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Common Sense Approach to the Selection, Design/Fabrication, & Testing of Safe Operational Power Sources

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Outline

Common Sense Approach

- Background
  - Bob’s Terms/Advice
- Selection
- Design/Fabrication &
- Testing of Safe Power Sources
- Safety Testing of UltraLast AA Cells

BACKGROUND

MY PHILOSOPHY:

- USE A BATTERY ONLY IF NEEDED
- KISS
- USE COMMON SENSE
- FEEDBACK REQUIRED

EQUIPMENT PROBLEMS

THE CAUSES:

- ANTENNAES
- BATTERIES
- CONNECTORS

BATTERY / PORTABLE EQUIPMENT

AS

BULLET / GUN

BATTERIES
THE “ACHILLES HEEL”
OF
TECHNICAL OPERATIONS

Battery Bob's Mottos:

"Trust but verify"
Ronald Reagan

"Test everything;
retain what is good."
1 Thessalonians 5

PREMATURE BATTERY FAILURE CAN:

- CREATE LIFE THREATENING SITUATIONS
- RESTRICT COLLECTION INFORMATION

MOST BATTERY PROBLEMS ARE CAUSED BY PEOPLE WITH:

- **LITTLE OR NO INFORMATION**
- **MISINFORMATION**
- **LACK OF TRAINING/EXPERIENCE**

BATTERY BOB’S

TERMS/ADVICE

THE CAPACITY, ENERGY, POWER RELATIONSHIP

$$E \neq P$$

$$E_{Wh} = \underbrace{V_L(V) \times \overbrace{I_L(A)}^{}}_{P_L\ (W)} \times t\,(h)$$

$$C\ (Ah) = I_L(A) \times t\,(h)$$

L - load

THE CAPACITY, ENERGY, POWER RELATIONSHIP SYMBOLS

E = Energy (Work) (Wh)

P = POWER (W)

V = Voltage (V)

C = Capacity (Ah)

I = Current (A)

t = TIME (h)

L = load

AVOID BATTERY PROBLEMS BY:

- **Checking Mfgr's Spec Sheet**

  Note: No Standard Spec Sheet
- **Buying from High Volume Stores**
- **Knowing Date Codes**
- **Screening (Primary) OCV & CCV**
- **Screening & Matching (Secondary)**
- **Using Common Sense**

BATTERY BOB'S AXIOMS:

- THERE IS NO IDEAL CELL!
- ALL COMMERCIAL CELLS ARE ALWAYS UNDER DEVELOPMENT.
- KEEP BATTERY STASHES ROTATED & AVAILABLE TO ALL.
- DON'T MIX BATTERIES w/ BULLETS, COINS, or OTHER METAL ITEMS!

This is what happens if you do.

Name	Size	Chemistry	Temp oC	Temp oF
ECO	AA	Li/SOCl2	113-121	235-250
ECO	AAA	Li/SOCl2	94-106	201-223
Sanyo	CR-2N	Li/MnO2	61-70	142-158
Tadiran	TL-2200 C	Li/SOCl2	88	190
Tadiran	TL-2300 D	Li/SOCl2	70-90	158-194
Blue Star	D	Li/MnO2	50-116	122-241
Panasonic	BR-2/3A	Li/CF	149-151	300-304
Sanyo	HR-AA	Ni/MH	108-115	226-239
Sanyo	HR-4/3A	Ni/MH	73-75	163-167
Duracell	MX-1500 AA	Zn/MnO2	100	212
Sanyo	CR-2	Li/MnO2	76	169
Duracell	DL2/3A	Li/MnO2	91-93	196-199
Duracell	Ultra 123	Li/MnO2	78-93	172-199
Duracell	LM 123A	Li/MnO2	71-84	160-183

SECONDARY BATTERY CHEMISTRIES:

- **Nickel Cadmium-store discharged.**
- **Lead Acid-store charged.**
- **Nickel Metal Hydride-store discharged.**
- **Li-Ion-store 50% charged.**

- **Check out the equipment using the selected cell or battery instead of a DC power supply.**

- **The operation of equipment using a DC power supply may differ from the operation using other power sources.**

