International Space Station
Lithium-Ion Battery

Penni J. Dalton, NASA Glenn Research Center
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 Low Earth Orbit (LEO) Cycle Test Data
• Current Status
ISS Configuration - Battery Locations

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

Two Power Channels per IEA

Six Ni-H$_2$ Orbital Replacement Units (ORUs) per channel – 48 total

One Li-Ion and one Adapter Plate to replace two Ni-H$_2$ – 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
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
• One Li-Ion battery ORU replaces two Ni-H₂ ORUs
• Launch on Japanese HTV
• Six year battery storage life requirement
• Ten 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 and 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**: Ni-H₂ Cells
- **Battery A**: Commands & Data
- **Main Power Path**: +
- **Battery B**: Commands & Data

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

- **BCDU**: Battery Charge / Discharge Unit
- **Li-Ion**: Commands & Data
- **Main Power Path**: +
- **Battery**: Commands & Data
- **Adapter Plate**: Data Cable

**BCDU**: Battery Charge / Discharge Unit
**BIU**: Battery Interface Unit
**BSCCM**: Battery Signal Conditioning and Control Module
ISS Li-Ion Technical Definition Studies

- NASA Down Select to 4 cell candidates (April 2010)
- Battery Mounting/ MOD Kit Feasibility Report (includes ORU Max Weight Assessment) (May 2010 – Sept 2010)
- NASA Safety Risk Mitigation Activity (Jan 2009 – Sept 2010)
- NASA Risk Mitigation Safety Report (Nov 2010)
- Cell Selection NAR (Sept 2010)
- Battery ORU Specification and SOW Development (start Sept 2010)

Number of cell designs:
- 6 cell designs
- 4 cell designs
- 2 cell designs
ISS Li-Ion Cell Final Down-Select

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

Cell Qualification
- Cell Safety Testing
- Final Cell Selection Criteria
- MMOD Test Results
- Life Test Data
- Production Line Audit Results
- Manufacturer Performance
- Material Obsolescence & Availability Study

Final Down-Selection prior to Engineering Model (EM) build (July 2012)

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

- Two independent controls vs. thermal runaway (two 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 test setup

Ballistic Limit Testing

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 (Micro-Meteoroid Orbital Debris) protection
Safety Features - Radiant Heat Barriers

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

Radiant Heat Barrier (12 per ORU)
- Higher margin against thermal runaway propagation
- One barrier between each cell pair
- Reflects 787 reach-back safety additions
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
- Acceptance testing of 100% of cells
- Simulated LEO life cycle testing in 2% of cells in each lot
- For 1% of cells in each lot, 100 cycles at 100% DOD are performed, 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 ORUs

**Heater Matt**
Heater Plate Assembly

**P4 Connector**
(stowed for launch)

**EVA**
Hand Hold

**P1 & P2 Connectors**

**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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ISS Li-Ion Flight Battery Status

- Six Flight Li-Ion Adapter Plates on-dock in Japan, Tomioka: April 2016
- Six Flight Li-Ion Batteries on-dock in Japan, Tanegashima: May 2016
- Final charge to 4.1 V: May-June 2016
- Launch on HTV: NET October 2016
  - Each IEA will have three Li-Ion ORUs and three Ni-H₂ ORUs (not electrically connected) stored on top of three On-Orbit Adapter Plate ORUs
- Installation and start-up on ISS: October 2016
ISS Li-Ion Battery Future Plans

- Thermal runaway propagation testing is scheduled for May 2016 at White Sands Test Facility
- Six Li-Ion Batteries and six Adapter Plates launch in 2017, 2018, 2019 to provide a full complement on ISS
  
  ➤ Design challenges have been addressed
  ➤ Ready for successful and safe operation
Thank you to Tim North of Boeing Corporation for key contributions to this work