International Space Station Lithium-Ion Battery

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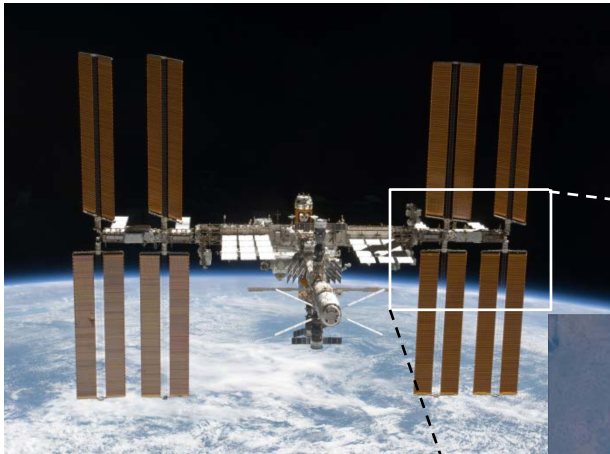
ISS Li-Ion Battery - Outline

- Configuration of Existing ISS Electric Power System
- Timeline of Li-Ion Battery Development
- Battery Design Drivers
- Technical Definition Studies
- Cell Selection
- Safety Features

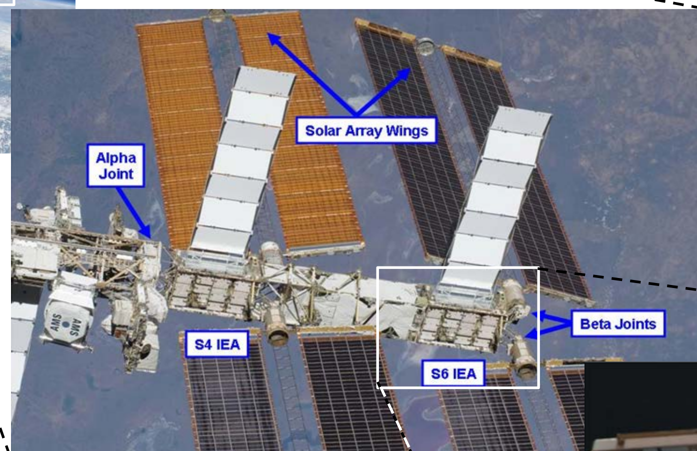
- Final Flight Adapter Plate and Battery Design
- Battery Charge Control and Low Earth Orbit (LEO) Cycle Test Data
- Current Status