- **Where possible simulate the actual use regime as closely as possible.**

SELECTION

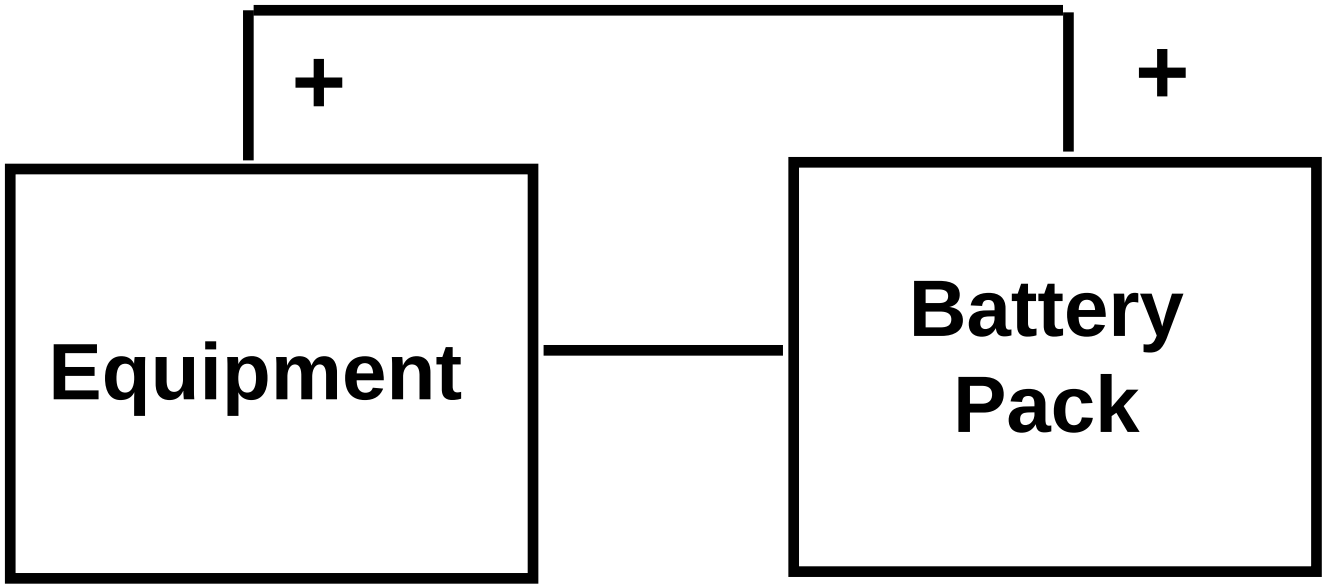
IF YOU WANT A BATTERY FROM ME PICK ONLY TWO BELOW:

