atmospheres

Turn off your radio product prior to entering any area with a potentially explosive atmosphere, unless it is a radio product type especially qualified for use in such areas as "Intrinsically Safe" (for example, Factory Mutual, CSA, or UL approved). Do not remove, install, or charge batteries in such areas. Sparks in a potentially explosive atmosphere can cause an explosion or fire resulting in bodily injury or even death.

NOTE: The areas with potentially explosive atmospheres referred to above include fueling areas such as below decks on boats, fuel or chemical transfer or storage facilities, areas where the air contains chemicals or particles, such as grain, dust or metal powders, and any other area where you would normally be advised to turn off your vehicle engine. Areas with potentially explosive atmospheres are often but not always posted.

Fig. 2 Excerpt from a Mobile Phone Users Manual

In contrast to the large number of filling station fires where a cell phone was listed as a possible ignition source, only one industrial incident was noted. The incident involved a flash fire on an offshore platform in the Gulf of Mexico. A contract panel specialist was working on an open panel that used fuel gas for instrumentation. The contractor's cell phone rang and was activated by flipping it open. A flash fire occurred and the contractor received second degree burns to his forearms and face. The incident prompted the US Department of the Interior to issue Safety Alert No. 5 in March of 2002 cautioning the use of portable electronic devices in hazardous locations. The bulletin recommended the use of hot work permits, intrinsically safe devices or third party approved devices in hazardous locations [6].

The US Department of Interior Mineral Management Service (MMS) Division followed up with a formal investigation. The cellular phone involved in the incident was sent to a third party testing agency for a battery of tests in a controlled laboratory environment. On conclusion of the investigation, the Department of Interior issued the following statement:

> *"Based on this information and MMS's investigation, we were unable to conclusively identify the ignition source of the fire. However, we have not ruled out the possibility that the fire could have been ignited by static electricity, a spark from the metal master control panel door coming into contact with a metal handrail, or a wrench striking metal inside the control panel."*[7]

Although the investigation concluded that it was highly unlikely that the cell phone was the primary source of ignition, the advisory cautioning against the use of cellular phones in hazardous locations remained in place.

IV. INDUSTRY REGULATIONS AND PRACTICES

A. Government Regulations

Government regulations related to cell phone use in hazardous locations vary in scope and detail. In the US, the NEC does not make a direct reference to the use of cellular phones but implies they fall under the general classification of electrical and electronic equipment. NEC Article 500.8 [8] requires that all electrical and electronic equipment be approved for use in hazardous locations and shall be identified by any of the following:

1) *Equipment listing or labeling*
2) *Evidence of equipment evaluation from a qualified laboratory or testing agency*
3) *Evidence acceptable to the authority having jurisdiction such as a manufacturer's self evaluation or an owner's engineering judgment.*

In Canada, the Canadian Electrical Code requires that all electrical equipment used in hazardous locations be subject to the rules of section 18. A note in the CEC appendix specifically addresses battery powered equipment including *"transceivers, paging receivers and battery or voice powered telephones"* and requires such devices be approved by a third party certification authority for use in a hazardous location [9].

The CEC requirements are further reinforced by a suggested change to the 2005 Occupational Health and Safety Regulations that specifically requires cellular telephones used in hazardous locations be certified.

In Europe, ATEX 94/9/EC directive requires all equipment used in potentially explosive atmospheres be certified for the appropriate gas group, temperature classification and be suitably labeled [10].

B. Recommended Practices

From a regulatory perspective, it would appear that cellular phones, unless certified for use, shall not be used in a Class I hazardous location. This clarity was somewhat contradicted by the ISA publication ISA-RP12.12.03-2002 *"Recommended Practice for Portable Electronic Products Suitable for Use in Class I and II, Division 2, Class I Zone 2 and Class III, Division 1 and 2 Hazardous (Classified) Locations"*

ISA-RP12.12.03-2002 was written as a guideline for the safe use of general purpose battery powered portable equipment in hazardous locations. It was developed to address situations where portable and battery powered equipment was required, but unavailable as listed for use in a classified location. This may be due to rapidly changing technology, or the need for time consuming and expensive third party certifications for products with a limited market.

ISA-RP12.12.03-2002 describes the minimum precautions required for using a portable electronic device in a classified location. In Class 1 Division 2/Zone 2 locations, a product may be listed, or used with a gas free work permit, or when the product meets the design and performance criteria for a PEP (Portable Electronic Product) as specified in the document.

A PEP product is defined as a "*battery powered or photovoltaic cell powered apparatus that can be hand-held or that is intended for use while worn on a person's body.*" Certain PEPs may be suitable for use in hazardous locations if they are deemed "*incapable of causing an ignition under normal conditions*."

PEPs are further broken down into PEP 1 and PEP 2 product categories. A PEP 1 device does not require labeling or permitting for use in a hazardous location. In contrast, a PEP 2 device requires a PEP 2 marking stating the evaluating company name and the supporting document reference number or code.

Examples of PEP 1 products include electronic wrist watches and hearing aids. Examples of PEP 2 devices include calculators, hand held testers and "*some cell phones*".

C. Industry Practice

To determine the extent of cell phone use in hazardous locations, an on-line survey was conducted. The survey targeted firms in the oil and gas industry who were operators of large scale petrochemical facilities. Results of the survey indicated that cell phones are in general use by Operations personnel, however, they are not the primary means of communication in classified areas. All companies responding restricted the use of cell phones in hazardous locations with 60% banning them outright. Where cell phones were permitted, they were required to be listed and approved by a third party certification authority. Appendix A summarizes the results of the survey.