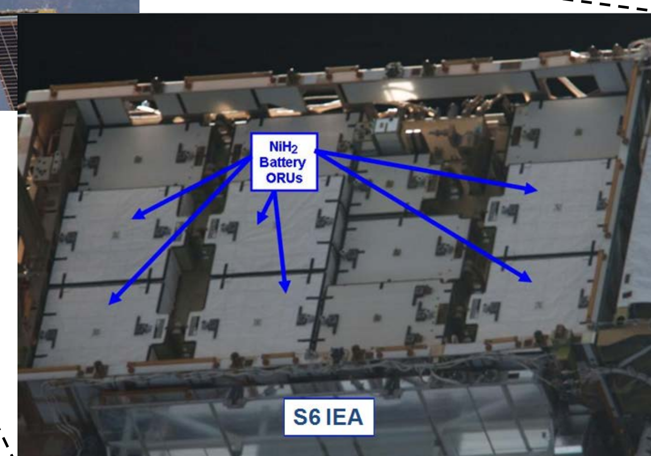
ISS Configuration - Battery Locations



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

Two Power Channels per IEA



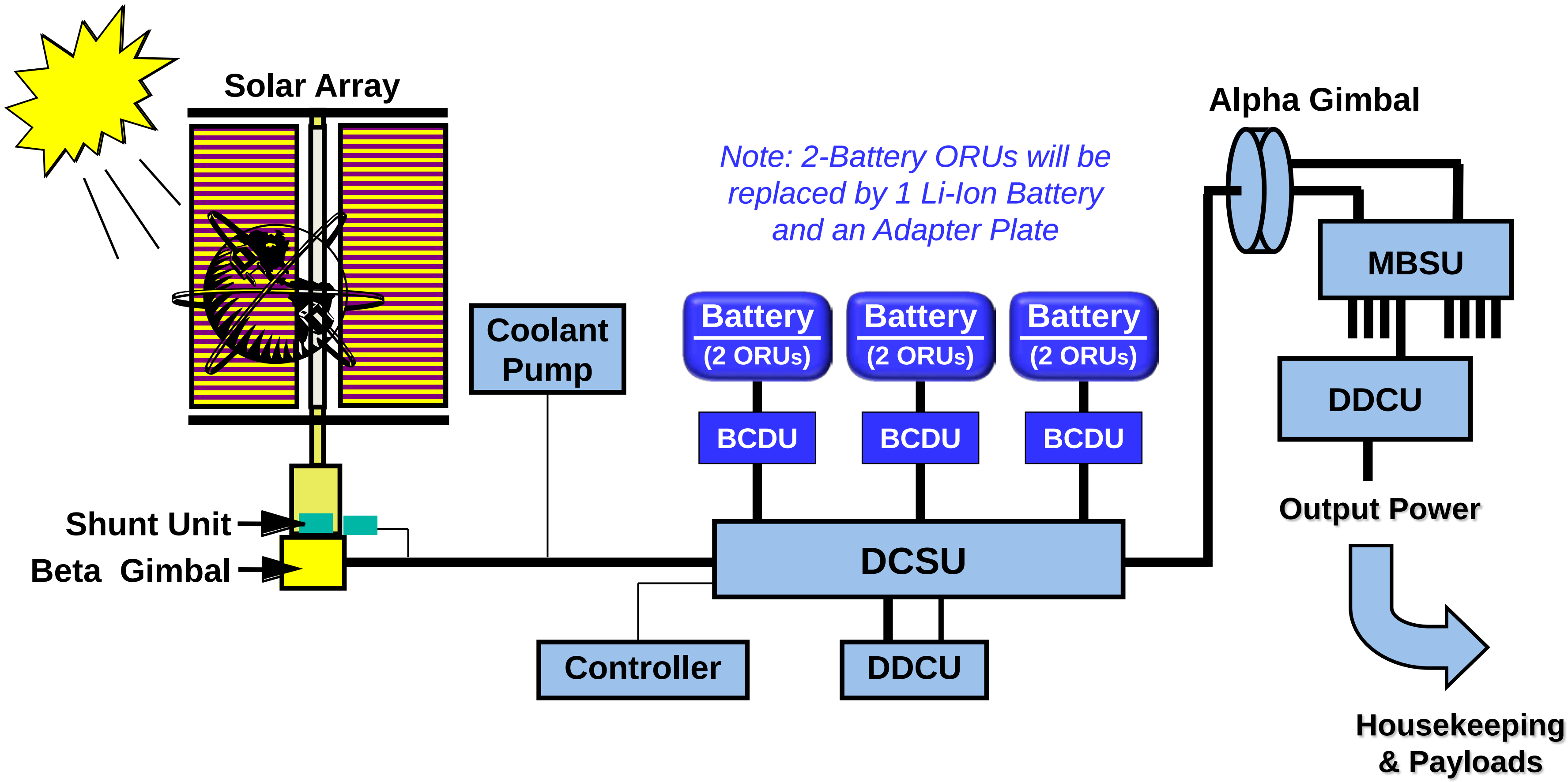


Six $Ni\text{-}H_2$ Orbital Replacement Units (ORUs) per channel – 48 total

One Li-Ion and one Adapter Plate to replace two $Ni\text{-}H_2$ – 24 total Li-Ion batteries

