



# High Voltage Li-Ion Space Batteries 2007 NASA Battery Workshop

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- ABSL's experience with high voltage systems
  - High voltage: safety focus
  - Pre-Space Battery High Voltage Work
  - AHPS
  - KSLV-1
  - Future Programs

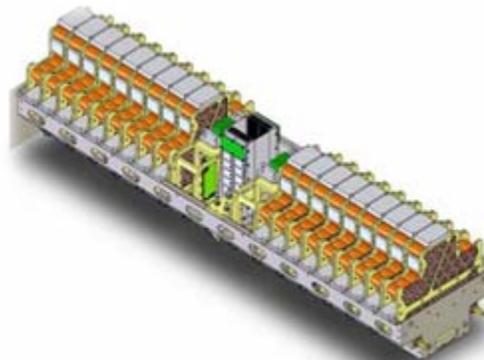
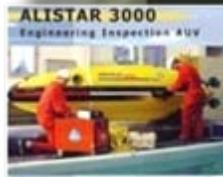
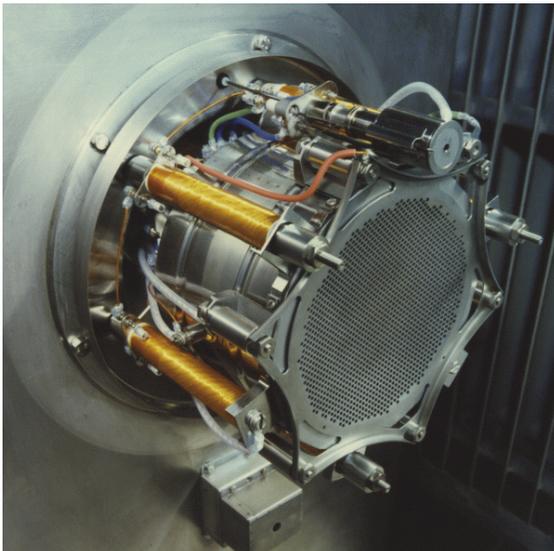
# Safety & High Voltage

- Voltages as low as 50 V can pose a severe risk to human operators
- ABSL has safely built and delivered batteries in excess of 300 V
- Consideration of safety during build, test, shipping, integration, and operation in such high voltage application is, therefore, critical

