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

- One Li-Ion battery ORU replaces two Ni-H$_2$ 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)

- **Battery A**
  - **Ni-H₂ Cells**
  - **BSCCM**

- **Battery B**
  - **Ni-H₂ Cells**
  - **BSCCM**

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

- **Battery**
  - **Li-Ion Cells**
  - **BSCCM**

**BCDU**: Battery Charge / Discharge Unit

**BIU**: Battery Interface Unit

**BSCCM**: Battery Signal Conditioning and Control Module

---

Existing

New
ISS Li-Ion Technical Definition Studies

NASA Safety Risk Mitigation Activity
(Jan 2009 – Sept 2010)

6 cell designs

Battery Cell & ORU Packaging Report
(May 2010 – Sept 2010)

Electronics Package and Charge Control Report
(May 2010 – Sept 2010)

NASA Risk Mitigation Safety Report
(Nov 2010)

4 cell designs

Battery ORU Specification and SOW Development
(start Sept 2010)

Cell Selection NAR
(Sept 2010)

2 cell designs

System Level Thermal Report
(May 2010 – Sept 2010)

MMOD Protection Report
(May 2010 – Sept 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)

NASA Production Line Audits
(May 2010 – Aug 2010)

Sparing Analysis Report
(May 2010 – Sept 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

- 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-H\textsubscript{2} 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

Cell 10-Pack

~3.5” Spacing between 10-Packs

~2” ~1” Spacing between Cells
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

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

### Charge Current Profile

<table>
<thead>
<tr>
<th>Point</th>
<th>Highest of the Cell Terminal Voltages</th>
<th>Charge Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td>EOCV + 19mV</td>
<td>55</td>
</tr>
<tr>
<td>Point 2</td>
<td>EOCV + 19mV</td>
<td>49</td>
</tr>
<tr>
<td>Point 3</td>
<td>EOCV + 18mV</td>
<td>44</td>
</tr>
<tr>
<td>Point 4</td>
<td>EOCV + 17mV</td>
<td>39</td>
</tr>
<tr>
<td>Point 5</td>
<td>EOCV + 16mV</td>
<td>36</td>
</tr>
<tr>
<td>Point 6</td>
<td>EOCV + 15mV</td>
<td>33</td>
</tr>
<tr>
<td>Point 7</td>
<td>EOCV + 14mV</td>
<td>30</td>
</tr>
<tr>
<td>Point 8</td>
<td>EOCV + 13mV</td>
<td>26</td>
</tr>
<tr>
<td>Point 9</td>
<td>EOCV + 12mV</td>
<td>22</td>
</tr>
<tr>
<td>Point 10</td>
<td>EOCV + 11mV</td>
<td>19</td>
</tr>
<tr>
<td>Point 11</td>
<td>EOCV + 10mV</td>
<td>16</td>
</tr>
<tr>
<td>Point 12</td>
<td>EOCV + 9mV</td>
<td>13</td>
</tr>
<tr>
<td>Point 13</td>
<td>EOCV + 8mV</td>
<td>10</td>
</tr>
<tr>
<td>Point 14</td>
<td>EOCV + 7mV</td>
<td>7</td>
</tr>
<tr>
<td>Point 15</td>
<td>EOCV + 6mV</td>
<td>4</td>
</tr>
<tr>
<td>Point 16</td>
<td>not applicable</td>
<td>1</td>
</tr>
</tbody>
</table>
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
Acknowledgments

• Thank you to Tim North of Boeing Corporation for key contributions to this work