ISS Configuration - EPS Schematic

Electrical Power Channel – 1 of 8



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

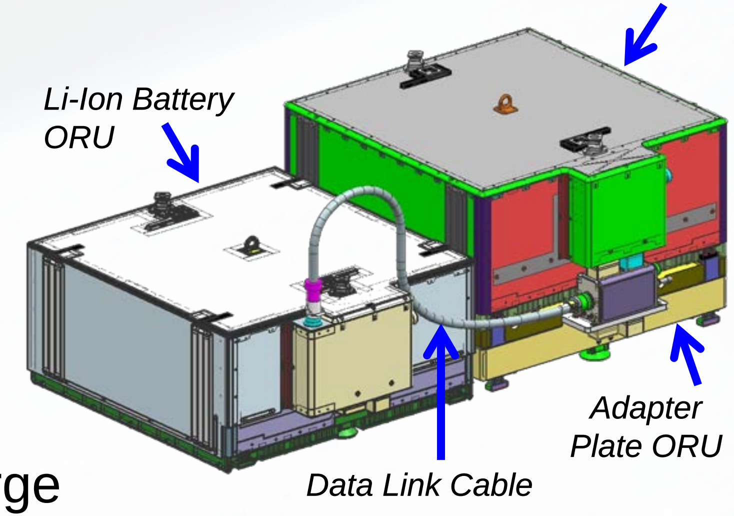
Timeline of ISS Li-Ion Development

- **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

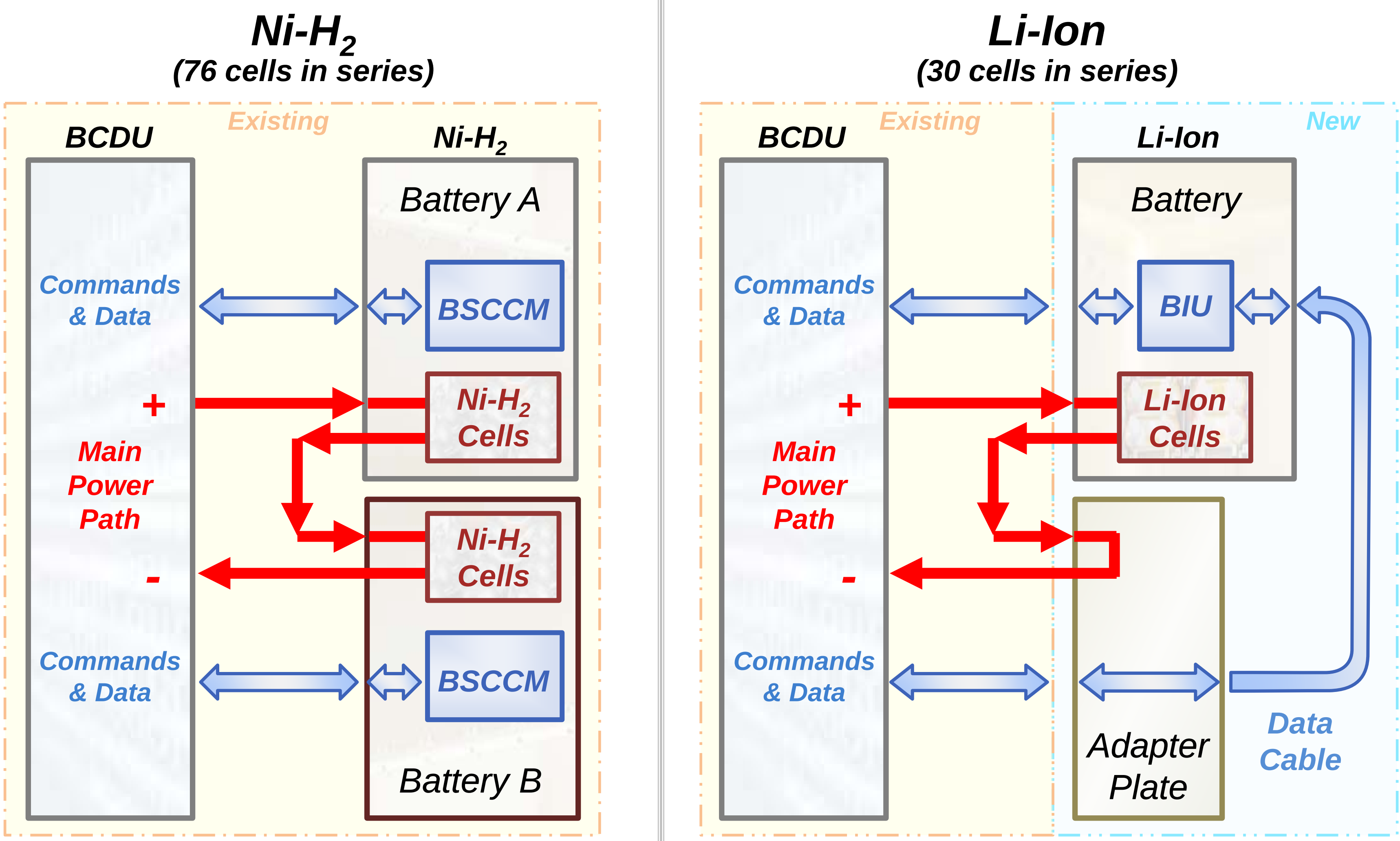
ISS Li-Ion Battery Key Design Drivers

- 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)