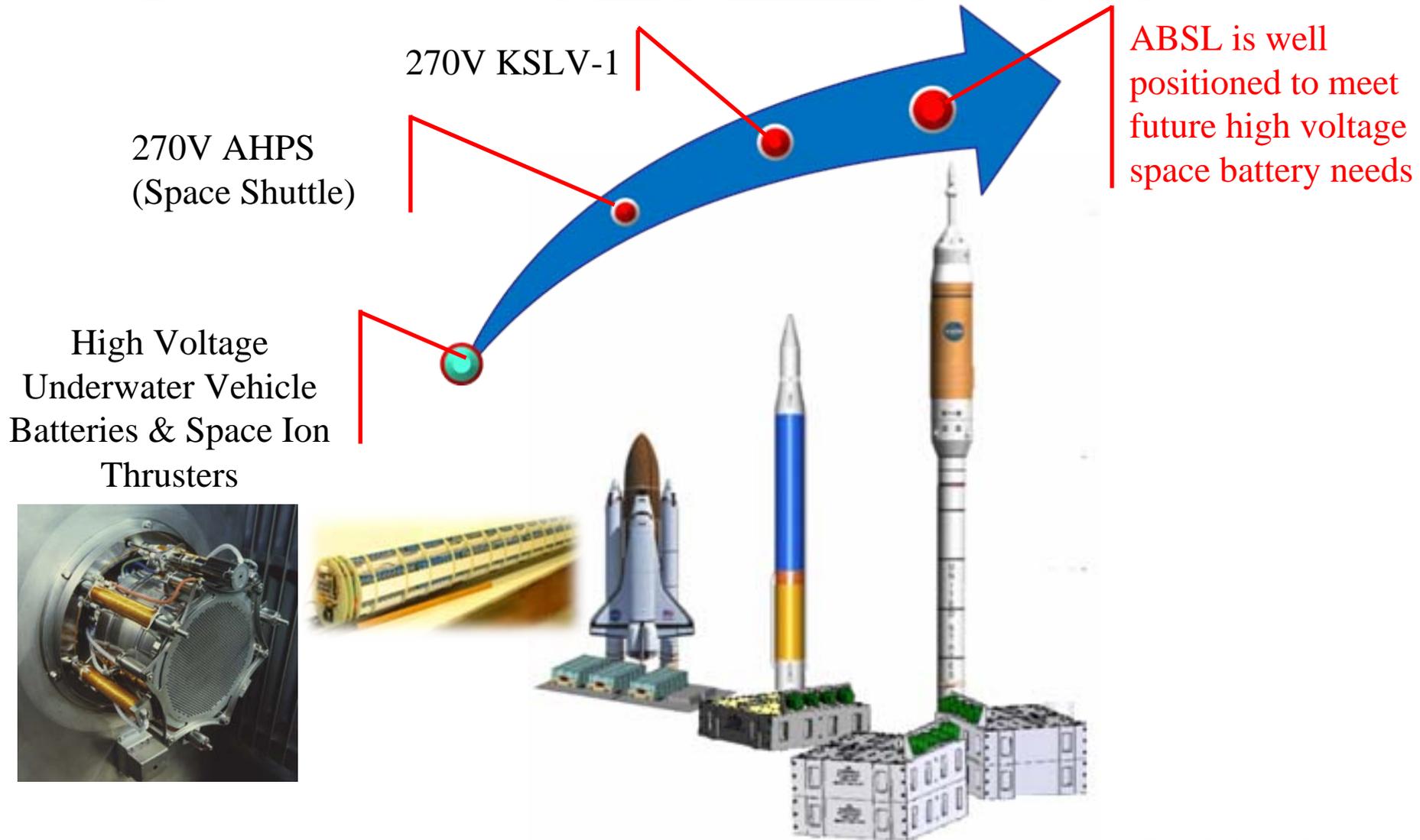


## Before High Voltage Space Batteries...

- Design, manufacturing and testing of Li-Ion batteries up to 120V and 65kWh for autonomous underwater vehicle applications
- Ion Thrusters: Development, build and testing (~1kV)