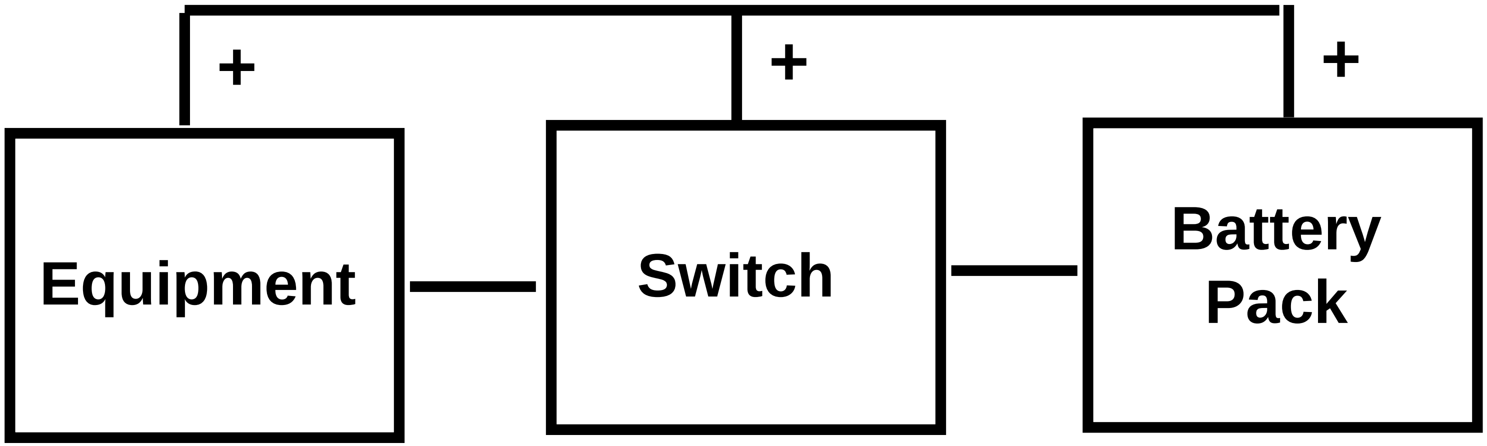
- QUICK
- CHEAP
- SMALL
- RELIABLE

Basic Tips for the User in the Selection of Batteries for Operational Use:

- Define your need as fully as possible.
- There is no ideal power source.
- Don’t make the choice of a power source a last minute decision.
- Keep the power source design simple.

TYPICAL BATTERY PACKS


+
+
Equipment
Battery
Pack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+
+
Equipment
Switch
Battery Pack

BATTERY

DESIGN/FABRICATION

CONSIDERATIONS

IF I DESIGN A BATTERY, SHOULD IT BE, A PRIMARY OR A RECHARGEABLE BATTERY?

IF I DESIGN A BATTERY, CAN I FABRICATE IT SAFELY? IN TIME?

IF I DESIGN A BATTERY, CAN I SHIP IT SAFELY? LEGALLY? IN TIME?

FOR LITHIUM BATTERY SHIPMENT QUESTIONS SEE YOUR SHIPPING OFFICER FOR GUIDANCE

WHAT DO I DO WITH THE BATTERY AFTER I HAVE FINISHED WITH IT???

CAN I DISPOSE OF IT SAFELY? LEGALLY?

FOR BATTERY DISPOSAL QUESTIONS SEE YOUR SAFETY OFFICER FOR GUIDANCE

APPLIED BATTERY DESIGN

SIMPLE APPLICATIONS

MAJOR DESIGN CONSIDERATIONS

1) **VOLTAGE**
2) **LOAD CURRENT**
3) **BATTERY LIFE**
4) **SIZE AND WEIGHT**
5) **ENVIRONMENTAL REQUIREMENTS**
6) **SAFETY VENTING**
7) **SAFETY FUSING**
8) **LAYOUT OF PACK TO REDUCE IR LOSSES**
9) **LAYOUT OF PACK TO REDUCE I^2R LOSSES**
10) **DIODE ISOLATION**
11) **CONNECTORS**
12) **LOW VOLTAGE CUTOFF FOR SOME Li CELLS**

MAJOR DESIGN CONSIDERATIONS VOLTAGE

- The devices with which the batteries are used have limitations on the maximum and minimum voltages between which they will work properly.
- The devices may also have limitations on the maximum voltage beyond which they will be permanently damaged.
- There might also be limitations on the minimum voltages below which they will have to be “reset”.
- Does the device perform consistently over the voltage range?
- Is there a preferred voltage?
- Are there multiple voltages required in one pack?

MAJOR DESIGN CONSIDERATIONS
VOLTAGE

- Batteries have maximum, minimum, and typical voltages. How do these match with the device requirements?
- If the battery's operating voltage range does not match the requirements of the device being powered, an electronics package may be needed to regulate the voltage. Otherwise, the full capacity of the battery might not be useable.
- An electronics package might also be needed to control the charging of the battery.

MAJOR DESIGN CONSIDERATIONS
CURRENT

- Affects the life of the battery
- Affects the size of the wiring in the pack and connectors
- Continuous high load current may have a thermal impact
- What is the nature of the current? Is it pulse? Continuous? A mixture of both?

MAJOR DESIGN CONSIDERATIONS *CURRENT*

PEAK CURRENT

- The voltage and capacity available from a battery is affected by the discharge current.
- As the current increases, the voltage decreases.
- As the current increases, the amount of capacity that the battery can deliver decreases.
- At some currents, the battery will not produce a usable voltage.