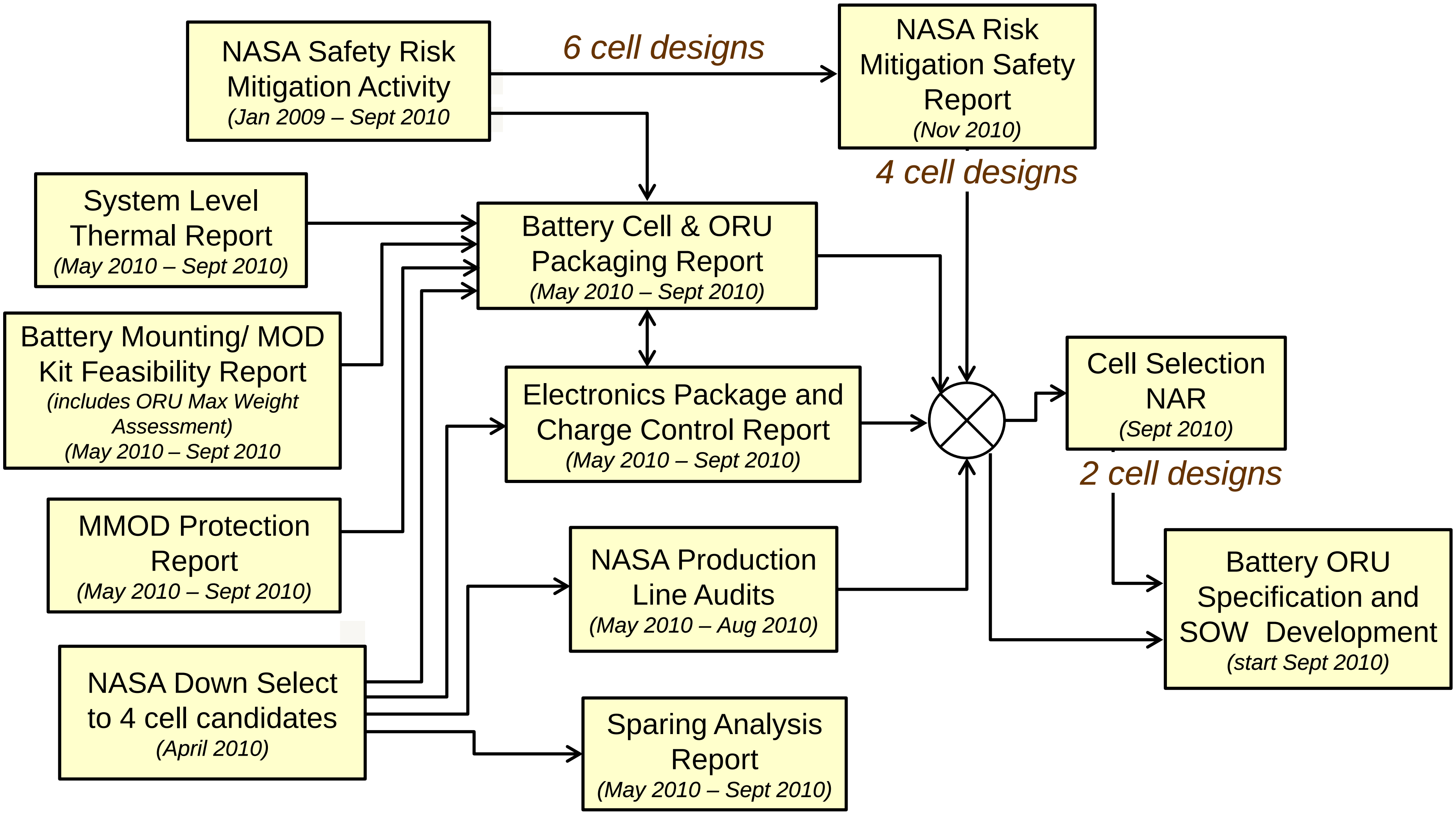
- Maximum battery ORU weight ~430 lbs
- Non-operating temperature range (Launch to Activation): -40 to +60 °C
- No changes to existing IEA interfaces and hardware
  - Use existing mounting, attachment, electrical and data connectors
  - Use existing Charge/Discharge Units and Thermal control systems