V. REQUIREMENTS FOR IGNITION OF A FLAMMABLE ATMOSPHERE

To further examine this issue, a basic understanding of the ignition process is required.

To ignite a flammable atmosphere:

a) An ideal flammable mixture must be present in sufficient quantity to create a hazard
b) An active ignition source must be present
c) The ignition source must have sufficient energy to ignite the flammable atmosphere

A. Requirements for an Ideal Flammable Gas Mixture

For an ideal flammable mixture to exist, the flammable material must be in the vapor or gaseous state; the vapor to air mixture concentration must be between the lower flammable limit (LFL) and the upper flammable limit (UFL) and the temperature must be below the auto-ignition temperature of the flammable material. The flammable region, as illustrated in Fig. 3 is the area where the presence of an external ignition source may potentially cause a fire or explosion.

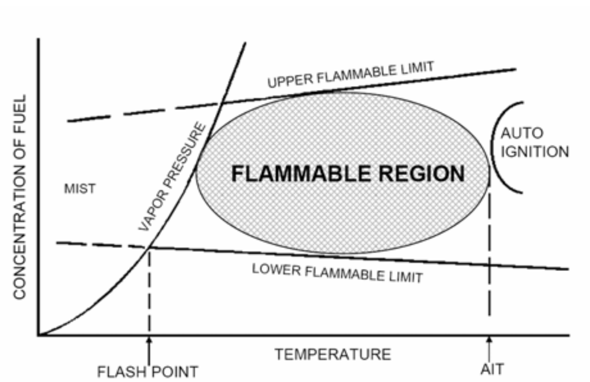

Fig. 3 Flammability Relationships

The probability of an ideal flammable gas vapor-air mixture being present at any given time is influenced by a number of material and environmental factors. The flashpoint of the flammable material, the material's density relative to air, the source, rate and geometry of release and the quantity of air movement all influence the degree and the extent of the hazard. To assess if a hazard exists at any given time requires quantifying these variables. This is often very difficult to do in practice.

The purpose of a hazardous area classification is to subjectively assess the probability of a flammable mixture being present within an area at any given time. Facilities within North America may be classified using the Division or Zone method of area classification. Class I, Division 1 locations are areas where there is *likely* to be ignitable concentrations of flammable gases or vapors. Class I, Division 2 areas are locations where ignitable concentrations of hazardous materials are *unlikely* to exist; and should they exist will do so for a very short time.

The Zone method of area classification divides hazardous locations into three risk categories. A Class I, Zone 0 location is where a flammable concentration of a gas or vapor is expected to exist on a continuous basis. Class I, Zone 1 areas are locations where a flammable atmosphere is *likely* to exist; and a Class I, Zone 2 location is where a flammable atmosphere is *unlikely* to exist. It should be noted that these subjective probabilities are based on normal operating conditions. Catastrophic failure events are not considered.

API RP 505 provides additional guidance in defining a hazardous area classification based on the theoretical presence of a hazardous mixture as illustrated in Table I.

TABLE I
Relationship between Zone Classification and the Presence of Flammable Mixtures (API RP 505) [11]

Zone	**Flammable Mixture Present**	***% of time per year***
0	1000 hrs or more per year	> 10%
1	> 10hrs and < 1000hrs per year	0.1% - 10%
2	> 1hr and < 10 hrs per year	0.01% - 0.1%
Unclassified	< 1hr per year	< 0.01%

B. Requirements for an Active Ignition Source

For a device in intermittent use, the probability of the device becoming an ignition source in the presence of a flammable gas is a function of how often and for what duration the device is used. A cell phone can be considered an intermittent use device and is deemed 'active" when it is in the process of transmitting and receiving radio frequencies.

To conserve power, a cell phone will operate in a "sleep" mode awaiting an incoming signal or activation by the User. While the cell phone is in sleep mode, power levels are reduced to a minimum and the risk of ignition is negligible. Once the cell phone receives an incoming call or is activated by the User, it may be exposed to a flammable atmosphere and has the potential to become an ignition source.

C. Ignition Source Energy Requirements

For an electrical ignition to occur an electric spark must arc across a contact gap that exceeds the minimum quench gap distance and the spark energy generated must exceed the minimum ignition energy requirements for the flammable material. Quenching refers to the "cooling" process that occurs when the heat energy of a spark or flame is transferred to an adjacent surface. The quench gap is the largest passage that can prevent propagation of a flame through a passage when it is filled with a flammable fuel-air mixture.

The size of a quench gap is experimentally determined and varies with the mixture composition, the surface geometry and the pressure and temperature of the surrounding atmosphere. A 2.0 mm quench gap distance is typically used for methane and 0.6 mm gap used for hydrogen.

The minimum ignition energy required to ignite a flammable mixture varies with the material composition and the air mixture ratio. Fig. 4 illustrates the minimum spark energy required to ignite methane and hydrogen as a function of % volume to air concentration. The ignition spark energy is at a minimum at the stoichiometric air mixture ratio. The energy required for ignition increases as the percent air/mixture ratio deviates from the stoichiometric ratio. Table II illustrates the material characteristics; minimum ignition energy and minimum quench gap distance required for the ignition of methane and hydrogen.

