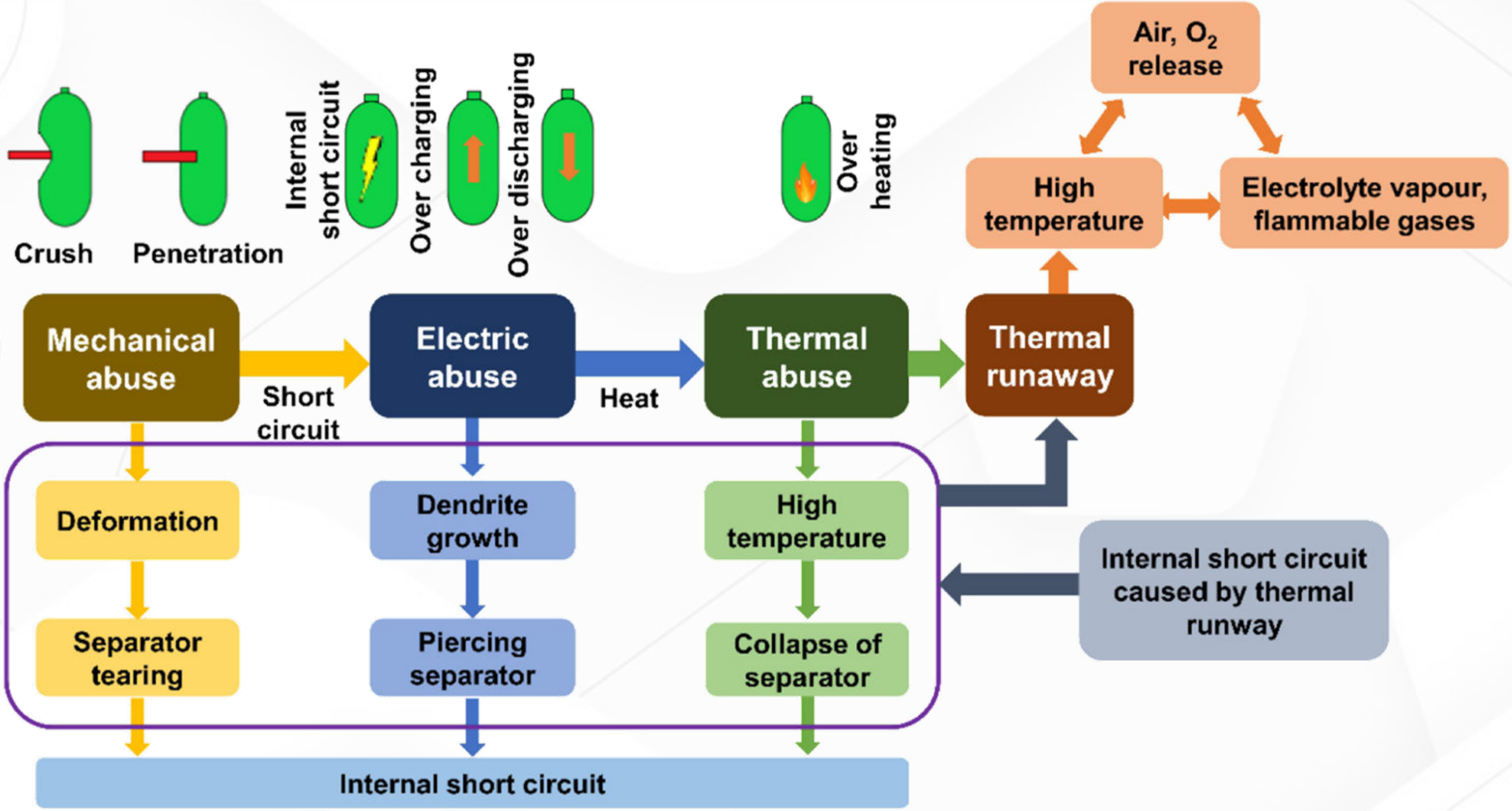
# Discussion on JSC 20793 Revision D Requirements for Crewed Space Exploration

