SAFETY ISSUES
AND
LITHIUM ION TECHNOLOGY

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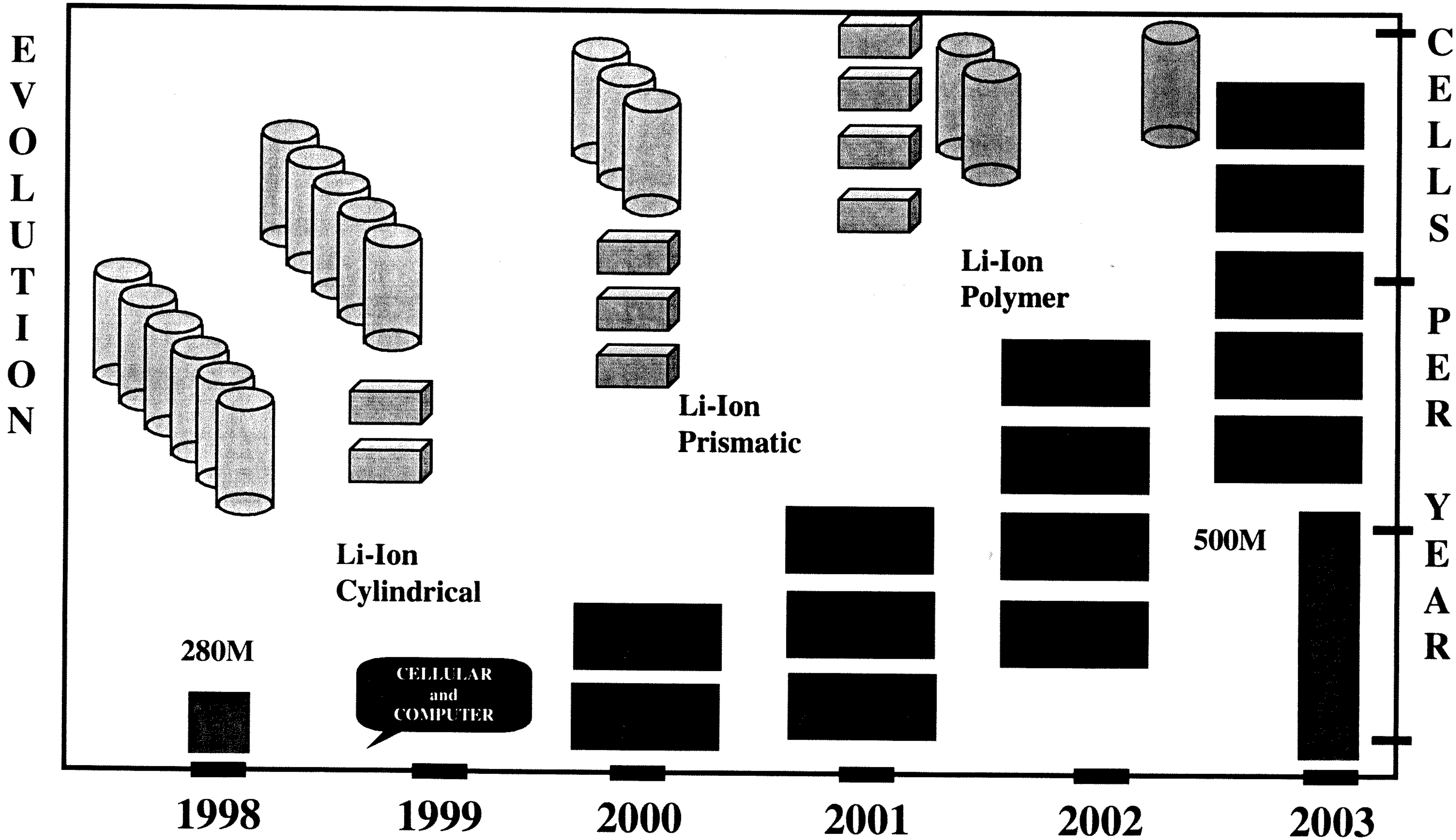
★ Presentation Outline

- Lithium Ion & Lithium Ion Polymer Technology Roadmap
- Current Trends in Lithium Ion Industry
- Design Guidelines - Technology to Market
- Motorola's Wall-to-Host Energy System Philosophy
- Safety Issues with Lithium Ion Technology
  - Events Leading to Overheating
  - Lithium Ion Cell Overcharge Profiles
  - Thermal Runaway Efects
  - Thermal Stability vs. State of Charge
  - Overcharge Protection
  - Shutdown During Overcharge
  - Current Interrupt Device
  - Shutdown Separator
- Safety Test Procedures
- Conclusions