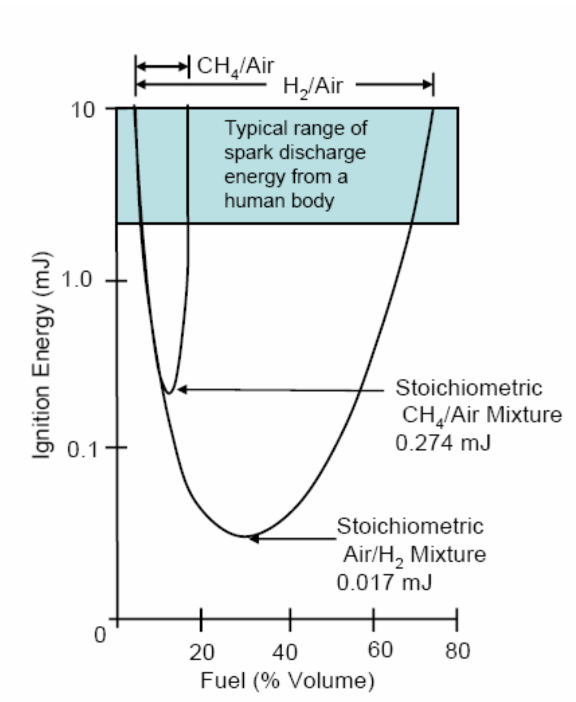

Fig. 4 Spark Energy Required to Ignite Methane and Hydrogen

TABLE II
Physical Properties of Hydrogen and Methane

	Hydrogen	Methane
Autoignition temperature	520º C	630º C
Lower flammable limit	4% by vol.	5.3% by vol.
Upper flammable limit	75% by vol.	17% by vol.
Stoichiometric mixture	29.5% by vol.	9.5% by vol.
Density relative to air at STP	0.07	0.55
Minimum ignition energy	0.017 mJ	0.274 mJ
Group Classification	Group B, IIC	Group D, IIA
Quench Gap Distance	0.66 mm	2 mm
Minimum ignition energy	0.017 mJ	0.274 mJ

VI. CLASSIFICATION OF IGNITION SOURCES

A number of statistical models have been developed for the purpose of classifying ignition sources. The framework developed by Rew & Spencer (1997) builds on the research done by a number of previous references including Cox, Lees and Ang [15]. The model provides a means of ranking ignition sources into various groups based on their ignition potential as illustrated in Table III. Ignition sources range from open flames that are assigned an ignition probability of 1.0 to intrinsically safe devices with an ignition probability of 0.0.

For reference purposes, a typical zone 2 approved equipment device would fall into the "weak" category with an ignition probability of 0.01[15].

TABLE III
Framework Ranking System for Ignition Sources
Rew & Spencer (1997) [2]

Category (Strength of Source)	Examples of Ignition Sources	Ignition Potential
Certain	Pilot Lights Fired Heaters Flares	p = 1
Strong	Hot Work Electrical Faults, Smoking	p > 0.5
Medium	Vehicles, Substations, Unclassified electrical equipment, Engines, Hot surfaces	0.5 > p > 0.05
Weak	Office Equipment, Electrical Appliances Mechanical Sparks Static electricity	p < 0.05
Negligible	Intrinsically safe equipment Radio Frequency Sources	p = 0

VII. EVALUATION OF A CELL PHONE AS AN IGNITION SOURCE

To evaluate and classify the ignition potential of a cell phone, the design criteria and test methods outlined in ISA-RP12.13.03-2002 for a PEP 2 device is used as a basis.

The PEP2 criterion applicable to a cell phone is as follows:

1) Radio frequency transmission energy is limited to a safe level
2) No sparks visible in normal operation
3) No power on-off switch that directly interrupts the battery current
4) No motors unless it can be demonstrated that the motor incorporates non-arcing technology
5) No external connections of accessories are used in the hazardous area
6) Exposed terminals (battery charging terminals) are recessed or diode protected to prevent a discharge caused by the accidental shorting of the terminals
7) No excessive temperatures in normal operation
8) Cell or battery is secured so it will not fall out in a specified drop test
9) No damage that exposes electrical/electronic circuitry as a result of the drop test

The ISA performance tests were applied to a representative sample of 8 cell phones from five different manufacturers. Upon completion, each cell phone was dismantled and examined for any components that might pose an ignition risk. Where a potential ignition hazard was identified, additional tests were done to further assess the ignition hazard.

Appendix B provides a complete summary of the test results. The following sections discuss the PEP 2 criterion and provide comment on the ignition risks identified.

A. Radio Frequency Energy

Radio devices that emit electromagnetic frequencies may create a spark hazard in the presence of an open circuit antenna loop as illustrated in Fig. 6. The extent of the hazard is related to the strength of the radio frequency radiation emitted while transmitting.

