International Space Station
Lithium-Ion Battery
NASA Aerospace Battery Workshop
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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
Note: 2-Battery ORUs will be replaced by 1 Li-Ion Battery and an Adapter Plate
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
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-H₂ ORUs
  - Li-ion ~15 kWh vs. Ni-H₂ ~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
- BSCCM: Battery Signal Conditioning and Control Module
- Commands & Data
- Main Power Path
- Battery A
  - Ni-H₂ Cells
- Battery B
  - Ni-H₂ Cells
- BSCCM

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

- BCDU: Battery Charge / Discharge Unit
- BIU: Battery Interface Unit
- Commands & Data
- Main Power Path
- Battery
  - Li-Ion Cells
- Adapter Plate
- Data Cable

BDTU: 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 Production Line Audits (May 2010 – Aug 2010)


NASA Risk Mitigation Safety Report (Nov 2010)

Battery ORU Specification and SOW Development (start Sept 2010)

Cell Selection NAR (Sept 2010)

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

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 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 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-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

<table>
<thead>
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<th>Charge Current Profile</th>
<th>Highest of the Cell Terminal Voltages</th>
<th>Charge Current</th>
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<td>Point 2</td>
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<td>EOCV + 17mV</td>
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<td>EOCV + 16mV</td>
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Life Test Program

- Cell Life Testing performed at Crane and at GRC

![Cell Testing at NSWC Crane Lab and NASA-GRC](image-url)
Life Test Program

- ORU Life Testing at Aerojet Rocketdyne

Li-Ion Battery ORU Life Test Voltage Retention Test Data

- Week 16 Test error resulted in ~ 1.15 A-hr discharge
- Week 22 Chamber Condenser failure resulted in temperature change

Chamber Temperature

- 78 °F (first 21 weeks)
- 73 °F (week 23 on)

Elapsed Weeks

| Week 22 Chamber Condenser failure resulted in temperature change | Ongoing |
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?