ISS Upgrade to Li-Ion



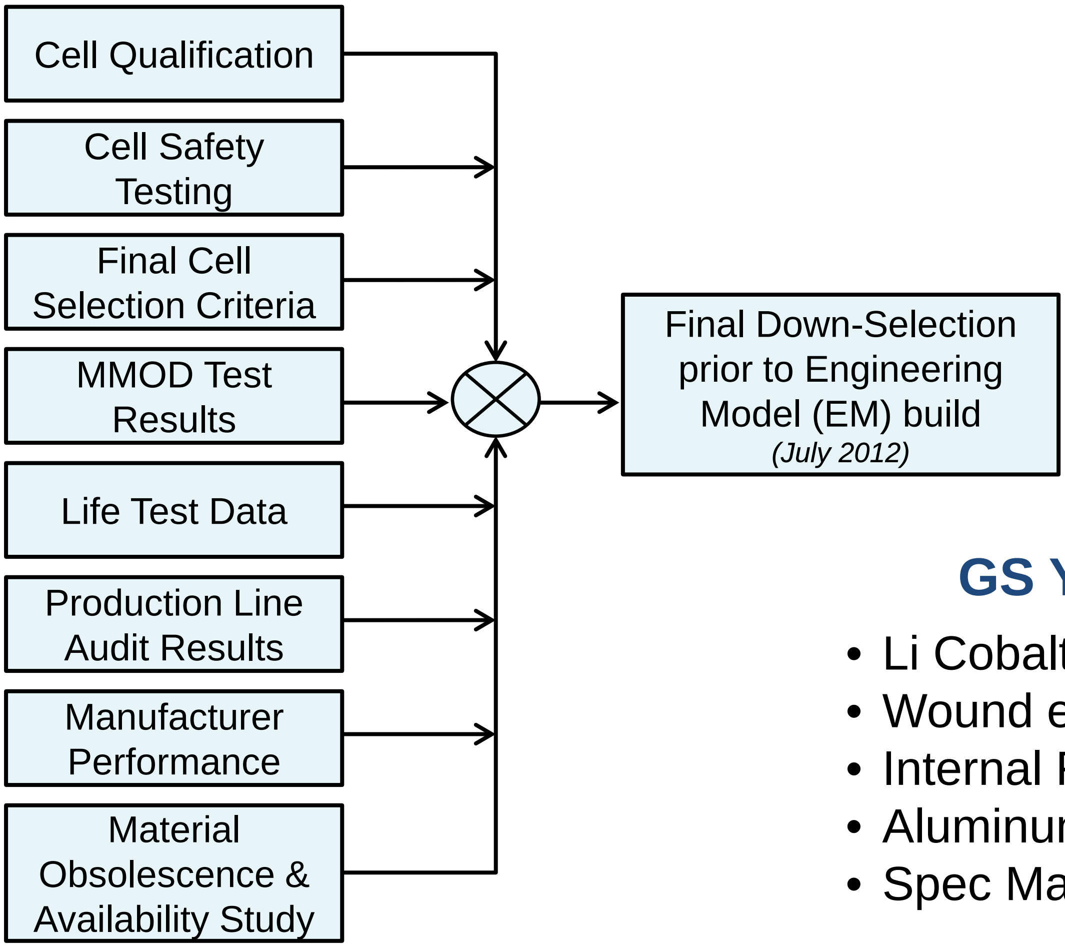
BCDU: Battery Charge / Discharge Unit
BIU: Battery Interface Unit
BSCCM: Battery Signal Conditioning and Control Module

