International Space Station
Lithium-Ion Battery
NASA Aerospace Battery Workshop
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Penny J. Dalton, NASA Glenn Research Center
Eugene Schwanbeck, NASA Johnson Space Center
Tim North, The Boeing Company
Sonia Balcer, Aerojet Rocketdyne
ISS Li-Ion Battery - Outline

- Configuration of Existing ISS Electric Power System
- Timeline of Li-Ion Battery Development
- Battery Design Drivers
- Technical Definition Studies
- Cell Selection
- Safety Features
- Final Flight Adapter Plate and Battery Design
- Battery Charge Control and LEO Cycle Test Data
- Cell and ORU Life Test
- Current Status
ISS Configuration - Battery Locations

Batteries are located in the 4 Integrated Equipment Assemblies (IEAs)

- 2 Power Channels per IEA
- 8 Power Channels total

6 Ni-H₂ ORUs per channel – 48 total

1 Li-Ion and 1 Adapter Plate to replace
2 Ni-H₂ – 24 total Li-Ion batteries
ISS Configuration - EPS Schematic

Electrical Power Channel – 1 of 8

Note: 2-Battery ORUs will be replaced by 1 Li-Ion Battery and an Adapter Plate

EPS:: Electric Power System
BCDU: Battery Charge / Discharge Unit
DCSU: DC Switching Unit
DDCU: DC-to-DC Converter Unit
MBSU: Main Bus Switching Units

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ISS Li-Ion Battery Project Overview

• Battery ORU (Orbital Replacement Unit)
  • Battery ORU Design and Manufacture
  • Baseplate Design and Manufacture
  • Enclosure Design (HOU) and Manufacture (AASC)
  • Li-Ion Battery Cells (GS Yuasa)
  • Charge Control Electronics Design and Manufacture
• On-Orbit Adapter Plate (Atec)
• Flight Support Equipment (FSE) Interface Hardware
• Li-Ion Battery Status/Charging Unit (SCU)
• Software Updates (PVCA, PCS, PMCA, and CCS)
• Testing
  • ORU Verification and Qualification Testing
  • Battery Cell Qualification and Acceptance Testing
  • Battery ORU Life Testing
  • ISS Systems Integration Testing
  • Battery Cell Safety Characterization/Abuse Testing and Battery Cell Life Testing
  • Post Delivery ORU Freezer/Refrigerator Storage
• Automated Test Equipment Design and Manufacture

Color Key (Scope):
- NASA
- Boeing
- ORU Supplier AR (Aerojet Rocketdyne)
- Joint Boeing/AR
Timeline of ISS Li-Ion Development

- **2009-2010** – Preliminary risk and feasibility studies
- **December 2011** - ISS Program Authority To Proceed with design, development and the fabrication of 27 Li-Ion ORUs and 25 on-orbit Adapter Plate ORUs
- **Jan-Jun 2012** - Cell Safety Testing and Cell Qualification
- **July 2012** - Final cell down-select
- **December 2012** - System Preliminary Design Review
- **November 2013** - System Critical Design Review
- **March 2016** - First flight Li-Ion battery delivered to Kennedy Space Center for shipment to Tanegashima, Japan


ISS Li-Ion Battery Key Design Drivers

- 1 Li-Ion battery ORUs replaces 2 Ni-H\textsubscript{2} ORUs
  - Li-Ion ~15 kWh vs. Ni-H\textsubscript{2} ~4 kWh each
- Launch on Japanese HTV
- 6 year battery storage life requirement
- 10 year/60,000 cycle life target (minimum 48 A-hr capacity at end of life)
  - ORU will have cell balancing circuitry
  - ORU will have adjustable End of Charge Voltage (EOCV)
- Maximum battery ORU weight ~430 lbs
- Non-operating temperature range (Launch to Activation): -40 to +60 °C
- No changes to existing IEA interfaces and hardware
  - Use existing mounting, attachment, electrical & data connectors
  - Use existing Charge/Discharge Units and Thermal control systems
ISS Upgrade to Li-Ion

**Ni-H₂**
(76 cells in series)

- **BCDU**: Battery Charge / Discharge Unit
- **Ni-H₂**: Nickel-Hydrogen
- **Cells**: 76 cells in series
- **Battery A**
- **Battery B**
- **Commands & Data**
- **Main Power Path**
- **BSCCM**: Battery Signal Conditioning and Control Module

**Li-Ion**
(30 cells in series)

- **BCDU**: Battery Charge / Discharge Unit
- **Li-Ion**: Lithium-Ion
- **Cells**: 30 cells in series
- **Battery**
- **Commands & Data**
- **Main Power Path**
- **BSCCM**: Battery Signal Conditioning and Control Module
- **BIU**: Battery Interface Unit
- **Adapter Plate**
- **Data Cable**