Lithium Ion & Lithium Ion Polymer Technology Roadmap

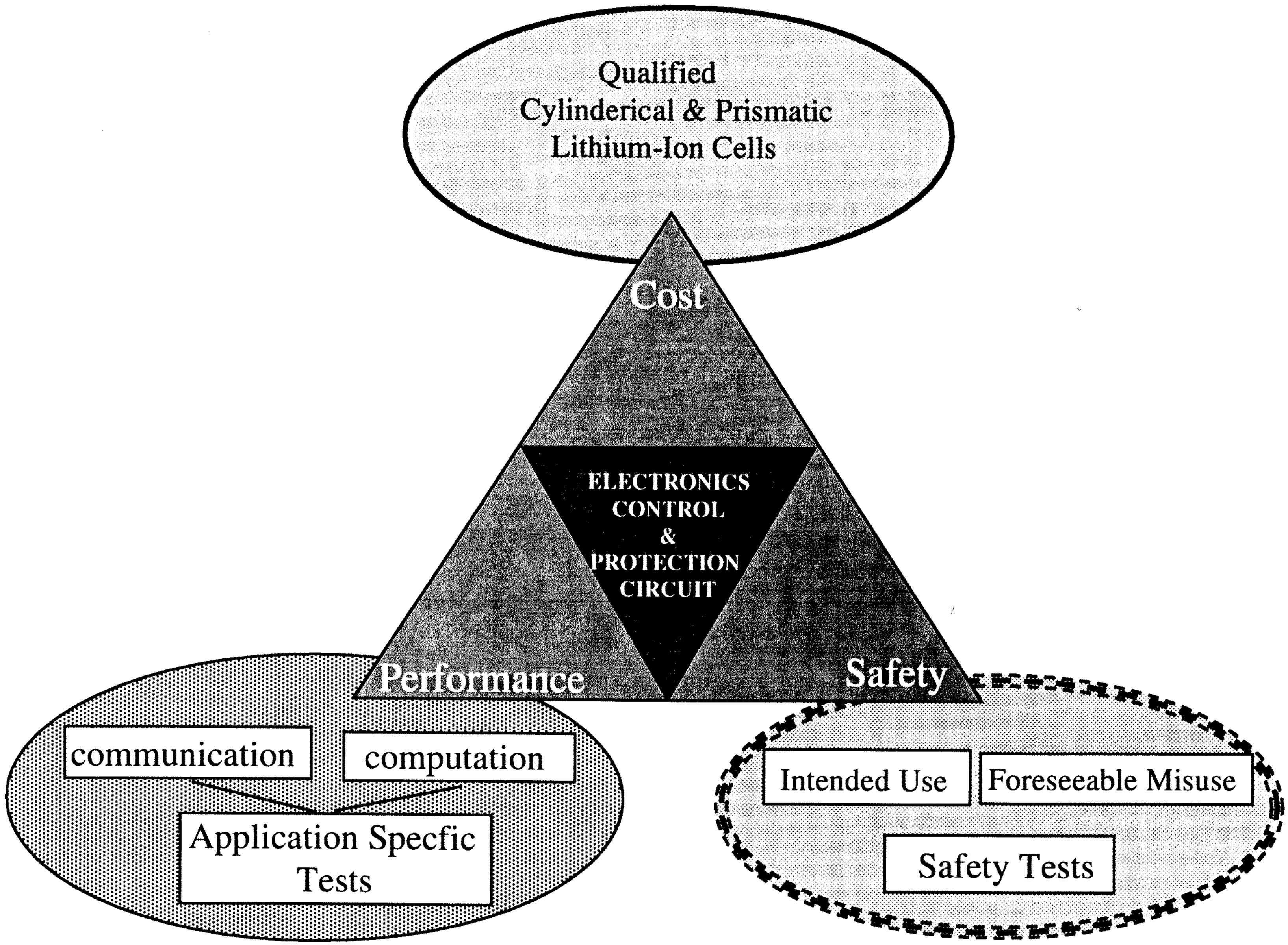


Current Trends in Li-ion Industry

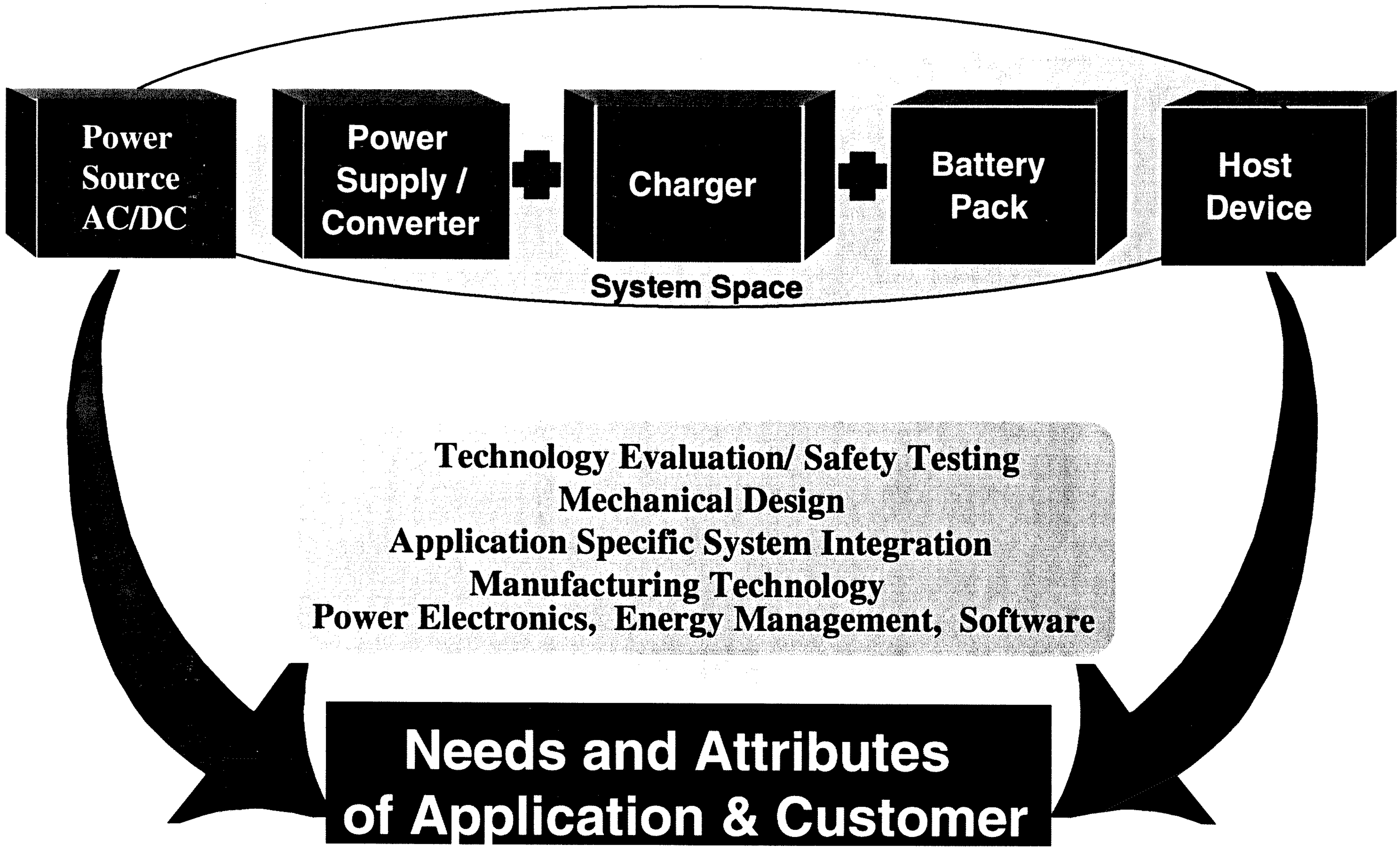
- **Continued rapid growth in marketplace**
  - Transition from "specialty product" to "commodity"
  - Will familiarity bring complacency with respect to safety?

- **"Next generation" Li-ion technology**
  - Electrode materials (cathode)
  - "Li-ion polymer"
  - Safety implications must be carefully evaluated