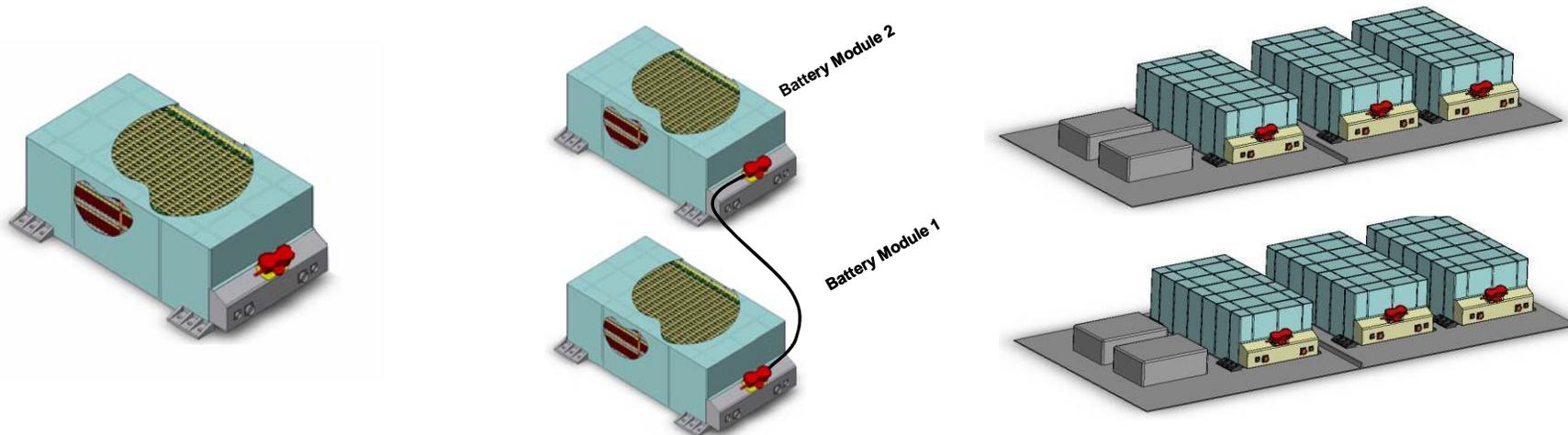
# High Voltage Space Batteries





- AHPS = Advanced Hydraulic Power System
- Mission critical battery providing power to steer SME and control surfaces during gliding descent and landing
- Shuttle Safety Upgrade to replace hydrazine-fueled turbine Auxiliary Power Unit (APU) System
- \$50 Million contract won in a competitive tender for NASA JSC and United Space Alliance
- 270 V, 140 Ah Li-Ion Battery to drive an Electro-Hydraulic Drive Unit (EHDU)
- Following a highly successful Intermediate Design Review (IDR), the program was cancelled in response to the Shuttle retirement plan

# AHPS (Battery System)



Parameter	Module	System
Configuration	43s92p	(86s92p) x 3 for redundancy
Nominal Voltage	135 V	270 V
Energy @ EOL	14.4 kWh	28.8 kWh
Envelope	99 x 53 x 33 cm	99 x 106 x 33 cm
Mass	205 kg	410 kg

# Building on AHPS Heritage

Identified the necessity of understanding and overcoming corona issues

Delivered a high voltage battery design that minimized the risk of corona

Identified general production, test, and operation risks

Developed and consolidated safe building and operational guidelines

Identified the need for safer handling, transportation and storage

Devised engineering solutions and ground-specific safety features

Identified the risk of standard space component failure at high voltages

Carefully selected and qualified high voltage tolerant components

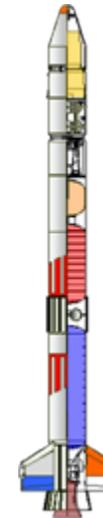
# KSLV-1 Battery Project



<http://www.kari.re.kr/>



- KSLV-1 Launch Vehicle Batteries
- Multi Million Dollar Award: July 2005
- 20 Li-Ion Batteries Deliverable (10 QMs and 10 FMs)
- Three new designs space qualified
  - 28V FTS
  - 28V Pyro Activation
  - 270 TVC
- 28V Avionics battery “build to print”
- 10 Li-Ion batteries per Vehicle