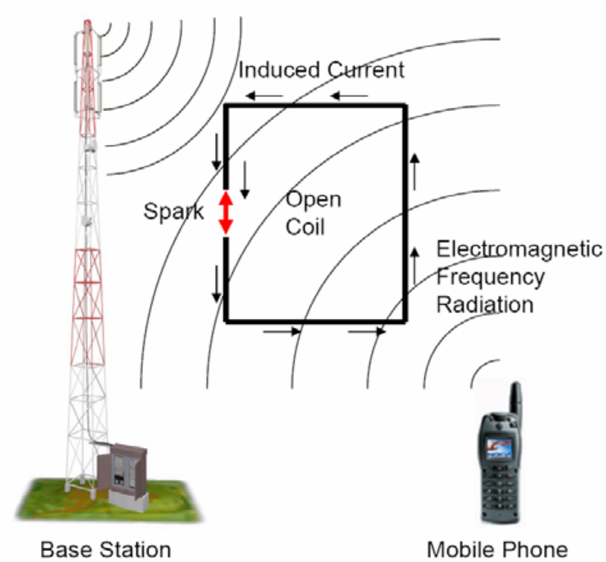

Fig. 6 Induced Spark Hazard from RF Radiation

The safe radio frequency energy transmission levels are defined in BS 6656 "*Assessment of inadvertent ignition of flammable atmospheres by radio-frequency radiation – Guide"* [12] and are used as a PEP performance criterion. The maximum RF energy that may be emitted from a PEP 2 device must be less than:

- 2 W maximum output averaged over 20 microseconds for Groups A and B and Group IIC
- 3.5 W maximum output averaged over 100 microseconds for Group C and Group IIB
- 6 W maximum output averaged over 100 microseconds for Group D and Group IIA

Under normal operating conditions, a 2.5G mobile phone radiates between several hundred milliwatts and 0.7 watts of RF energy depending on the signal strength to the base station (the weaker the signal the more power a mobile phone handset will send). This is well under the maximum 2 watts of radio frequency energy considered safe under all conditions and therefore eliminates RF energy as a potential ignition source.

B. Arcing/Sparking Components in Normal Operation

1) *Contacts and Switching Devices:* The potential for a cell phone to arc or spark in normal operations is related to the technology and energy switching levels used for keyboard and switching functions. All cell phones examined used a dome switch keyboard technology. The dome switch technology uses a hybrid of membrane and mechanical components to allow two circuit board traces to contact under a plastic "dome" or bubble.

One key advantage of the dome switch keyboard technology is that it effectively seals the switching contacts from the environment. While primarily designed to prevent liquid contamination of the keyboard, it also creates a vapor-tight barrier that effectively eliminates the keyboard as a potential source of ignition.

ISA-RP12.12.03-2002 requires only the on-off switch be examined for arcing-sparking potential. All cell phones in the test group used the same switch for on-off functions indicating an electronic circuit switch was used for power control. A dome membrane type switch was observed in all cases. On this basis, the ignition risk associated with switching and control functions was deemed negligible.

2) *Vibrator mechanism:* Seven of the eight cell phones in the test group incorporated a vibrate ring feature. The vibrator mechanism on a typical mobile phone consists of a DC micro-motor turning a counterweight. The spinning counterweight provides the vibration effect.

The micro-motor used for a cell phone vibrator mechanism incorporates a coreless motor design. A coreless motor replaces a rotating iron armature with a light weight copper coil. The copper coil then rotates around a stationary magnet system. Fig. 7 illustrates a coreless micro-motor design.

A typical vibrator pager micro-motor will have a voltage input of 1.25V and a running current of 120ma. Within the cellular phone circuitry, the vibrator motor is controlled by a micro motor driver chip that controls and protects the motor operation. The controller chip will provide a stabilized DC output and limits both the temperature and current to the motor.

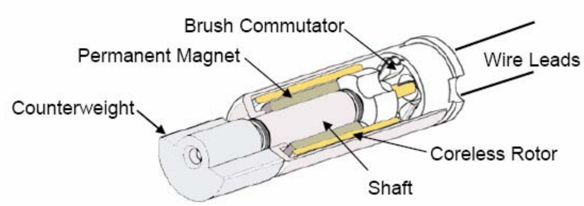

Fig. 7 Coreless Vibrator Micro-motor

The coreless micro-motor design requires a precious metal or graphite brush commutator system. A commutator system is an arcing sparking component by nature and must be considered a potential ignition source. To determine if the vibrator function might pose an ignition risk, micro-motors were removed from 5 of the 7 cell phones in the test group and placed in an explosion chamber with a Group IIC stoichiometric hydrogen mixture to simulate a worst case flammable mixture environment. The micro-motors were alternately energized for 10 seconds with a 1.5V DC power source to simulate a vibrator operation.

No ignition events were observed with any of the micro-motors tested. Based on these results, the probability of a cell phone micro-motor igniting a flammable atmosphere can be considered negligible.

C. Drop Tests

ISA-RP12.12.03-2002 requires a PEP2 certified product to be dropped from a height of 2 meters to a horizontal concrete surface. The device must survive without exposing any internal circuitry or the battery becoming disconnected. The test is repeated six times in a variety of orientations.

Within the test group, only one cell phone survived without the battery disconnecting on impact. In all other cases, the battery separated from the cell phone one or more times. In all cases, when the battery was reconnected, the cell phone worked properly with no physical or operational damage observed.

The probability of a spark being created as a result of the battery disconnect is difficult to assess. The more likely scenario would be the dropped object itself posing the ignition risk. In theory, an object the size of cell phone can discharge 10-20 mJ of energy under ideal conditions. This risk is common to all objects. Without conclusive results and given the remote likelihood of a battery disconnect or dropped object creating a spark hazard, the spark ignition potential of a dropped cell phone was given a weak rating in accordance with the Rew and Spencer (1997) model.

D. Battery circuit

Most modern cell phones use a Lithium Ion battery cell as a power source. The Li-Ion technology provides a low energy-to-weight ratio; do not suffer from a memory effect and have a very low self-discharge rate when not in use. There are however, some inherent risks associated with Li-Ion battery cells. An unprotected Li-Ion cell can easily rupture, ignite or explode if short circuited, over charged or exposed to high temperatures.

