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-H₂ Orbital Replacement Units (ORUs) per channel – 48 total

One Li-Ion and one Adapter Plate to replace two 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

Housekeeping & Payloads

Output Power

Alpha Gimbal

Solar Array

Coolant Pump

Shunt Unit

Beta Gimbal

Battery (2 ORUs)

Battery (2 ORUs)

Battery (2 ORUs)

BCDU

BCDU

BCDU

Controller

DDCU

MBSU

DDCU
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 Cells**: Nickel Hydride Cells
- **Battery A**: Existing
- **Battery B**: New
- **BSصم**: Battery Signal Conditioning and Control Module
- **Main Power Path**: Commands & Data

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

- **BCDU**: Battery Charge / Discharge Unit
- **Li-Ion Cells**: Lithium-Ion Cells
- **Battery**: Existing
- **Adapter Plate**: New
- **Data Cable**: Commands & Data

**BIU**: Battery Interface Unit

**Legend**
- Existing
- New
ISS Li-Ion Technical Definition Studies

1. NASA Safety Risk Mitigation Activity (Jan 2009 – Sept 2010)
2. ISS Li-Ion Technical Definition Studies
3. NASA Down Select to 4 cell candidates (April 2010)
10. 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

- 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

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

~3.5” Spacing between 10-Packs
~2” Spacing between Cells
~1” Spacing between Cells
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**

- **J4 Connector**

- **J3 Test Connector**

**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>
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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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Nominal Orbit Cell Voltages

Nominal Orbit Current
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

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