Successfully Launched in 2002 KSR-III



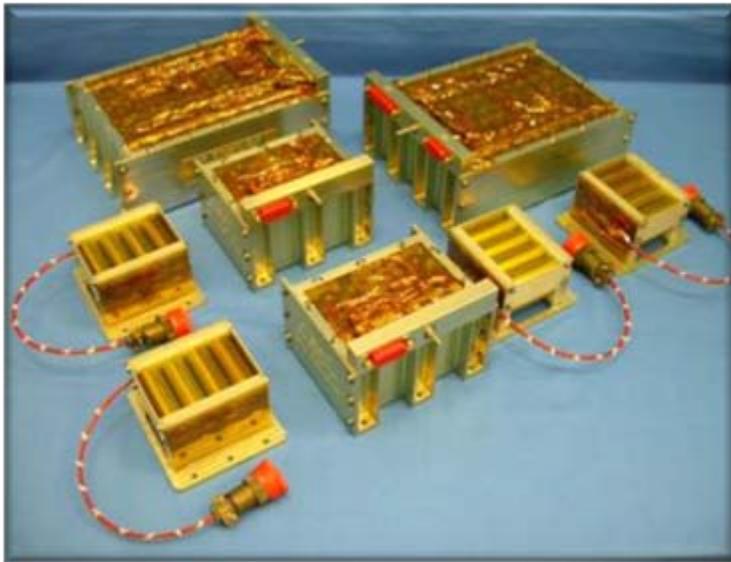
KSLV-1 1<sup>st</sup> flight in 2008



KSLV-II 1<sup>st</sup> flight planned 2015

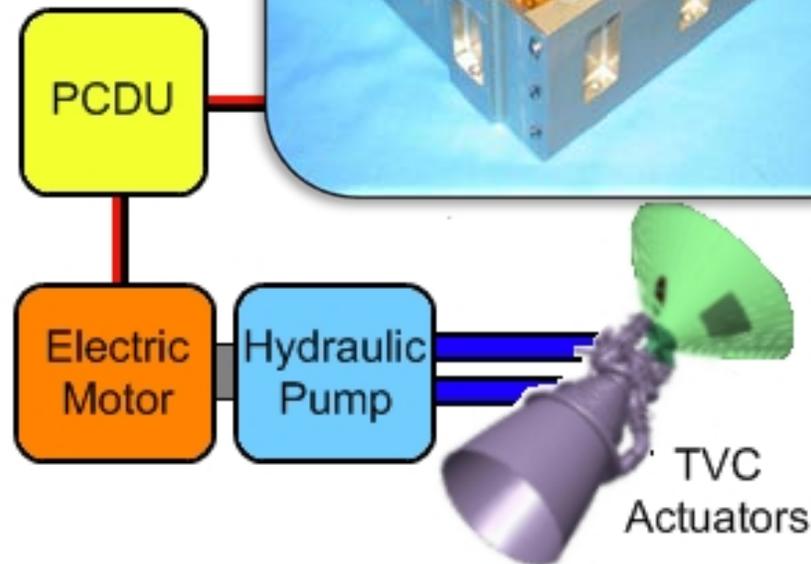
## KSLV-1 Battery Project

### 28V KSLV-1 Launcher Upper Stage Li-Ion Avionics Suite



*Set of 10 batteries per vehicle includes avionics, FTS, activation, and TVC batteries*

### 270V ABSL Thrust Vector Control Battery



## TVC Requirements & Drivers

### *Electrical*

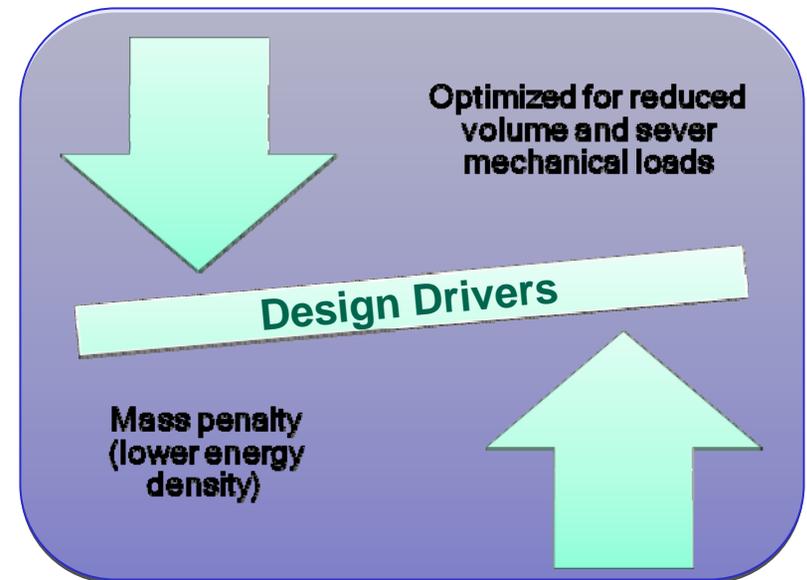
- Voltage Range 210V to 344.4V
- System Voltage : 250V-350V
- Average Discharge Power: **on request**
- Discharge Duration : 100sec