Design Guidelines - Technology to Market



"WALL - TO - HOST" ENERGY SYSTEM



Safety Issues

- High Energy Density
- Flammable Electrolyte
- Possible presence of Li metal (abuse conditions)
- Limited thermal stability of electrode materials
- Irreversible electrolyte electrolysis

Li-ion

organic electrolyte → oxidized & reduced products

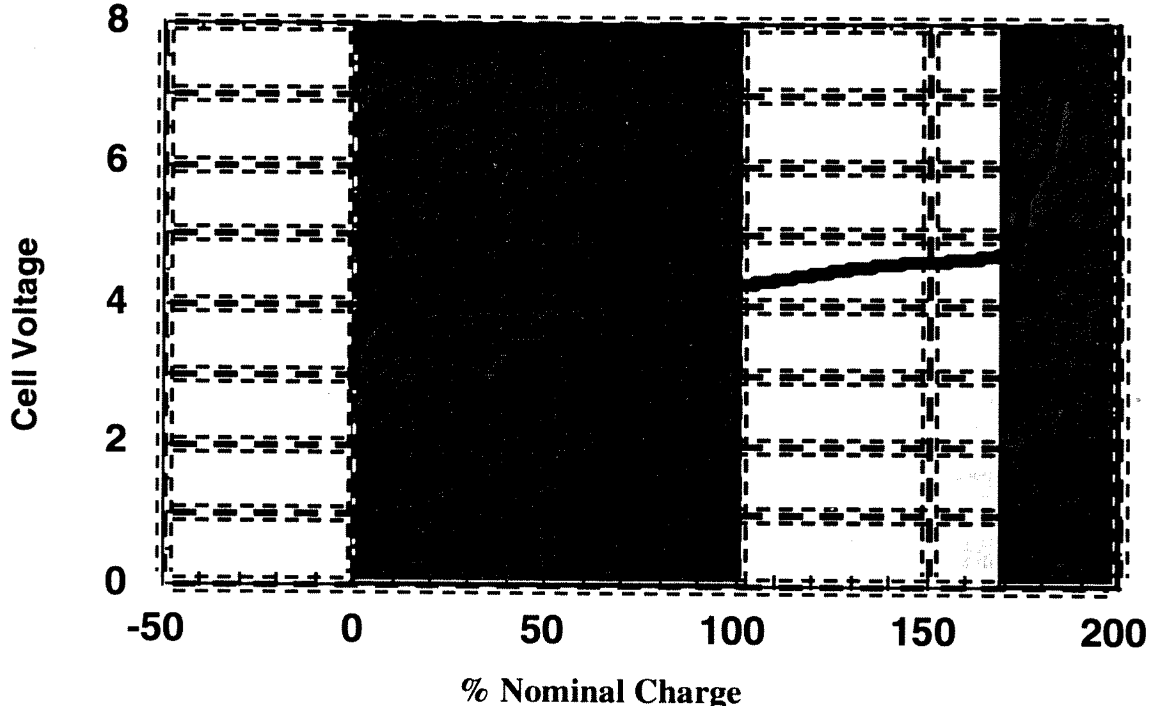
Decomposition onset - 4 to 5 V per cell
IRREVERSIBLE!