To minimize the risks associated with using Li-Ion cell technology, a built-in IC protection circuit is incorporated into the battery pack as illustrated in Fig. 8. The battery cell also incorporates a cell vent system designed to limit the internal pressure to a safe level should a fault occur.

There have been a number of recent incidents where a Li-Ion cell has exploded causing personal harm in the form of 2nd degree burns. The mobile phone industry responded by launching a large scale recall of the mobile phones involved. What was later discovered is that many of the battery units at fault were counterfeit cells manufactured by unauthorized third parties. The battery cells did not incorporate the battery protection circuits that all legitimate manufacturers use in their design.

To insure public safety and to promote standardization of Li-Ion cell protection systems, the IEEE is currently in the process of releasing IEEE P1725 "Standard for Rechargeable Batteries for Cellular Telephones" [13]. The standard provides specific recommendations designed to limit component failures that lead to hazards. The standard recommends the use of output current limiting devices, thermal protection circuits and at least two overcharge protection functions designed to prevent overcharging a battery cell. The standard also provides recommendations on connector/terminal arrangements designed to prevent accidental short circuits.

All cell phone manufacturers in the test group incorporated a battery protection circuit to prevent short circuits and with the exception of one cell phone, all incorporated recessed terminals. It should also be noted that despite the protection circuitry, all batteries were labeled with warnings that burns or injury could result from shorting the battery terminals with metal objects.

To determine the effectiveness of the protection circuitry, the battery terminals were shorted in a darkened environment to determine if any visible sparks could be detected. No sparks were observed throughout the test group. The test results were consistent with a similar study done in 1999 by the Center for the Study of Wireless Electromagnetic Compatibility, University of Oklahoma [3] on 3.6V Li-Ion cells. Based on these observed results, the ignition potential associated with shorting the battery terminals was considered negligible.

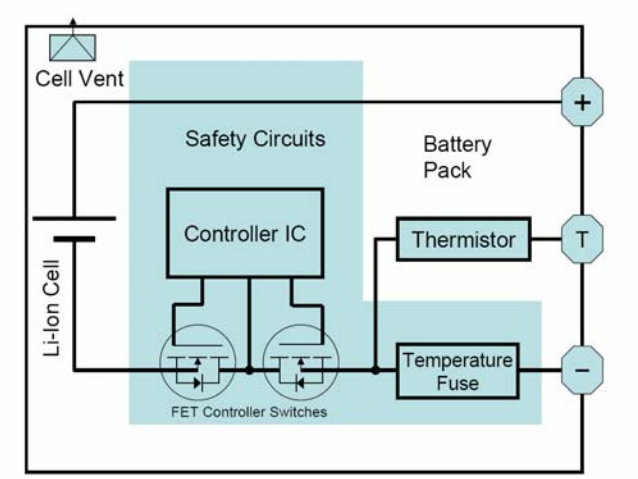

Fig. 8 Lithium-Ion Battery Protection Circuit

E. Excessive Temperatures in Normal Operation

In normal operation, the operating temperatures of cell phone components are well below the auto-ignition temperatures of all flammable materials.

Under abnormal conditions, the only component that could potentially act as a heat source is a short circuited battery. To determine if this was a potential risk, a test was performed to measure temperature rise under short circuit conditions. The surface temperature of the battery cell was measured prior to the battery terminals being shorted for a period of ten minutes. The temperature was again measured and compared to the original reading. In all cases, no measurable increase in temperature was noted. This implies that probability of a surface temperature reaching a flammable material autoignition temperature even under abnormal operating conditions is remote. The ignition risk associated with excessive temperatures was considered negligible.

F. Static Electricity

Although ISA RP12.12.03 does not specifically address the potential for static build-up on PEP, it is worth discussing as many of the incidents involving cell phones in a fire or explosion were eventually traced back to a static discharge.

For a static ignition to occur, a capacitive build-up of energy must occur on a non conductive surface. The energy stored on the charged surface must exceed the minimum ignition energy of the fuel mixture. The stored energy E on a part of capacitance C at a voltage V is based on the following relationship:

$$E = 0.5CV^2$$

The breakdown strength of air is around 6MV/m, therefore the minimum quench gap distance of 2mm corresponding to methane requires an ignition voltage of approximately 6kV. A stoichiometric mixture of methane requires 0.274 mJ of energy for ignition and thus requires an object to have a capacitance of at least 11pF. Similarly, a stoichiometric mixture of hydrogen requires 0.017 mJ of energy and therefore requires the object to have a capacitance of 0.94pF. Smaller objects require a higher voltage to provide the required ignition energy.

To determine if an object the size of a cell phone can build up a sufficient capacitance charge, the guidelines for enclosures provided in ANSI/ISA 12.00.01-2002 (IEC 60079-0 Mod) “Electrical Apparatus for Use in Class 1, Zone 0,1&2 Hazardous (Classified) Locations: General Requirements” [14] was used as a test criteria for cell phone enclosures.

By limiting the surface area of a plastic enclosure to less than 100 cm^2 for Group IIA (methane), and 20 cm^2 for Group IIC (hydrogen) an object can be considered inherently safe. The surface area dimensions for all cell phones in the test group ranged between 180 and 225 cm^2. Although the surface area exceeds the minimum no-test criteria, the surface area is minimal when compared to the surface area of a human body.