ISS Li-Ion Technical Definition Studies



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

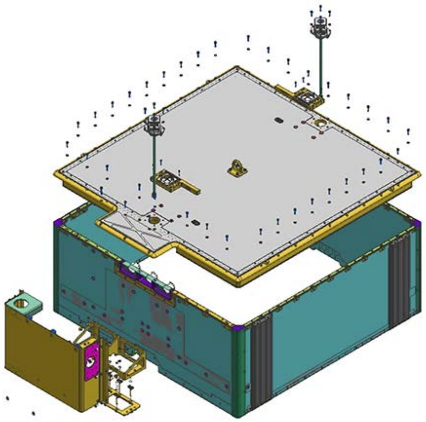
- Li Cobalt Oxide / Carbon Graphite
- Wound elliptical prismatic electrode
- Internal Fusible link
- Aluminum Case, 50 x 130 x 263 mm
- Spec Mass: 3530 grams (~7.8 lb)

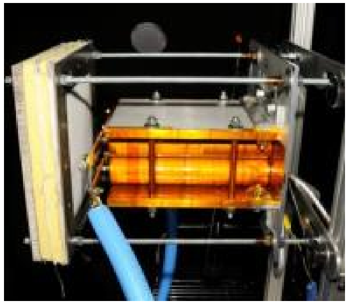
ISS Li-Ion Battery Safety Features

Battery-Level Safety Features

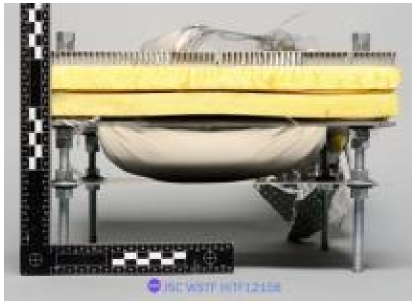
- Two independent controls vs. thermal runaway (two fault tolerant)
- Voltage and temperature monitoring of all 30 cells
- Circuit protection/fault isolation at the individual cell level for both high/low voltage and high temperature
- Physical separation between cell pairs and 10 packs
  - Thermal radiant 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