Safety Issues
Events Leading to Overheating

- Normal operation
  - High Currents and/or Poor Heat Exchange
  - Minimal risk in current applications
  - Scale-up to high power/large cells requires careful evaluation

- Abuse conditions
  - Severe thermal exposure
  - External short-circuit
  - Internal short-circuit
    - Manufacturing flaw
    - Mechanical abuse (crush, penetration)
    - Creates severe local heating
  - Overcharge

Safety Issues
Li-ion Overcharge



- Region I: overdischarge
  - Benign failure
- Region II: normal operation
- Region III: cell degradation
  - Li plating begins
  - Electrolyte decomposition
  - Excessive delithiation of cathode
- Region IV: risk of thermal runaway
  - Complete delithiation of cathode
  - Impedance/voltage/heating increases

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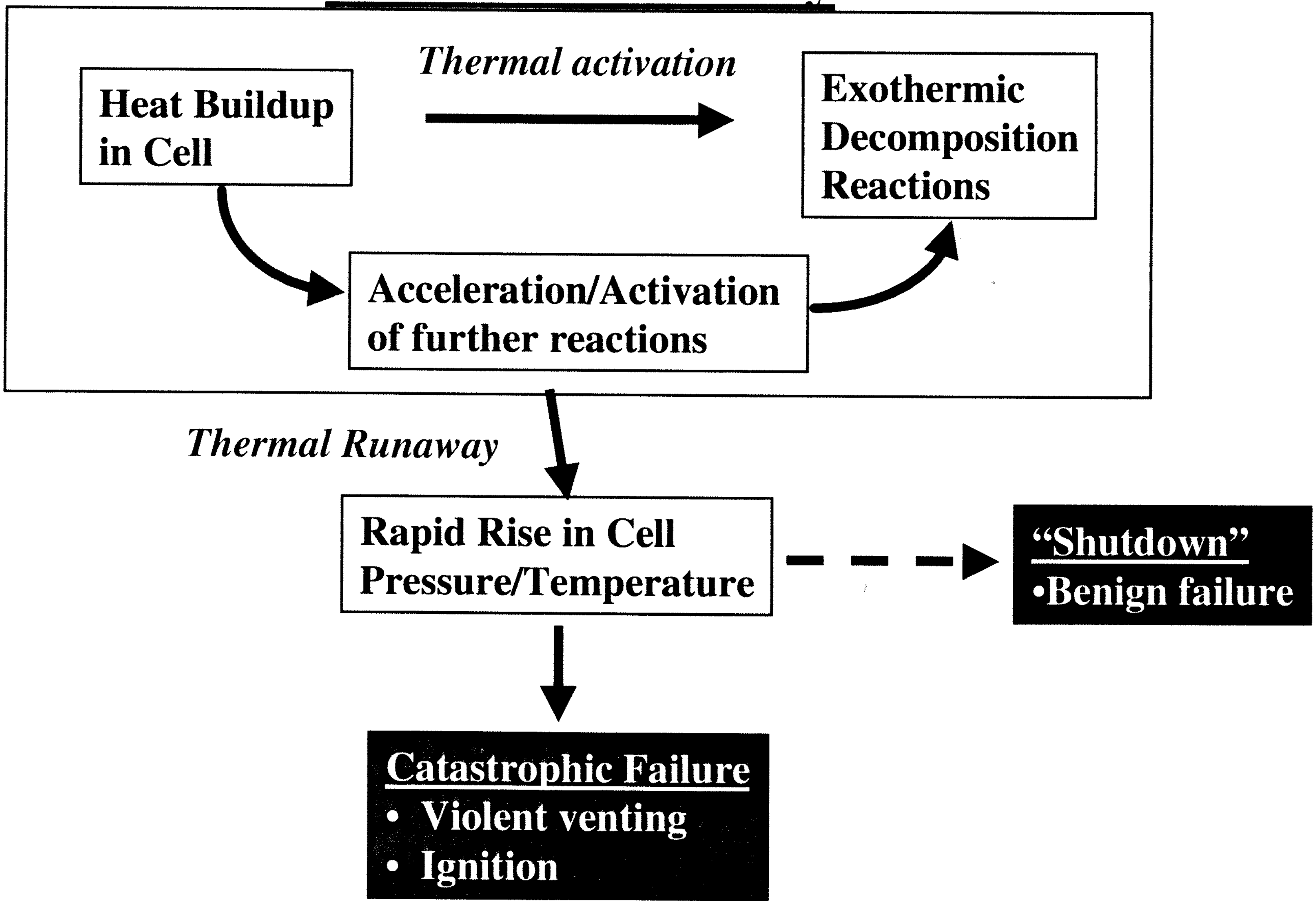
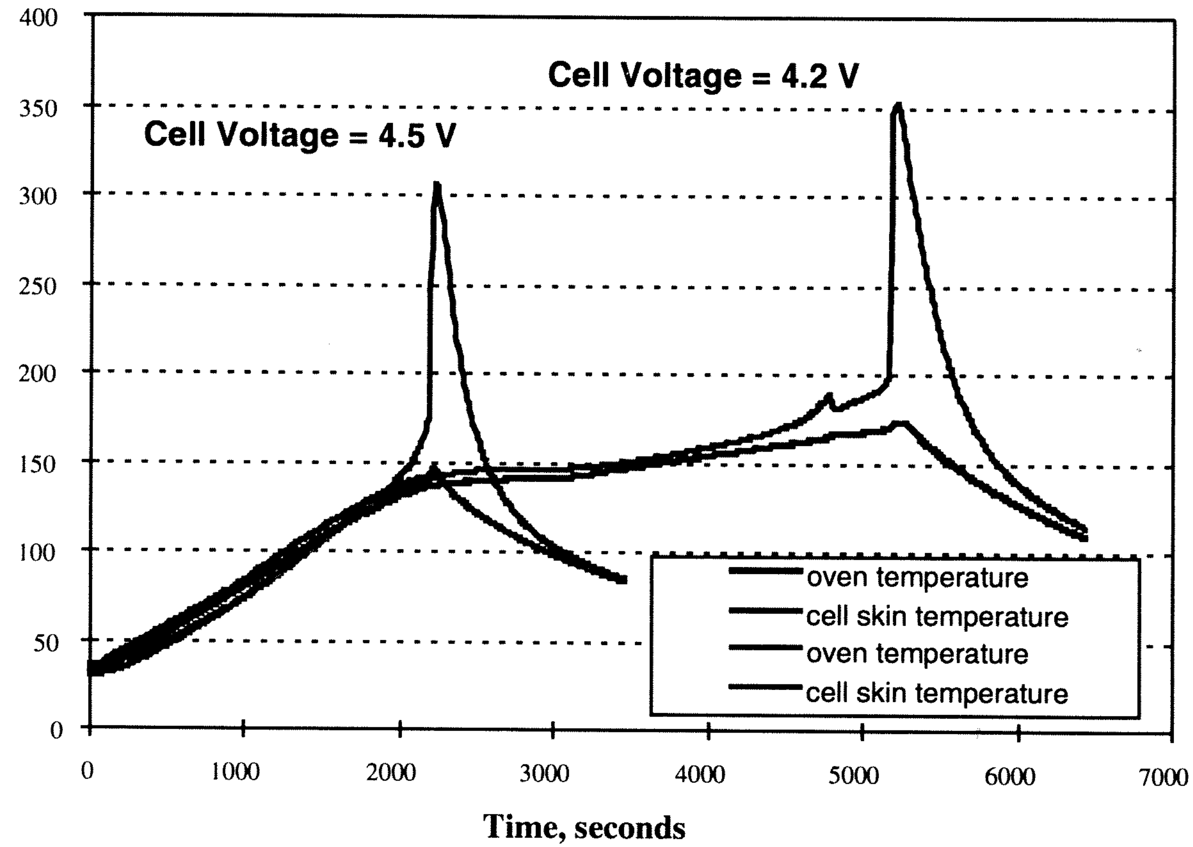
Safety Issues
Thermal Runaway



Safety Issues
Thermal Stability vs. State of Charge



Cell Voltage = 4.2 V

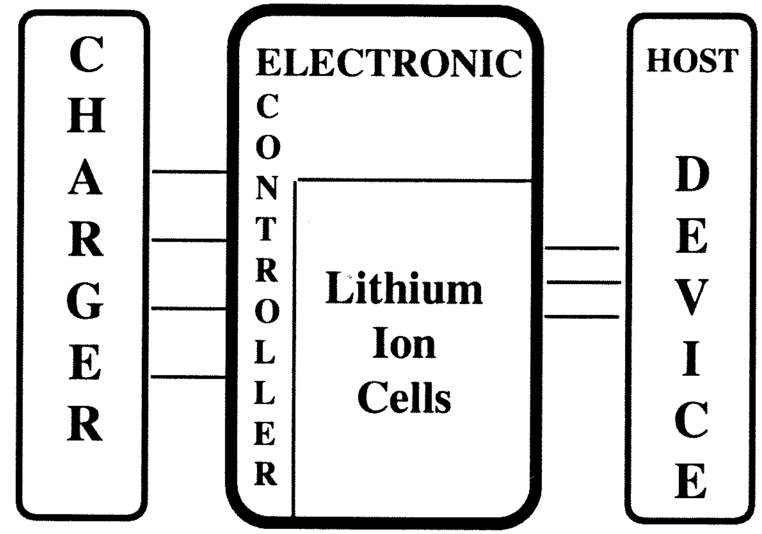
- Normal charge regime
- Critical cell temperature - 170Þ C