KULR Open House, October 2024

# Thermal Runaway and its Causes




*Wang, et. al., "A review of lithium ion battery failure mechanisms and fire prevention strategies." Prog. Energy Combust. Sci. 2019, 73, 95–131*

# Thermal Runaway and its Causes

# Robosimian Fire Example


https://www.youtube.com/watch?v=hm18s-NYLZU&t=17s

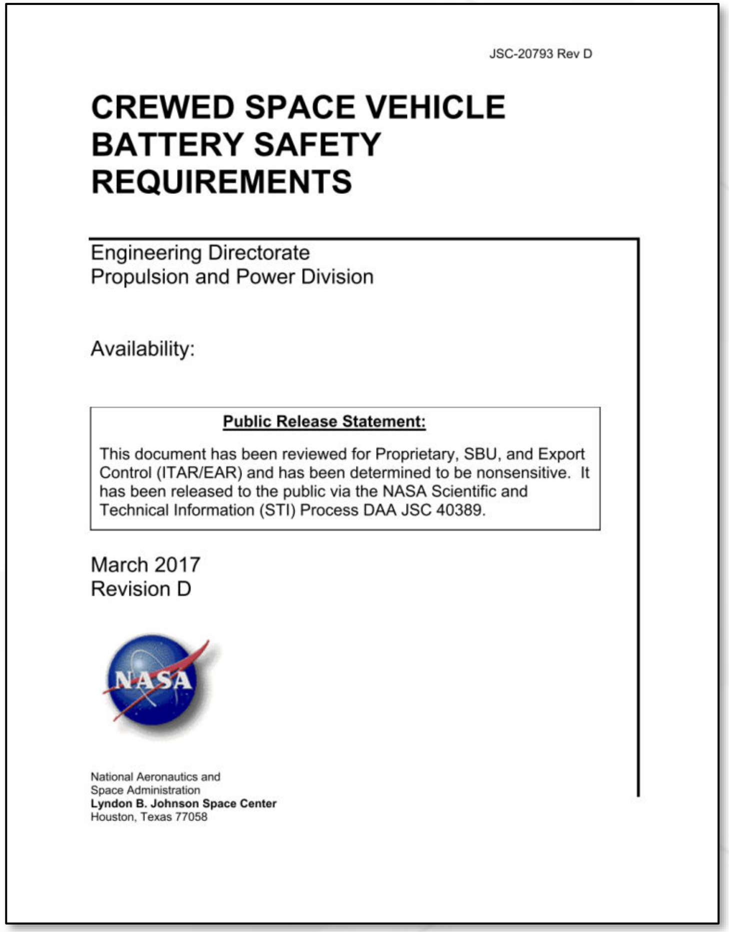
# Thermal Runaway Risks Require Mitigation in High Cost, High Risk Applications

NASA Robosimian Incident


Boeing 787 Dreamliner


NASA Orion Test

*Risks Addressed with JSC 20793 Revision D*


JSC-20793 Rev D

**CREWED SPACE VEHICLE BATTERY SAFETY REQUIREMENTS**

Engineering Directorate
Propulsion and Power Division

Availability:

**Public Release Statement:**

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March 2017
Revision D

National Aeronautics and
Space Administration
**Lyndon B. Johnson Space Center**
Houston, Texas 77058

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# Strategy in JSC 20793 Revision D