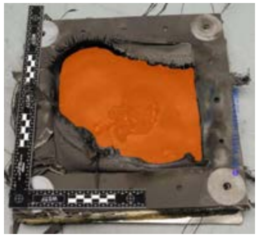


Ballistic Limit Testing

Over Match - Penetration testing

10 mm 2017-T4 Aluminum Sphere @ 6.86 km/s

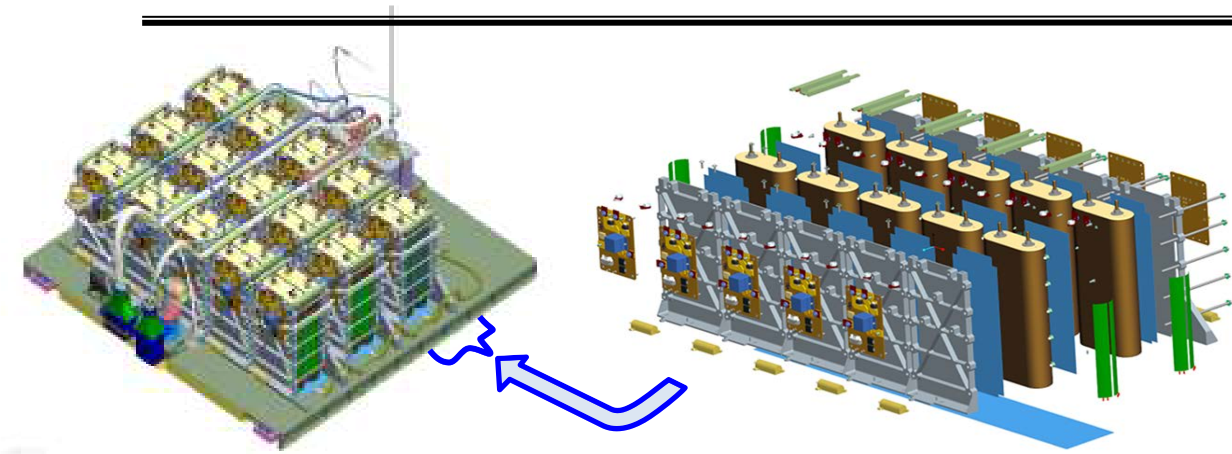
MMOD Shield



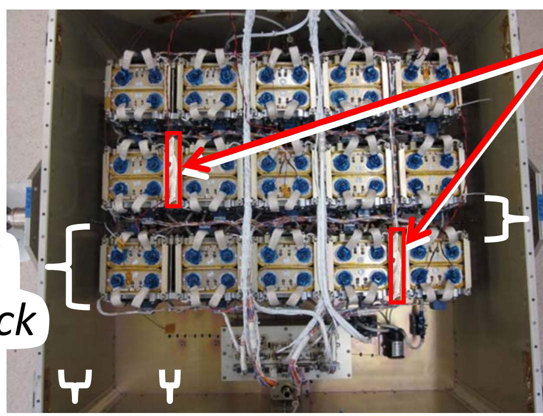
Overcharge Containment Testing

Note: Existing Ni-H_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

ISS Li-Ion Cell Safety Features

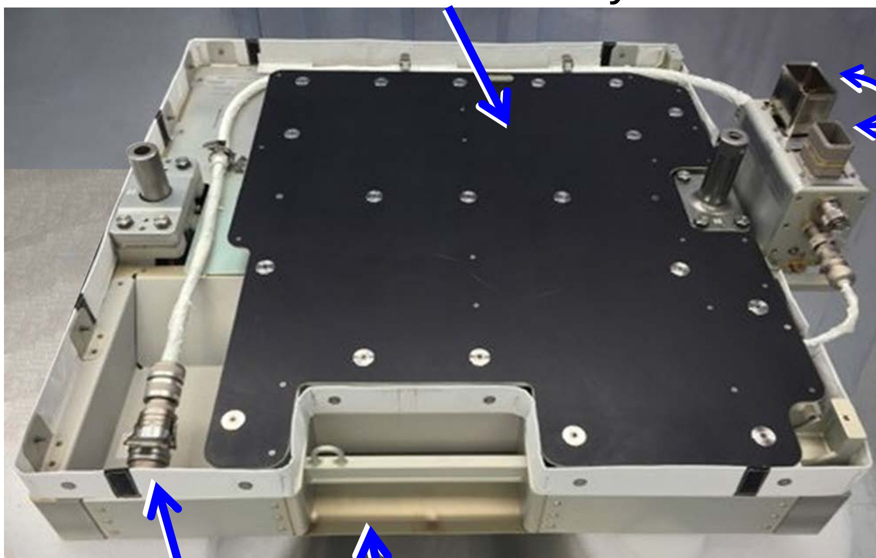
<u>Cell-Level Safety Features and Controls</u>

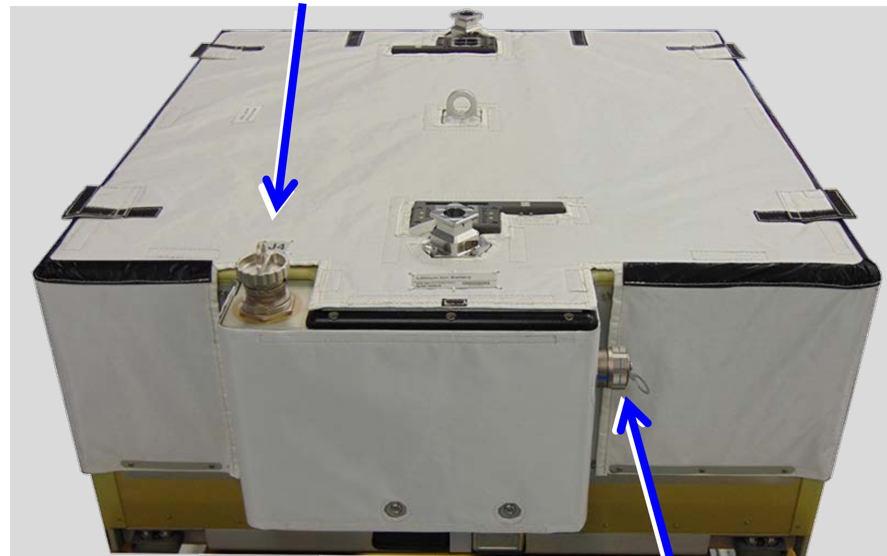
- Manufacturing Process controls include 100% materials screening and chemical analysis plus annual configuration/production line audits
- Acceptance testing of 100% of cells
- Simulated LEO life cycle testing in 2% of cells in each lot
- For 1% of cells in each lot, 100 cycles at 100% DOD are performed, 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

J4
Connector





P4 Connector
(stowed for launch)