MAJOR DESIGN CONSIDERATIONS
CURRENT

PEAK CURRENT

- EVALUATE PRIMARY vs. SECONDARY
- Primary - good energy density (energy measured in Wh)
- Secondary - good power density (power measured in watts)
- Hybrid - utilize the best characteristics of each *(but with added complications)*

MAJOR DESIGN CONSIDERATIONS *CURRENT*

AVERAGE CURRENT

- The number of Ampere-hours that are required is determined by the average current consumed by the device being powered.
- If an average current is not known, it can be calculated from the individual loads, the currents during all operating conditions, and the duty cycle.

MAJOR DESIGN CONSIDERATIONS *LIFE*

How Long Before The Battery Can Fail?

- *Shelf Life*
  - How long must the battery be available before the device operating time starts?
- Operating Life
  - How long must the battery power the device?
- What about End of Life?
  - How Will The Battery Be Shut Down?

MAJOR DESIGN CONSIDERATIONS
LIFE

SHELF LIFE

- Effects of self discharge on battery life.
- Passivation - high initial pulse need.
- Cell seals - different seals start to leak at different times.
- Storage time before operation.
- Battery maintenance during storage.
  - Some chemistries need to be kept charged lead acid
  - Some chemistries have “memory effects”

MAJOR DESIGN CONSIDERATIONS *LIFE*

OPERATING LIFE

- Effects of discharge current on useable battery capacity.

- Effects of temperature on useable battery capacity.

MAJOR DESIGN CONSIDERATIONS *SIZE & WEIGHT*

CAN THE BATTERY BE CONCEALED?

- Will the weight give it away? *Too heavy or too light?*
- Will the size give it away? *Too big?*
- Will it fit in the electronics package? *Wrong shape?*
- Certain chemistries swell upon discharge.
- If a cell should go bad, is there enough capability left in the other strings to handle the mission?
  - Often a trade-off of size/weight versus redundancy.

MAJOR DESIGN CONSIDERATIONS
ENVIRONMENTAL REQUIREMENTS

- The performance of a battery is affected by the environment in which it will be used.
- Temperature has an impact on the battery.
  - Useable capacity.
  - High power pulses.
  - Function & Survivability
- The performance and battery design can be affected by other factors
  - Will the battery need to be moved?
  - How will it be moved
    - Road vehicle, Aircraft - Passenger/Cargo, Camel, Etc.
- Worldwide use? Indoor use? Outdoor? Tactical? Jungle? Desert? Snow? Salt fog?

MAJOR DESIGN CONSIDERATIONS *THINGS TO PONDER*

- SAFETY VENTING
  - If a cell should vent, a path for the escaping gases needs to be provided
  - How does this impact on the mechanical design of the electronics package?
- SAFETY FUSING
  - Depends on cell chemistry and/or # of cells

MAJOR DESIGN CONSIDERATIONS
PACK LAYOUT TO REDUCE LOSSES

- HEATING LOSSES = I^2R
- VOLTAGE LOSSES = IR
  - Length and size of wiring in the pack
  - Cell interconnects and location
- DIODE ISOLATION
  - Parallel strings of cells need to be diode isolated
  - Voltage drop across diodes
- CONNECTORS
  - Size and type
  - Wire leads?

MAJOR DESIGN CONSIDERATIONS *REFINING THE CHOICES*

- Verify cell selection will meet Operational Requirements

- **Electrical**
- **Environment**
- **Size and Weight**
- **Transportation**
- **Delivery Schedule**
- **Redundancy**
- **Reliability**
- **Cost**
- **Safety**
- **Further trade-offs**

MAJOR DESIGN CONSIDERATIONS
CELL SELECTION

NOT ALL CELLS PERFORM THE SAME

- This is true for:
  - Different chemistries
  - Same chemistries, but different manufacturers
  - Same chemistry and manufacturer, but different sizes
  - Same chemistry and manufacturer, but different manufacture date
- Not all cells are equally predictable or reliable in their performance.

PERFORMANCE
RELATIVE TO MODEL

Different versions of cells give different performance characteristics

Even if they are the same chemistry, manufacturer and size

PERFORMANCE
RELATIVE TO MANUFACTURING DATE

Cell manufacturers change the way cells are built. A cell built one year may be different from another year.

There are many reasons:

- **Cost/Profit**
- **Competitive performance**
- **Build-to-build variation**

PERFORMANCE
RELATIVE TO SIZE

Different size cells give different performance characteristics

Even if they are the same chemistry, manufacturer and general construction (i.e. prismatic, bobbin, spiral wound).