The male human body has a surface area of approximately 18,000 cm^2 and a capacitance in the range of 100-300 pF under ideal conditions. A human body charged to 6 kV stores around 3.6 mJ of energy; more than enough to ignite a hazardous mixture under ideal conditions. The ratio of charge build up by a cell phone compared to a human body is insignificant under these circumstances. In all likelihood, a static charge build-up would be the result of a human body static discharge rather than a static discharge from the cell phone itself.

It should be noted that a metallic object such a mobile phone case can act as an electrode and increase the risk of a static electric discharge from a charged human body.

Based on the analysis, the ignition risk resulting from a static build-up on the surface area of a cell phone was considered negligible.

G. Test Results Summary

None of the cell phones tested met the ISA RP12.13.03-2002 criteria for a PEP 2 device. The primary ignition risks noted were related to the risk of the battery separating from cell phone circuit or an impact spark discharge after being dropped. All other ignition risks were deemed negligible. Given the potential for a battery disconnect or spark impact discharge, the overall ignition source ranking for a cell phone best be described as a “weak” with an ignition potential of between 0.0 and 0.5 in accordance with the Rew and Spenser (1997) framework.

VII. COMPUTER MODELLING

As discussed in section V, the ignition of a flammable mixture requires an ideal flammable mixture and an active ignition source with sufficient energy to ignite the mixture. The relationship can be described in mathematical terms as follows:

$$\rho(FE)_t = \rho(FA) \times \rho(IGN) \times Ta/(Ta+Ti)$$

where:

$\rho(FE)_t$ = Probability of a Fire or Explosive Event at time t
$\rho(FA)$ = Probability of a flammable gas is present
$\rho(IGN)$ = Probability a spark ignition event of sufficient energy
Ta = Time a device is active
Ti = Time a device is inactive

All variables in the equation are subject to a range of probabilities which lends itself to a Monte Carlo statistical simulation analysis. A Monte Carlo simulation was applied to a range of different values for $\rho(FA)$, $\rho(IGN)$, *Ta* and *Ti* to generate a theoretical range of values for $\rho(FE)_t$. The simulation was run for 500 iterations using the following input models.

A. ρ(FA) - Flammable Atmosphere Present

The probability of a flammable mixture being present within a Division/Zone 2 classified location at any given time was modeled as a uniform distribution as illustrated in Fig. 9. The distribution approximates the probability of a flammable gas being present of between 1 hour and 10 hours per year which is consistent with definition of Class I, Division 2 or Class I, Zone 2 hazardous location.

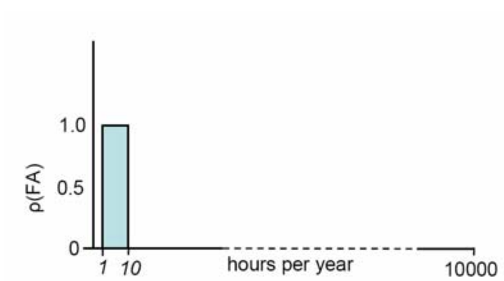

Fig. 9 Probability Distribution for a Flammable Gas being Present within a Class I Division/Zone 2 Area

B. ρ(IGN) - Spark Ignition Event of Sufficient Energy

To model the probability of ignition risk, a triangular distribution was selected with a range of values between 0.01 and 0.05 with a mode (most likely) value of 0.02. The probability distribution is illustrated in Fig. 10.

The value 0.01 was selected as the lower bound based on premise that a certified Class I, Division 2 or Zone 2 device has a theoretical ignition risk of 0.01. The 0.05 upper bound is based on the Rew and Spenser (1997) model for a "weak" ignition sources as illustrated in Table III. The most likely value (mode value) was set at 0.02 and reflects the very low number of potential ignition sources identified in the test group. The probability distribution selected is conservative and allows for the wide variety of cell phone configurations and technologies.

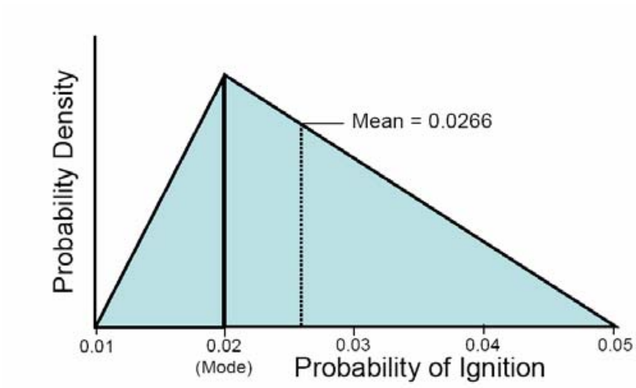

Fig. 10 Probability Distribution for an Ignition Event

C. Ta, Ti - Proportion of Time a device is Active and Inactive

The probability of a cell phone being active at any given time is given by the following relationship:

$$\rho(\text{Device Active}) = Ta / (Ta + Ti)$$

where:

Ta = Time device is active
Ti = Time device is inactive

A typical cell phone call lasts between 30 seconds and 20 minutes with an average duration of 3 minutes 15 seconds. For the purpose of the analysis, it is assumed that any conversations lasting longer than 20 minutes would likely be done in a non-hazardous area. The frequency of calls will vary with the individual and the model assumes the interval between calls varies between 3 minutes and 8 hours with the average being 20 minutes.