Cell Voltage = 4.5 V

- Overcharged cell
- Critical cell temperature - 140Þ C

Safety Issues
Overcharge Protection

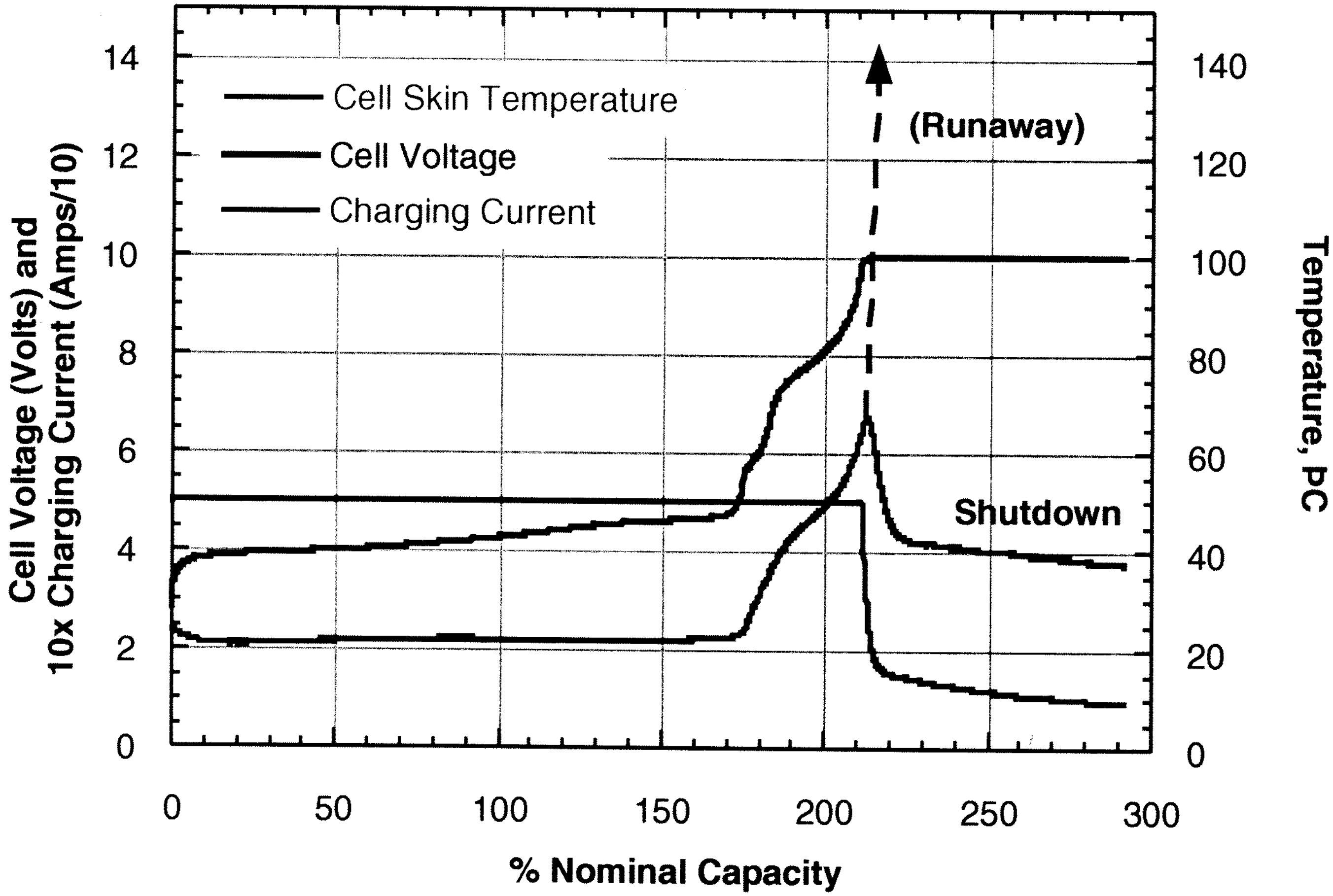
- **Redundant Electronic Protection**



- **Cell Design Parameters:**
  - Electrode coating parameters
  - Cell dimensions
  - Materials ratios