### *Thermal*

- (Prior Lift-Off): 10°C to 30°C
- (Operational): 0°C to 40°C

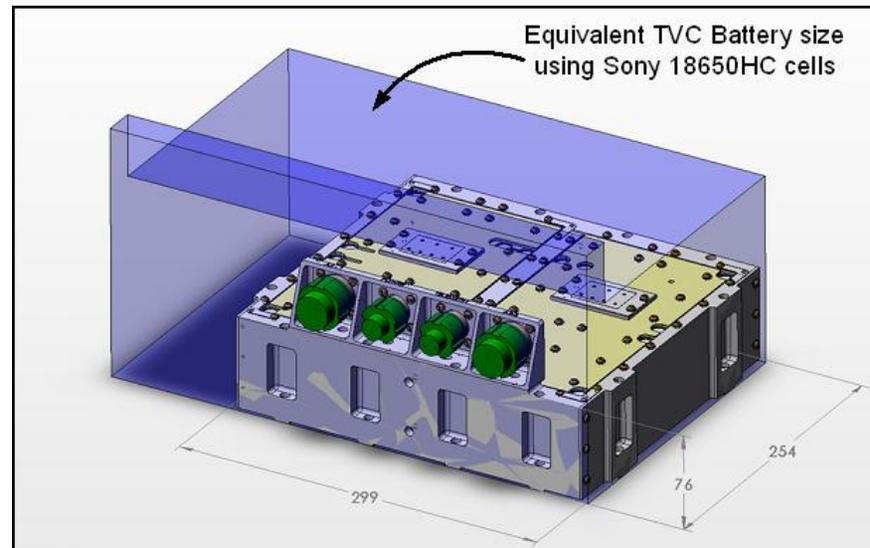
### *Mechanical*

- Restrictive Volumetric Envelope
- Random Vibration: **on request**
- Spectral Shock: **on request**



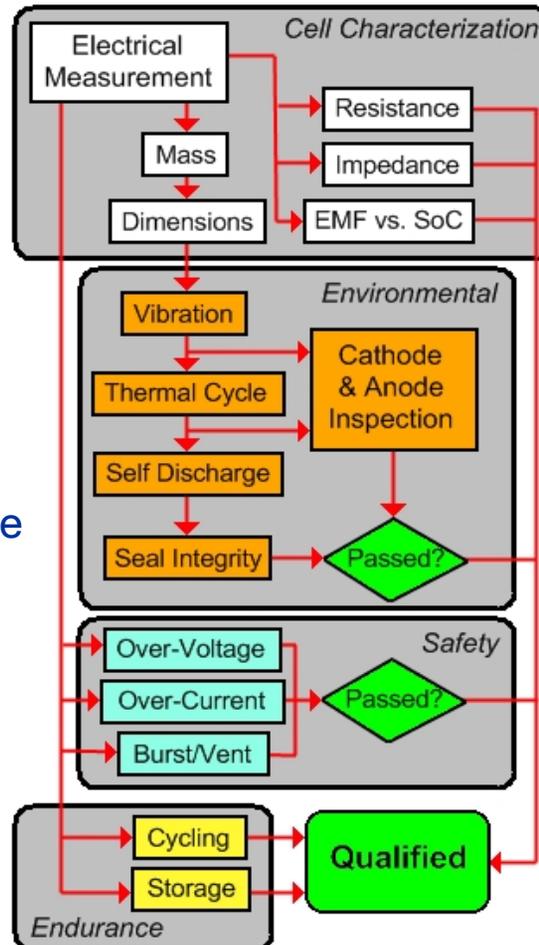
# TVC Cell Selection

- KSLV-1 TVC Battery baselined at 82s6p using ABSL 18650HC Cells
- However, as this application was primarily power driven, ABSL recognized that a high rate cell would improve performance
- The high rate ABSL 18650HR cell was qualified specifically for this application, and reduced the configuration to 84s2p - providing 2/3 mass and volume savings (over baseline AHPS cell)