A triangular distribution was again used to model the values of Ta and Ti with the mode values of 3.25 minutes for Ta and 20 minutes for Ti. The probability distributions for Ta and Ti are illustrated in Fig. 11.

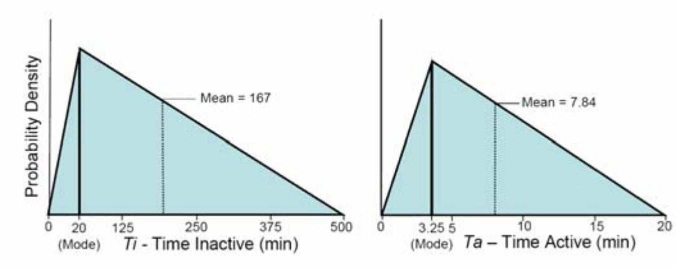

Fig. 11 Input Distributions for Ti and Ta

D. Probability Model Simulation

A Monte-Carlo statistical simulation using a Latin Hypercube sampling method was done for 500 iterations. The resulting output distribution was derived as illustrated in Fig. 12. The summary statistics associated with the simulation are provided in Table IV.

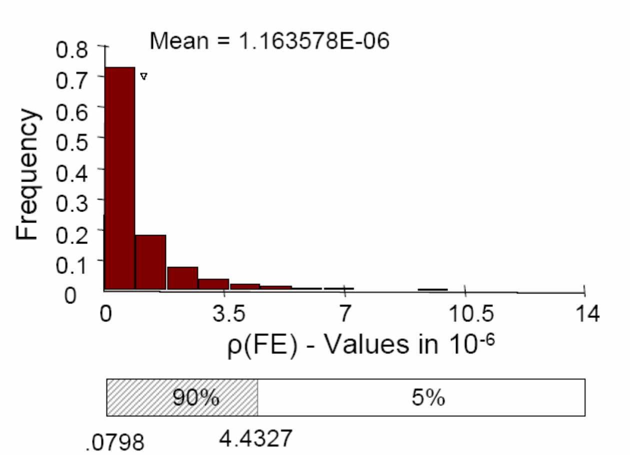

Fig. 12 Probability Distribution of a Fire or Explosion Resulting from an Ignition by a Cellular Phone

TABLE IV
Summary Statistics

Output Statistics - Fire/Explosion Probability							
Name	**Min.**	**Mean**	**Max.**	**x1**	**p1**	**x2**	**p2**
ρ(FE) =	2.73E-08	1.16E-06	1.37E-05	7.98E-08	5%	4.43E-06	95%

Input Parameters				
Name	**Min.**	**Mode**	**Mean**	**Max.**
ρ(FA) =	1.01E-04		5.50E-04	9.99E-04
ρ(IGN) =	1.06E-02	2.0E-02	2.67E-02	4.90E-02
Ta =	0.562	3.25	7.834	19.293
Ti =	6.956	20	167.688	471.013

The results indicate that the probability of a fire or explosion initiated by a cell phone is in the range of 0.0789E-06 and 4.4327E-06 with a 90% confidence level, with a mean value of 1.16E-06. This would imply that the probability of a cell phone causing a fire or explosion in a

Class I, Division 2/Zone2 hazardous location is in the range of approximately one in a million.

VIII. CONCLUSION

Cell phones are commonly used in petrochemical operations however; government regulations and company policies strictly limit the use of cell phones in hazardous locations. The representative sample of cell phones subjected to the ISA RP12.12.03-2002 design and performance criteria failed to pass the requirements for a PEP 2 device. This would imply that all cell phones in the test group posed an ignition risk in hazardous location.

Further testing and analysis indicated the greatest risk was associated with dropping a cell phone on a hard surface. The impact caused the battery to disconnect in the majority of cases and could potentially create an impact spark under ideal conditions. All other potential ignition risks were deemed negligible.

The Monte Carlo model simulation results estimated the probability of a fire or explosion resulting from the use of a commercial grade cellular phone in a Class I Division 2/Zone 2 hazardous location as negligible. This conclusion concurs with several previous studies where cell phones were deemed a negligible hazard in gasoline pumping operations.

While the research and conclusions of this paper indicate the probability of a cell causing an ignition in a Class I, Division/Zone 2 location are minimal, the authors do not suggest the potential hazard can be ignored. Mobile communication devices that are third party listed for use in hazardous locations are commercially available and serve to eliminate the risk of ignition. In all case, appropriate safety measures in accordance with Occupational Health and Safety (OH&S) regulations, electrical codes and other regulations must be observed.

IX. ACKNOWLEDGEMENTS

The Authors would like to acknowledge Dave Adams, P.Eng. and Greg Law from CSA International for their valued assistance and the use of their explosive testing facilities in Edmonton, Canada.

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H. VITA

Allan Bozek, P.Eng., MBA graduated from the University of Waterloo in 1986 with BASc in Systems Design Engineering and a MBA from the University of Calgary in 1999. He is a Principal with EngWorks Inc. providing consulting engineering services to the oil and gas sectors. Allan is a registered professional engineer in the provinces of Alberta, British Columbia, Saskatchewan and the Northwest Territories and Nunavut. He has been a member of the IEEE since 1989. Allan's areas of expertise include hazardous area classification, power systems, heat trace and digital control systems design for large scale industrial facilities.

Marty Cole has worked for Hubbell Canada for over 25 years and has been involved with hazardous locations for much of that time. He is a member of the Canadian Electrical Code (CEC) Part I - Section 18 Subcommittee and CSA's Integrated Committee on Hazardous Location Products. He was vice-chair of the task force that added the IEC Zone System to Section 18 and chaired the committee that adopted the IEC 60079 Series standards as CSA standards.