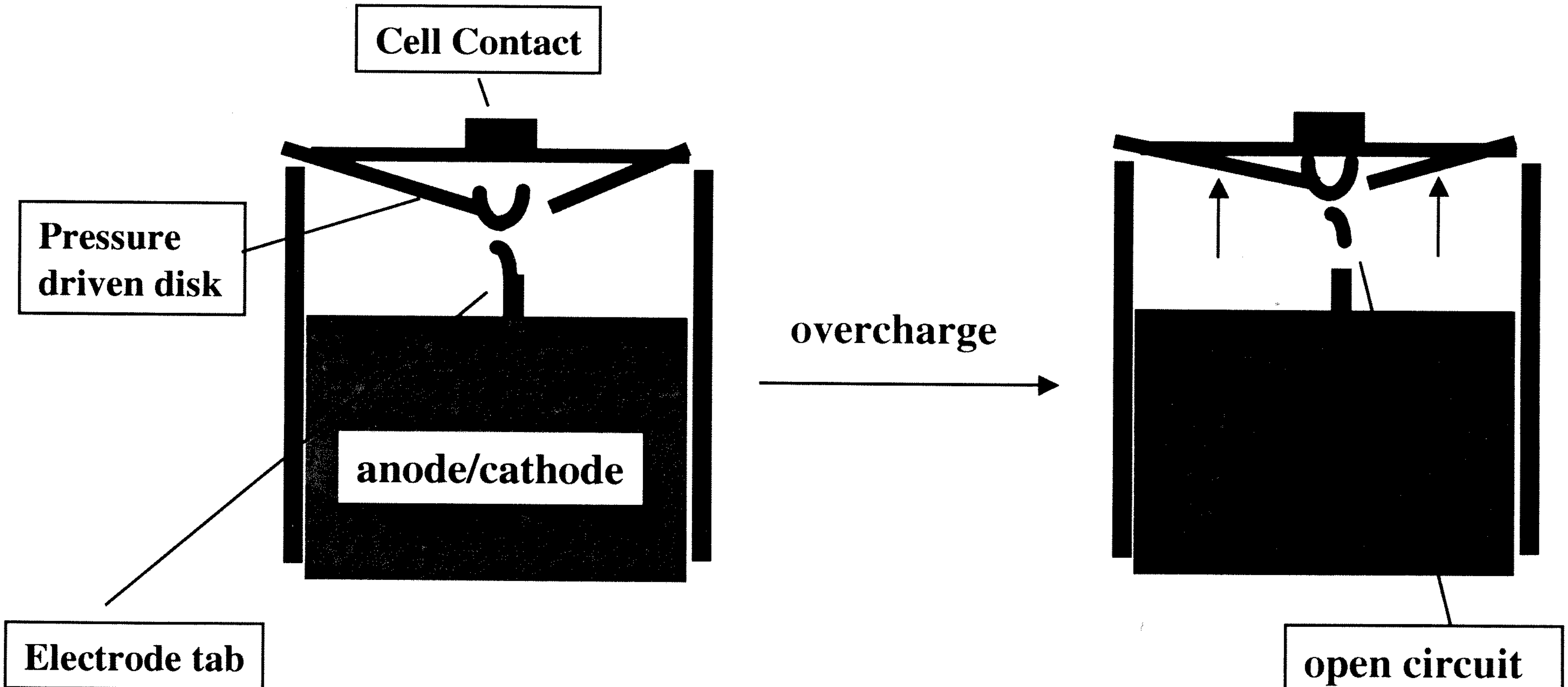
- **Cell level "shutdown" mechanisms**
  - Round cells: current -interrupt device
  - Prismatic cells: shutdown separator

Safety Issues
Shutdown During Overcharge



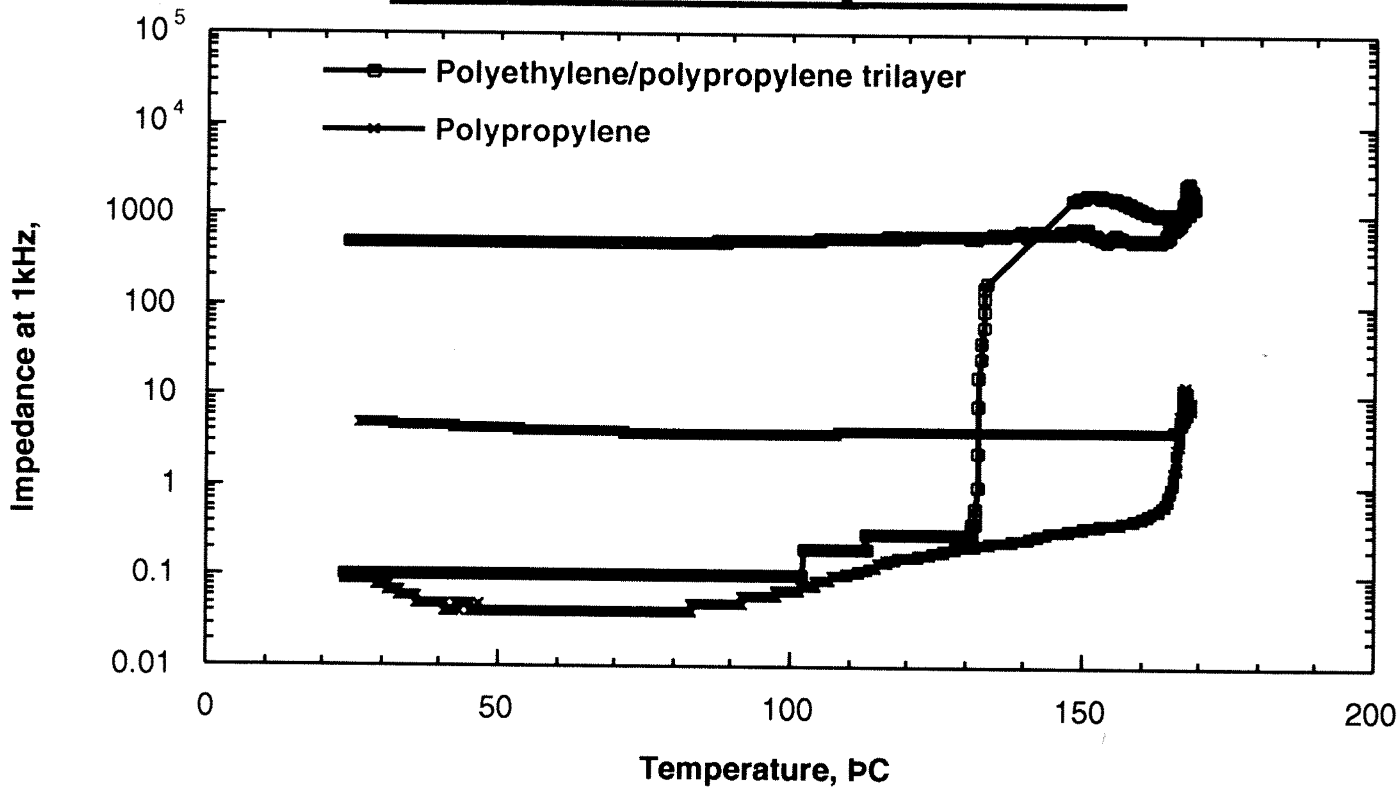
Large impedance increase ⟶ Current reduced/eliminated