# Space Qualified ABSL 18650HR Cell

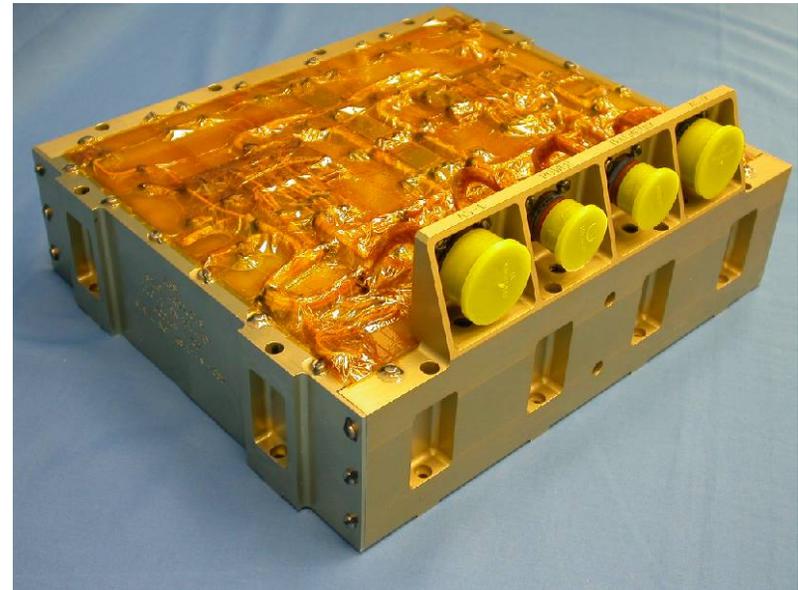
## ABSL Proven Process for Space Battery Cells Qualification



- **Chemistry:** Advanced cathode, graphite anode
- **Description:** An extremely robust, high power cell for satellites and launch vehicles with an excellent safety performance
- **Qualification:** Focus on high rate characterization, qualified to extremely harsh temperature and vibration environments

# TVC Battery Design

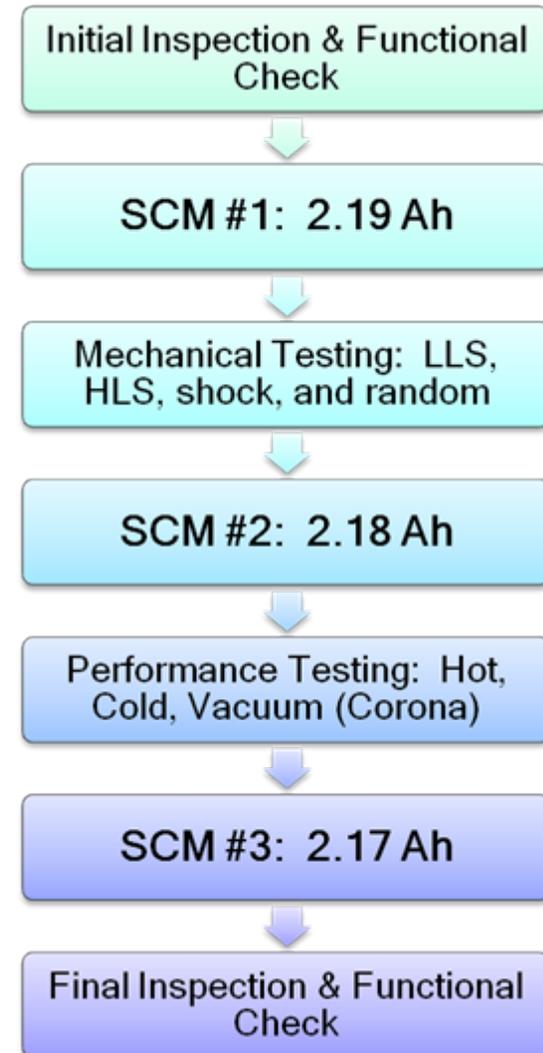
Parameter	Performance
Cell	ABSL 18650HR
Configuration	84s2p
Capacity	2.2 Ah
Open Circuit Voltage	344.4 V
Mass	On request
Volume	On request