EVA
Hand Hold

P1 & P2
Connectors

J3 Test
Connector

Adapter Plate ORU

Dimensions (LxWxH):	~ 41” x 36” x 15”
Spec Weight:	85 Lbs

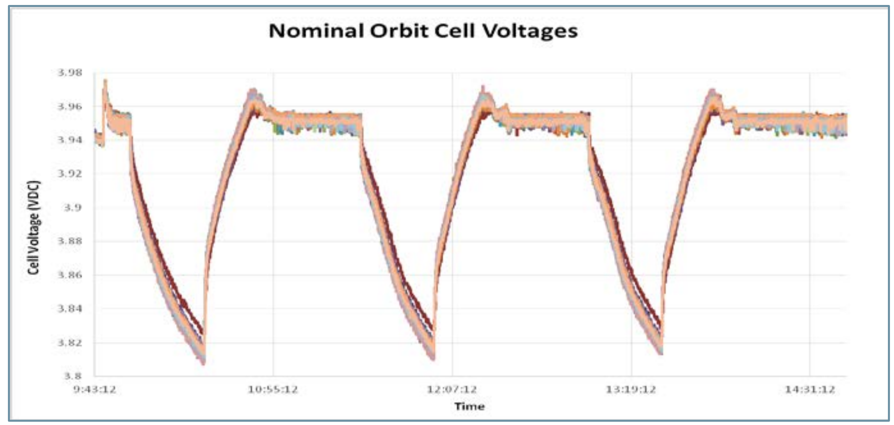
Li-ion Battery ORU

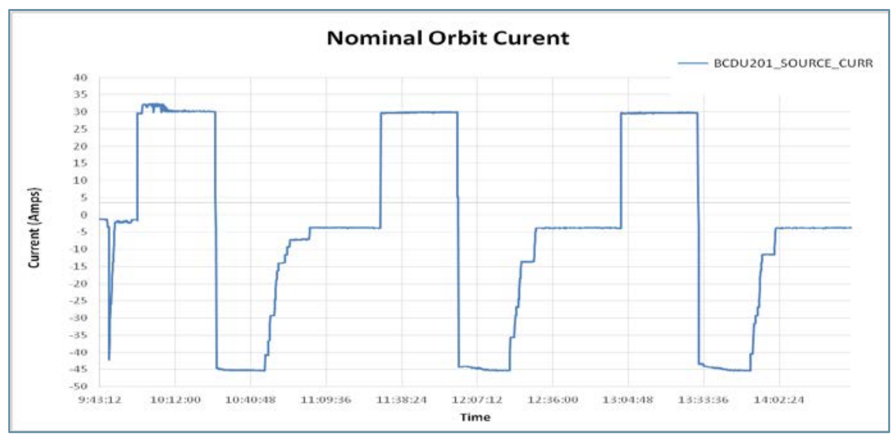
Dimensions (LxWxH):	~ 41” x 37” x 21”
Spec Weight:	435 Lbs

ISS Li-Ion Charge Control and Cycling

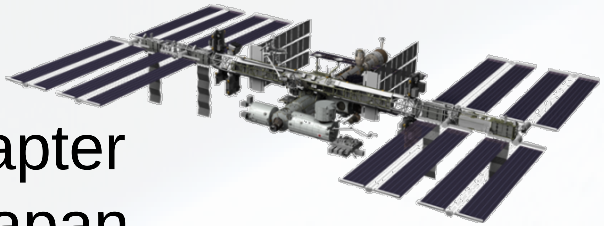
- Li-Ion charge current profile based on cell voltages
- Cell bypass/balancing at EOCV every orbit
- EOCV is ground command-able

Charge Current Profile		
	Highest of the Cell Terminal Voltages	Charge Current
Point 1	EOCV + 19mV	55
Point 2	EOCV + 19mV	49
Point 3	EOCV + 18mV	44
Point 4	EOCV + 17mV	39
Point 5	EOCV + 16mV	36
Point 6	EOCV + 15mV	33
Point 7	EOCV + 14mV	30
Point 8	EOCV + 13mV	26
Point 9	EOCV + 12mV	22
Point 10	EOCV + 11mV	19
Point 11	EOCV + 10mV	16
Point 12	EOCV + 9mV	13
Point 13	EOCV + 8mV	10
Point 14	EOCV + 7mV	7
Point 15	EOCV + 6mV	4
Point 16	not applicable	1





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-H_2 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