PERFORMANCE RELATIVE TO CHEMISTRY

Different chemistry cells give different performance characteristics.

Even if they are the same size, the chemistry has different characteristics associated with it.

There may be construction differences as well. These may be needed by the nature of the chemistry (Different materials in the can, etc.)

PERFORMANCE RELATIVE TO CUT-OFF VOLTAGE

The amount of Capacity that a cell can deliver can be greatly affected by how low a voltage that the cell can be discharged and still do useful work.

This can be affected by both discharge rate and temperature.

Low voltage cutoff a must for some high powered lithium batteries to prevent reversal.

MAJOR DESIGN CONSIDERATIONS
CELL AVAILABILITY

- **Forward Deployed**
- **Warehouse**
- **Contractor Stockpile**
- **Commercial Purchase**
- **Special Purchase**

MAJOR DESIGN CONSIDERATIONS

CELL LEVEL TESTING

- Qualification Testing
- Lot Acceptance
- Screening
- Specialized testing
  - Environmental
  - Mission Profile
  - Safety

MAJOR DESIGN CONSIDERATIONS
BATTERY LEVEL TESTING

- Environmental
- Safety
- Mission Profile
- Qualification
- Screening

BATTERY PROGRAM CHECK LIST

ELECTRICAL REQUIREMENTS

1. Max. No Load Volts: ____________ V
2. Steady-State or No-Pulse Load Data:
   - Max Volts: ____________ V
   - Min, (CUTOFF) Volts: ____________ V
   - Current at Max. Volts: ____________ V
   - Current at Min. Volts: ____________ V
3. Pulse Load Data (IF APPLICABLE):
   - Duration of Pulse: ____________ msec
   - Frequency of Pulses: ____________
   - Max. Volts ____________ V
   - Min. (CUTOFF) ____________ V
   - I @ Max. Volts (PEAK): ____________ mA
   - I @ Max. Volts (AVE.): ____________ mA
   - I @ Min. Volts (PEAK): ____________ mA
   - I @ Min. Volts (AVE.): ____________ mA
4. Duty Cycle: ____________ Hrs On-Off/Week
5. Service:
   - Actual On Time (MEDIAN): ____________ h
   - Electrical Capacity: ____________ Ah
   - Storage Time Prior to Use (MAX.): ____________ h
   - Total Unit Life (Max.) ____________ h

PHYSICAL REQUIREMENTS

1. Size if Prismatic:
   - Length: ____________ mm/in
   - Width: ____________ mm/in
   - Height: ____________ mm/in
2. Size if Cylindrical:
   - Diameter: ____________ mm/in
   - Height: ____________ mm/in
3. If Irregular Size, Specify: ____________
3. Weight: ____________ g/oz
4. Position of terminals (TOP OR SIDE): ____________
5. Submit Drawing (IF APPLICABLE) of Device Housing Cells/Battery Pack. (USE BACK OF SHEET FOR DRAWING.)

ENVIRONMENTAL REQUIREMENTS

(Note: The electrical requirements presume a temperature of 24 °C (75 °F). It is desirable to specify the electrical requirements at the maximum and minimum temperatures expected.)

1. Storage:
   - Expected Temp. Range: ____________ °C/°F
   - Expected Avg. Temp.: ____________ °C/°F
   - Expected Humidity Range: ____________
   - Expected Avg. Humidity: ____________
2. Use:
   - Max. Temp: ____________ °C/°F
   - Min Temp.: ____________ °C/°F
   - Expected Temp.: ____________ °C/°F
   - Expected Humidity Range: ____________
   - Expected Avg. Humidity: ____________
3. Shock and Vibration: ____________
4. Applicable Specifications: ____________
5. Other: ____________

OTHER REQUIREMENTS

1. Reliability: (What Minimum Capacity is Desired at What Confidence Level?)
   ____
2. Battery Disposal: ____________
3. External Signature: ____________
4. Transportation: (Very Important For DOT Regulated Power Sources.) ____________
5. Delivery Schedule (Include Testing): ____________
6. Operation Scenario(s) – (Be As Specific as possible. Use separate sheet for details if necessary. Classify appropriately.) ____________
   ____
   ____