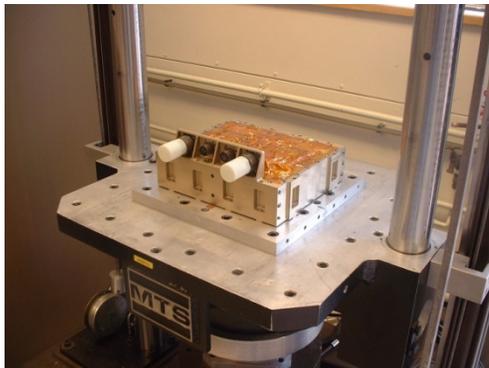
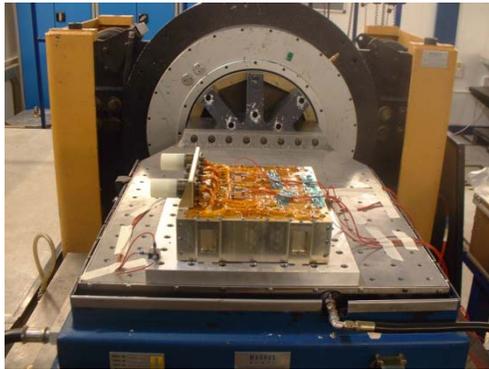
*Proprietary safety devices have been engineered into this design to provide maximum safety during build, test, shipping, integration, and operation.*

## TVC Battery Qualification

- Standard battery test flow, including harsh mechanical environment testing, operational and corona withstand test in vacuum
- SCMs confirm full battery health throughout test regime: <1% capacity loss



# TVC Battery Qualification Status

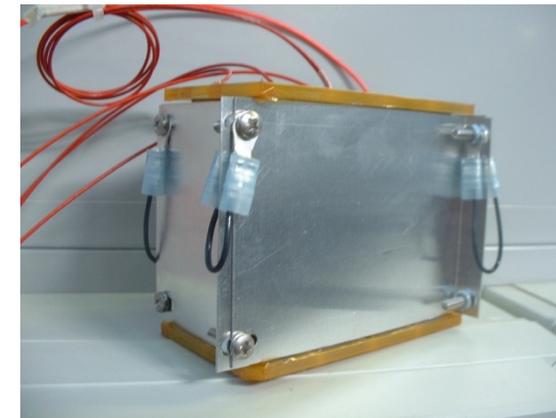
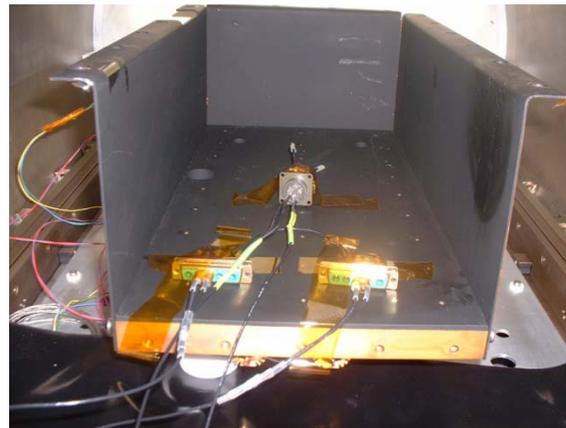
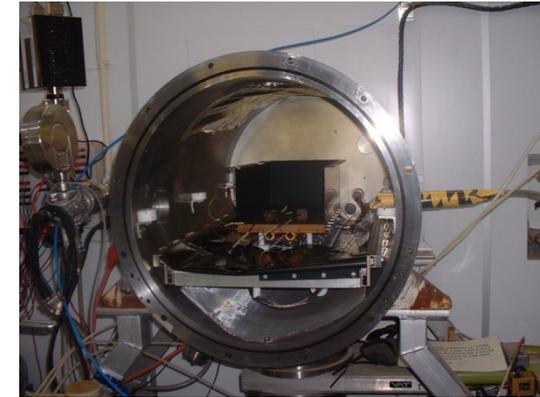
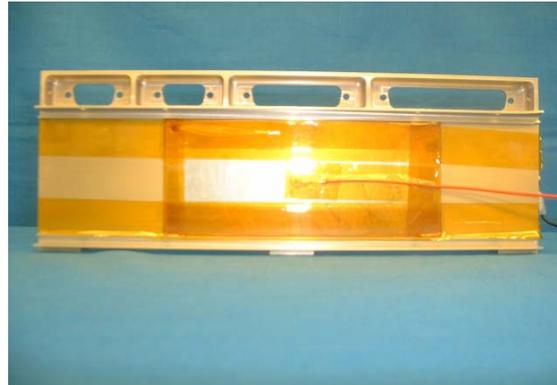