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BCDU: Battery Charge / Discharge Unit  
BIU: Battery Interface Unit  
BSCCM: Battery Signal Conditioning and Control Module
NASA Safety Risk Mitigation Activity (Jan 2009 – Sept 2010)

6 cell designs

NASA Risk Mitigation Safety Report (Nov 2010)

4 cell designs


Cell Selection NAR (Sept 2010)

2 cell designs

Battery ORU Specification and SOW Development (start Sept 2010)


NASA Production Line Audits (May 2010 – Aug 2010)


Battery Mounting/ MOD Kit Feasibility Report (includes ORU Max Weight Assessment) (May 2010 – Sept 2010)


NASA Down Select to 4 cell candidates (April 2010)
ISS Li-Ion Cell Final Down-Select

• Two designs taken through qualification, with down-selection made prior to EM build

GS Yuasa 134 A-hr cells
• Li Cobalt Oxide / Carbon Graphite
• Wound elliptical prismatic electrode
• Internal Fusible link
• Aluminum Case, 50 x 130 x 263 mm
• Spec Mass: 3530 grams (~7.8 lb)
ISS Li-Ion Battery Safety Features

Battery-Level Safety Features

• 2 independent controls vs. thermal runaway (2 fault tolerant)
• Voltage and temperature monitoring of all 30 cells
• Circuit protection/fault isolation at the individual cell level for both high/low voltage and high temperature
• Physical separation between cell pairs and 10 packs
  • Thermal radiant barriers between cell pairs
• Controlled direction of cell vents - prevent damage to cold plate, adjacent cells and IEA hardware
  • ORU pressure relief/flame trap to prevent ORU over-pressurization but contain flame in the event of a cell vent
• MMOD shielding in ORU and empty ORU slot
• Dead face device to remove power from output connector during ground or EVA handling
• Non propagation of failures beyond Battery ORU
Safety Features - MMOD Shielding

- MMOD Shielding
- Over Match - Penetration testing
  - 10 mm 2017-T4 Aluminum Sphere @ 6.86 km/s
- Overcharge Containment Testing

Note: Existing Ni-H₂ does not have MMOD protection
Safety Features - Radiant Heat Barriers

• ORU Layout – 3 Cell “10-Packs” and 12 Radiant Barriers

Radiant Heat Barrier (12 per ORU)
• Higher margin against thermal runaway propagation
• 1 barrier between each cell pair
• Reflects 787 reach-back safety additions

Cell 10-Pack

~2” Spacing between 10-Packs
~3.5” Spacing between cell pairs
ISS Li-Ion Cell Safety Features

Cell-Level Safety Features and Controls

- Manufacturing Process controls include 100% materials screening and chemical analysis plus annual configuration/production line audits
- 100% cell acceptance testing
  - Cell Matching performed based on ATP characteristics
- 2% of cells in each lot in simulated LEO life cycle testing
- 1% of cells in each lot undergo 100, 100% DOD cycles, followed by DPA
- Cell vent before burst and directional vent away from base plate and adjacent cells
- Individual cell fusing (internal fusible link)
- Shutdown separators between electrode windings
- Case neutral and electrically insulated from ORU structure
ISS Li-Ion Orbital Replacement Units

**Adapter Plate ORU**
- Dimensions (LxWxH): ~ 41” x 36” x 15”
- Spec Weight: 85 Lbs

**Li-ion Battery ORU**
- Dimensions (LxWxH): ~ 41” x 37” x 21”
- Spec Weight: 435 Lbs
ISS Li-Ion Charge Control and Cycling

- Li-Ion charge current profile based on cell voltages
- Cell bypass/balancing at EOCV every orbit
- EOCV is ground command-able

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<th>Charge Current</th>
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Life Test Program

- Cell Life Testing performed at Crane and at GRC
Life Test Program

• ORU Life Testing at Aerojet Rocketdyne

Week 16 Test error resulted in ~ 1.15 A-hr discharge

Week 22 Chamber Condenser failure resulted in temperature change

Voltage

Elapsed Weeks
ISS Li-Ion Flight Battery Status

• 6 Flight Li-Ion Adapter Plates integrated with Exposed Pallet in Japan, Tomioka: April 2016
• 6 Flight Li-Ion Batteries integrated with Exposed Pallet in Japan, Tanegashima: May 2016
• Final charge to 4.1V: May-June 2016
• Launch on HTV: NET December 2016
  • Each IEA will have 3 Li-Ion ORUs and 3 Adapter Plate ORUs
ISS Li-Ion Battery Future Plans

• Data analysis for NESC (NASA Engineering & Safety Center) Thermal runaway propagation test performed October 2016 at the White Sands Test Facility
• Launch of six Li-Ion Batteries and six Adapter Plates in 2017, 2018, 2019 to provide a full complement on ISS

➢ Ready for successful and safe operation
In Closing

- Acknowledgements
- Questions?