Marty is chairman of the Hazardous Location Products sub-section of Electro Federation Canada's (EEMAC) Wiring Products Section, a member of the Advisory Committee for the Objective Based Industrial Electrical Code (OBIEC), along with a number of other CSA Part 2 and IEC standards and technical committees. He has authored and co-authored a number of papers and articles on the subject of hazardous locations for the IEEE-PCIC, IEEE-IAS Magazine, EX Magazine and other industry publications.

Ken Martin graduated from the Southern Alberta Institute of Technology in 1982 in Electrical Engineering Technology and is an active member in The Alberta Society of Engineering Technology and received his C.E.T. in 1985. Presently after several years of selling in the petroleum/petrochemical community in Alberta he is an owner and technical sales representative for Brodwell Industrial Sales Ltd. in Calgary Canada. His primary focus is working with engineering firms and end users in the specifying of material for electrical equipment and controls in hazardous and non hazardous locations for over 18 years.

Appendix A
Survey of Major Producers Regarding Cell phone Use in Hazardous Locations

1. What is the primary means of communication for personnel working within a hazardous locations area?

Cell Phone	0%
Radio	80%
Land phone	0%
Other*	20%
Total	100%

*Comments
1 - Talking via air waves - no electronic allowed

2. Does your company issue cell phones to operations personnel? (if yes answer question 3 otherwise go to question 4)

Yes	80%
No	20%
Total	100%

3. Estimate the percentage of your operations personnel that routinely carry a mobile cell phone

0-10	0%
10-20	25%
20-40	50%
40-60	0%
80-100	25%
	100%

4. Does your company have a policy regarding the use of cell phones or two way radios in hazardous locations within their facilities? (if yes go to question 5, if no go to question 6)

Yes	100%
No	0%
Total	100%

5. Does the policy permit the use of these devices in facilities with hazardous locations?

Yes	40
No	60
Total	100%

6. Are there specific hazardous location rating requirements for the cell phones / radios for used in the facility?

Yes	80%
No	20%
Total	100%

7. Has your company had any recorded incidents related to the use of cell phones or radios in hazardous locations?

Yes	0%
No	100%
Total	100%

8. How does your company communicate their cell phone use policy to employees and visitors to their facilities?

Part of a safety orientation	0%
Safety handbook	25%
Permit practice	0%
Posted signs	0%
Other, Please Specify*	75%
Total	100%

*Comments
1-all of above
2-All of the above
3-Orientation & posted signs

9. Does your company have a policy for operating cell phones in company vehicles while driving?

Yes	80%
No	20%
Total	100%

10. How does your company communicate to visitors where areas classified as hazardous locations are?

Warning signs are posted in all areas	40%
Area Classification drawings in permit room	0%
No Policy in place	0%
Other, Please Specify*	60%
Total	100%

*Comments
1-Orientation, signs and Operation escorts
2-Onsite safety training is mandatory before entry.

Appendix B

Cellular Phone Summary Test Results

Sample Number	1	2	3	4	5	6	7	8
Generation	2G	2.5G	2.5G	2.5G	2.5G	2G	2.5G	2.5G
Year of Manufacture	1999	1999	2001	2001	1996	2001	2001	2001
Form Factor	Clamshell	Bar	Clamshell	Bar	clamshell	Bar	Bar	flip phone
Surface area (cm^2)	198.48	204.5	179.6	186.04	179.6	204.5	223.1	189.28
Weight (grams)	156	142.5	151	108	125	142.5	133	125
Battery Type	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Ni-MH	Li-Ion	Li-Ion
Battery Capacity	1600 mAh	900 mAh	850 mAh	750 mAh	900 mAh	900 mAh	800 mAh	900 mAh
Battery Voltage	3.6V	3.6V	3.6V	3.6V	3.6V	3.6V	3.6V	3.6V
Hazardous Location Warning in Manual	yes	yes	yes	yes	yes	yes	yes	yes
Battery Short Circuit Hazard Warning	yes	yes	yes	yes	yes	yes	yes	yes

Visual Analysis								
Power On-Off Switch	electronic	electronic	electronic	electronic	electronic	electronic	electronic	electronic
Vibrator	yes	yes	yes	yes	yes	no	yes	yes
Micro Contacts	no	no	no	no	no	no	no	no
Battery Security Method	single latch	single latch	dual latch	single latch	single latch	single latch	dual latch	single latch
Battery Connections	spring terminal	spring terminal	spring loaded flat	plug connection	spring terminal	spring terminal	spring terminal	spring terminal
External Electrical Connections	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
External Battery Charging Connections	Yes	No	No	No	No	No	No	No

Tests								
Drop Test	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Pass
Visual Damage Inspection	none	none	none	none	exterior damage	none	none	none
Operational test after Drop test	operated	operated	operated	operated	operated	operated	operated	operated
Battery Short Circuit (Visual)	No Spark	No Spark	No Spark	No Spark	No Spark	No Spark	No Spark	No Spark
Battery Short Circuit (Temp Rise ºC)	-3.6	-3	-0.5	-1	-0.8	-1.4	-0.7	-0.4
Vibrator Test (Test Chamber)	No Ignition	No Ignition	Not Tested	No Ignition	No Ignition	N/A	Not Tested	No Ignition