- **JSC 20793 addresses:**
  - General Battery Requirements (Section 4)
  - General Battery Hazards and Controls (Section 5)
  - Safety Relevant to Specific Battery Chemistries (Section 6): Chemistry-specific information.
- **For batteries >80Wh, cell-to-cell propagation prevention is required.**
  - Fire and gas produced for large batteries is catastrophic to the crew and the vehicle
  - Testing requirements provided in EP-19-001 memo
- **This creates a challenge as off-the-shelf (OTS) batteries are often not designed with propagation prevention in mind; often we only see this level of requirement in space, aerospace, and defense.**
- **5 key design guidelines stemming from JSC 20793 (ref. David Delafuente, Eric Darcy, and Sam Russell):**
  1. Prevent side wall breaches from propagating
  2. Provide adequate cell spacing and heat rejection
  3. Individually fuse parallel cells to prevent external shorting
  4. Protect the adjacent cells from the hot TR cell ejecta (solids, liquids, and gases)
  5. Prevent flames and sparks from exiting the battery enclosure

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# 20793 Abuse Testing Requirements

*Ref. D. Delafuente, Battery Safety and Propagation, Houston Safety Summit 2023.*

- **Full scale energy storage system with full electrical connections, structures, and safety features included.**
- **Charge the test article to the maximum mission state-of-charge (SOC).**
- **Conduct a minimum of 3 thermal runaway experiments with same or multiple test articles with trigger cell locations chosen to evaluate mission environment and worst-case scenario criteria.**
  - A single test article can be used for each experiment
  - Removal of debris and repair of flame arrestors is acceptable.
- **Fully Successful (minimum of 3 tests):**
  - Only the triggered cell(s) achieve TR
  - Other cells in the battery are not damaged, vented, ignited or leaking electrolyte, the CIDs, PTCs and/or fuses have not triggered
  - Neighboring cells can be cycled within ± five percent of pre-test capacity
  - No flames exit the battery enclosure

**Or**

  - No flames, sparks, gases, or fluids shall exit the containment vessel
  - Exterior temperatures of the containment vessel shall not exceed 60°C

- **Marginally Successful:** No cell-to-cell propagation nor flames exiting the system, but adjacent cells sustained damage (<u>minimum</u> 6 tests required)
- **Unsuccessful:** Battery fails to meet criteria for Fully or Marginally successful.