Parameter	Performance
<b>Thermal Qualification</b>	<p><i>Operational:</i> mission representative discharge at 0° C and 40° C</p> <p><i>Vacuum:</i> mission representative discharge at 20° C, &lt; 10<sup>-5</sup> torr</p>
<b>Mechanical Qualification</b>	<p><i>Random Vibration:</i> on request</p> <p><i>Spectral Shock:</i> on request</p> <p><i>Half-Sine Shock:</i> on request</p>
<b>Electrical Qualification</b>	Functional testing at multiple temperatures, extensive Corona testing

## TVC Battery Corona Qualification Testing

Key components and small battery assemblies tested for corona withstand to higher than operational voltage, and for long durations:

- Power and telemetry connectors
- Conformal coatings and construction materials
- Specially Coated metalwork Qualified
- Specially Coated battery samples qualified



# Proven High Voltage Procedures

	<b>KSLV1:TVC</b>	Ref: KSLV1-ABS-SP-0066
	Proprietary Information	Issue: 01 Date: 27/05/06
		Rev: - Date: - Page: 1 of 14

## TVC Battery: Safety Data Package

	Position	Name	Signature	Date
Prepared by	Product Assistant	W Maxwell		9/2/06
Reviewed by	Quality Manager	T Rice		10-02-06
Reviewed by	Technical Manager	K L Ng		21/02/06
Approved by	Product Assistant	W Maxwell		20/02/06
Released by	Project Manager	A Bennetti		22/02/06

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File # KSLV1-ABS-SP-0066-SP-SDP-01

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	<b>KSLV1 TVC LHON BATTERY</b>	Ref: KSLV1-ABS-PL-012
	Proprietary Information	Issue: 01 Date: 27/05/06
		Rev: - Date: - Page: 1 of 8

## TVC Li-Ion BATTERY Live Working Electrical Safety Test Plan

	Position	Name	Signature	Date
Prepared by	TM	K L Ng		27/02/06
Prepared by	SE	D. Reasco		30/3/06
Approved	AIT	P Jackson		11/4/06
Approved	Safety Officer	B Roberts		20/4/06
Approved	PA	T Rice		02/05/06
Released	PM	A Bennetti		01/05/06

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	<b>KSLV1</b>	Ref: KSLV1-ABS-UM-0115
	Proprietary Information	Issue: 01
		Date: 20/06/2006 Page: 1 of 51

## TVC Li-Ion Battery User Manual and Design Description

Please read this user manual  
before handling the TVC battery

	Position	Name	Signature	Date
Prepared by	TM	K L Ng		20/02/06
Reviewed by	SE	D Reasco		21/7/06
Reviewed by	PA	T Rice		21/02/06
Approved	PM	A Bennetti		21/02/06

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- 28V and 270V battery designs formally space qualified
- Flight Battery Set #1 delivered
- Flight Battery Set #2 delivered
- 28V and 270V batteries proven in TVC system level testing at KARI
  - Safety of ABSL handling procedures proven
- Maiden Flight set for 2008

## Future Programs

- ABSL can directly apply its 270 V TVC battery design or modify for future applications.
- All safety and corona protection mechanisms can be maintained.
- Performance can be improved by two means:
  - *Optimize Structure* : Less restrictive volume requirements could allow ABSL to recoup this loss.
  - *Next-Gen High Rate Cell* : Use of a next gen cell with superior high rate performance could yield significant mass and volume savings for certain applications.



***Only ABSL can provide a space qualified 270V Li-Ion battery via a build-to-print program, minimizing risk and cost.***

# Summary

- The world's only space qualified 270 V Li-Ion TVC battery
- High voltage design heritage for manned missions (AHPS), and an excellent record of passing NASA manned design review
- Unique understanding of Corona design principles for high voltage batteries, developed over many years of high voltage projects
- A safety-focused company culture with established procedures and proven design features that maximize safety from build to flight
- Immense company expertise in the use of Li-Ion for space, with a history including the most "firsts" and launches in the industry.
- A growing US facility with established US partners and suppliers



Questions?