FOR RECHARGEABLE POWER SOURCES ONLY

1. Desired Charge-Discharge Cycles: ____________
2. Depth of Discharge (DOD) ____________ %
3. Minimum Charging Time: ____________ h
4. Normal Charging Time: ____________ h
5. Charging Modes:
   - Constant Current: ____________
   - Current Trickle: ____________
   - Constant potential: ____________
   - Constant Potential (FLOATING): ____________
6. Types of Use:
   - Frequent: ____________ h/week
   - Standby: ____________ h/week
7. Charging Temp Range: ____________ °C/°F
8. Other Charging/Charger Info:
   ____

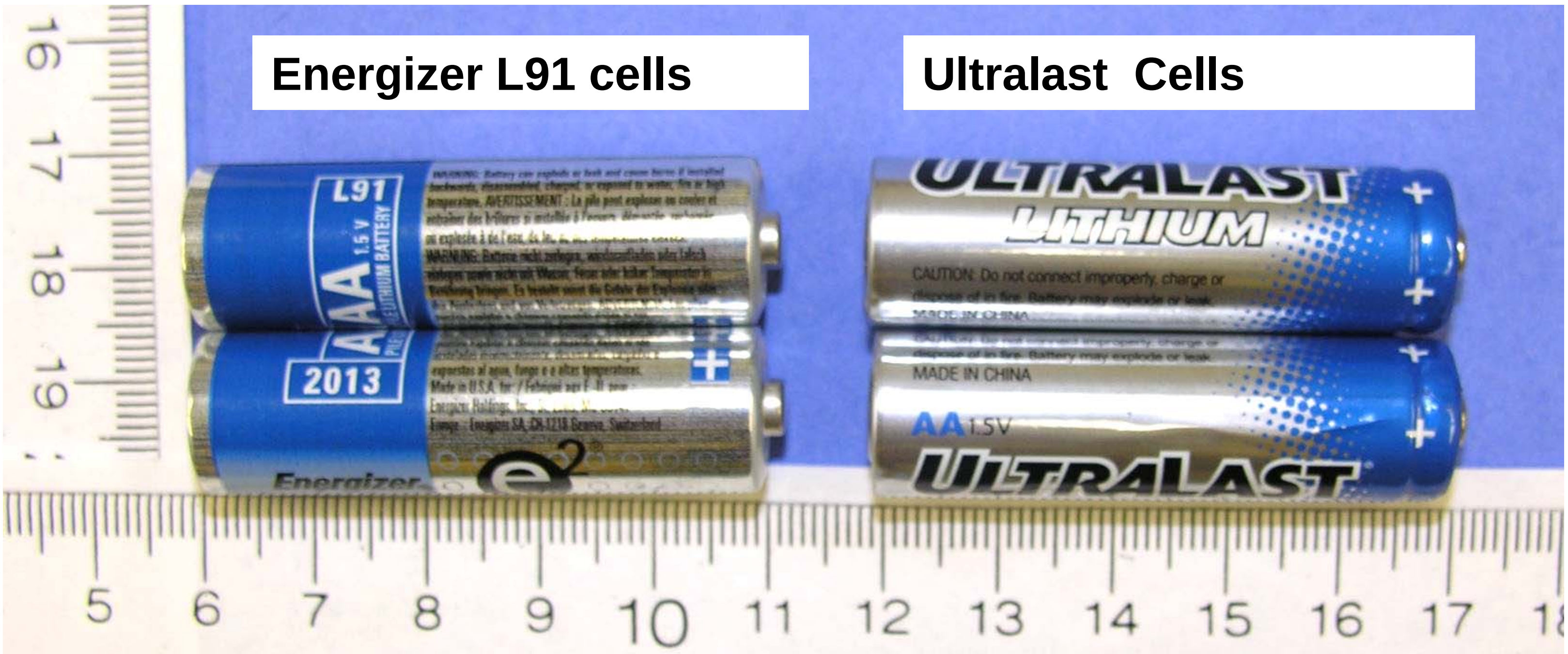
ULTRALAST Li/FeS_2 AA CELLS

Circa early 2006

Background Info

Chinese made AA Lithium Iron Disulfide (Li/FeS2)cells were shipped to the US and sold under the Ultralast label. The Ultralast label was very similar in appearance to the label Energizer uses for its Li/FeS2 AA cell Comparative Safety Testing was done on both the Energizer and Ultralast Li/FeS2 cells.