Safety Issues
Current Interrupt Device



- Pressure build-up triggers CID.
- Gas generating additives often used.
  Li_2CO_3 ---> CO_2

Safety Issues
Shutdown Separators



- Porous separator melts blocking ionic conduction
- Impedance increases 100x to 10,000x
- Current limited to small value

Safety Test Procedures 1

IEC tests	UL tests	Test Parameters	Remarks
Requires no fire, explosion			
Overcharge	Abusive overcharge	Charge at $2I_0$ to 6 V; insulated	*Based on EPD benchmarking*
High rate charge	Abnormal charge	Charge at $3I_0$ to Vref; 100% charge; insulated	modified IEC
Forced discharge	Forced discharge	Discharge at I_0 to -10 V; 12.5 hours, insulated	modified IEC
Short circuit	Short circuit	1) ambient 2) 60°C	same as UL/IEC
Thermal exposure	Heating	ramp to 150°C at 5 C/min; 150°C for 1 hour	modified UL
Requires no fire, explosion, leak, or vent			
Continuous charge		Charge at I_0 to V_{ref}. Maintain V_{ref} for 28 days	modified IEC

✹ Safety Test Procedures 2

IEC tests	UL tests	Test Parameters	Remarks
Requires no fire, explosion			
		1/8" nail; ambient	omitted from UL and IEC
Drop	Drop	3 times per plane from 1 m to concrete	IEC/UL combination
Flat plate crush	Flat plate crush	see UL2054	IEC/UL
Impact	Impact	see UL2054	IEC/UL
Requires no fire, explosion, leak, or vent			
Shock	Shock	see UL2054	IEC/UL
Vibration	Vibration	see UL2054	IEC/UL
High temp. storage and thermal shock	Mold stress relief Temperature cycling	75IC / 48h ; 5 min 20°C / 6h 5 min 20°C / 24h 70°C / 4h ; 20°C / 2h; -40°C / 4h ; 20°C / 2h ; 10 complete cycles store for 10 days	combined IEC and UL tests into single test; single set of samples
Altitude simulation		Vacuum chamber to S3 torr (50,000 ft) 1) ambient 2) 60°C	modified IEC

Conclusions

- Li-ion technology can be used safely in portable electronic devices only with electronic control & protection circuitry.

- Safety implications of new developments should be monitored carefully.

"Li-ion Polymer"

- Chemistry very similar to Li-ion
  - Carbon anode/metal oxide cathode
  - Packaging: soft polymer laminate vs. steel can

- Polymer"Gel" Electrolyte
  - Electrode/electrolyte "glued" together
  - Polymer blended with liquid solvent plasticizer
    - Typically same solvents used in conventional Li-ion
    - Flammable material

- Safety
  - Similar chemistry ⟶ Similar safety issues
  - *Expect safety to be comparable to existing Li-ion*

New Cathode Materials

Material	Reversible Specific Capacity, mAh/g	Thermal Decomposition Limit of Charged Material, °C
$LiMn_2O_4$	80-110	- 360
$LiCoO_2$	130-150	- 220
$LiNi_XM_YO_2$*	150-210	170-220

*M=Co, Al, etc. Doping levels vary from 0 to 20%.

Co	Mn	Ni and NiCo
"standard" material	low capacity	highest capacity
moderate thermal stability	high thermal stability	low thermal stability?
good cycle-life	low cycle-life?	good cycle-life?

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