Introduction



Introduction

UN TESTING
of
Energizer
&
Ultralast
AA Cells

UN TEST #5: External Short Circuit Test

- Six (6) undischarged Ultralast cells were subjected to a short circuit test of less than 100 milliohms while maintained at 55 °C.
- The output voltage, current, and skin temperature were continuously monitored during the test.
- The short circuit condition was maintained for a minimum period of one (1) hour after the cell skin temperature had returned to 55 °C. The cells were observed for an additional period of six (6) hours.

UN Test #5: External Short Circuit Test Results

- The highest maximum short circuit current was 10.47 amps, while the lowest was 6.54 amps.
- Two cells exhibited fire, with flames emanating from the positive end vent holes, the first cell at 2 hours, 31 minutes, and the second cell at 3 hours, with enough pressure release to pop the oven door open, and temperatures exceeding 170 °C (i.e. 341 °C, and 355 °C). The other four (4) cells oozed a tan colored material from the positive end, and two (2) of them reached 134 C.

Results-Comparison UN Test #5: External Short Circuit Test

- The Energizer L 91 cells, (with 10 cells tested under the same conditions), reached a highest maximum short circuit current of 14.13 amps, while the lowest was 12.57 amps.
- The highest skin temperature reached by any of the cells was 97 °C. None of the cells exhibited fire, rupture, disassembly, or temperature exceeding 170 C.

UN TEST #6: Impact Test
A Lot of Reaction #4 Cell.

Five (5) undischarged Ultralast cells were subjected to the United Nations Impact Test (Test # 6)

The cell under test rested upon a Pine wood “flat surface”, measuring 5 - 1/2 inches X 5 - 1/2 inches X ¾ inch thick. A 5/8 inch diameter hardwood dowel “bar” rested upon the center of the cell, such that the “bar” was perpendicular to the longitudinal axis of the cell and parallel to the “flat surface”. A 20 pound mass was allowed to fall a distance of 24 inches before impacting the “bar”.

UN TEST #6: Impact Test Cont'd.

Upon impact, and for a six (6) hour observation period thereafter, the first three (3) cells demonstrated no evidence of fire, disassembly, or temperature exceeding 170 °C. The highest temperature achieved by any of those cells was 27 °C.

UN TEST #6: Impact Test Cont'd.

The fourth (4th) cell, at 30 seconds after impact, reacted with the ejection of the positive end cap, followed by the violent expulsion of fire and burning material from the positive end (some of which penetrated the aluminum screen), thus, meeting the definition of disassembly. During the period of burning, the cell skin temperature rose to 601 ºC.

The fifth (5th) cell, upon impact, and for a six (6) hour observation period thereafter, reacted the same as the first three cells.

UN TEST #6: Impact Test Cont’d.-Comparison

Previously, the Energizer L91 cell had five (5) cells subjected to the Impact Test.

Upon impact, and for a period of six (6) hours thereafter, there was no evidence of fire, or disassembly, and the maximum case temperature achieved by any of the cells was 95 °C (maximum allowed = 170 °C). Although the end caps were dislodged, they did **not** penetrate the aluminum screen. Therefore, the cells did **not** meet the definition of disassembly.

UN TESTS #5 & #6: Conclusions:

- Ultralast Li/FeS2 cells failed UN Tests #5 & #6.
- Energizer Li/FeS2 cells did not fail UN Tests #5 & #6.
- Cells which do not meet UN Tests should not be imported into the US for sale.
- The Ultralast AA Li/FeS2 cells are no longer being sold in the US but other Chinese AA Li/FeS2 cells are available on the Internet.

Note: 49 CFR 171.12 (a) Battery Importers

"Each person importing a hazardous material into the US shall provide the shipper and the forwarding agent at the place of entry into the US timely information on the requirements of the regulations that apply to the shipment."

SAFETY TESTING
VIDEO of
ULTRALAST
Li/FeS_2
AA Cells

Contact Information