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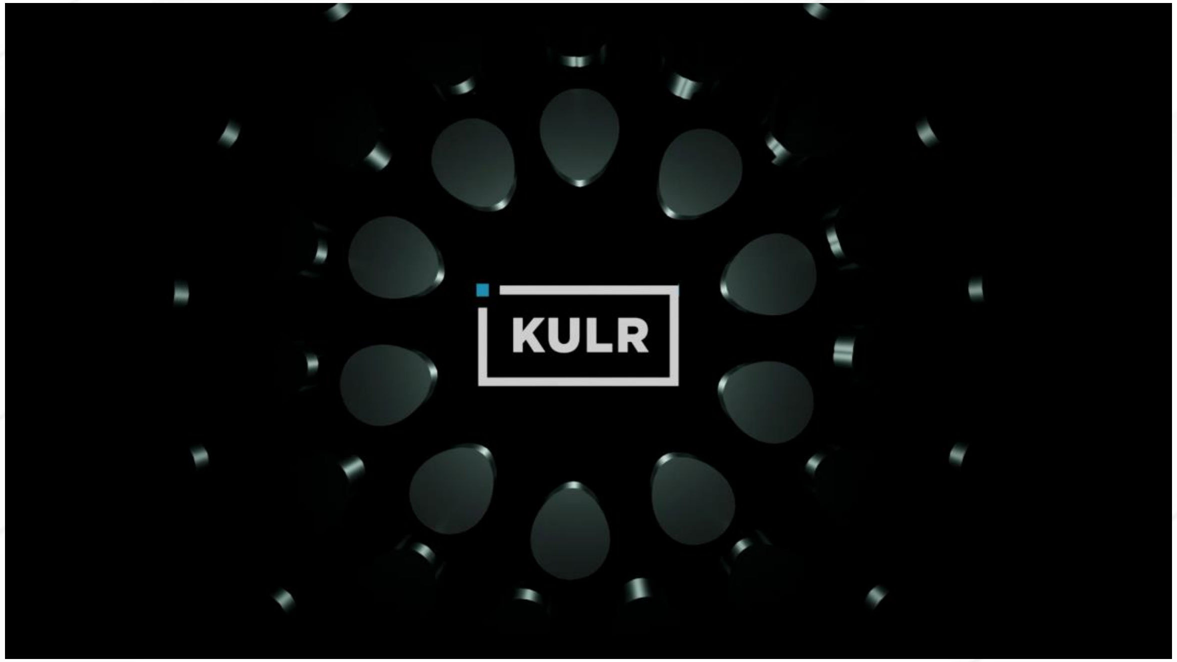
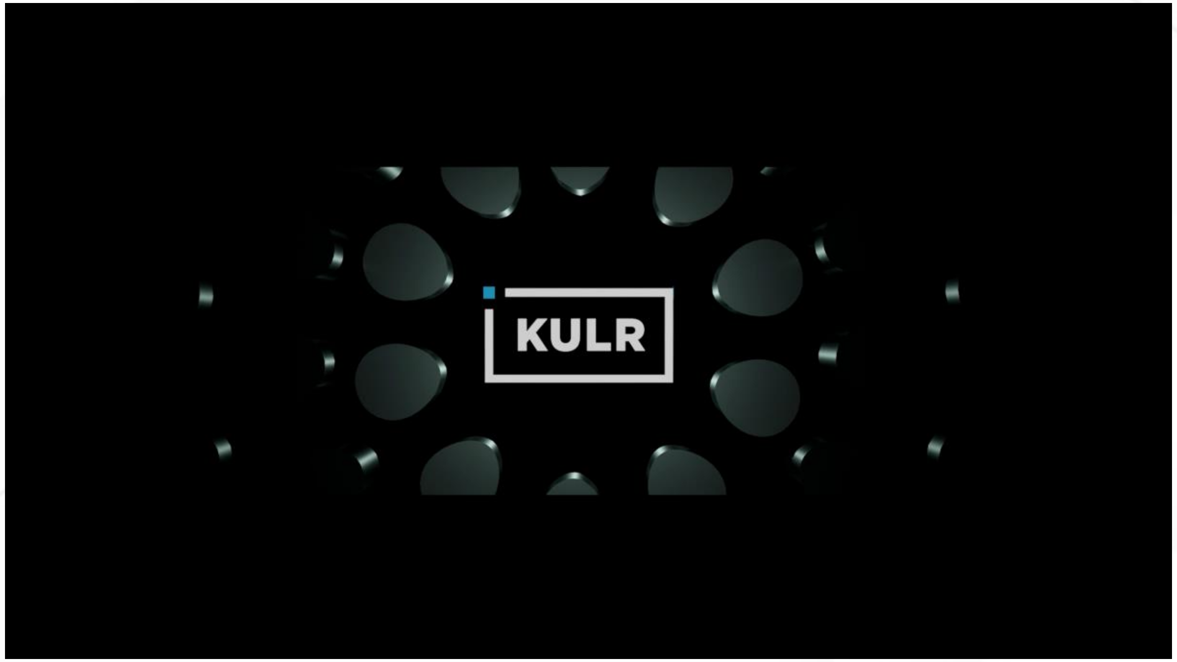
# KULR ONE Space Safety Performance




K1S 200 Wh Abuse Test Example (M35A)




K1S 400 Wh Abuse Test Example (M35A)

# KULR's Strategy

1. **Develop and provide in-house solutions that are centric to satisfying JSC 20793 Revision D:**
    - Cell Screening
    - Cell performance and abuse testing
    - Pack and module performance and abuse testing
    - Pack/module assembly in both prototyping and production environments
    - Electrical cyclers
    - Thermal / humidity chamber
    - Thermal vacuum chamber
    - Shock/vibration -> 2026 roadmap
2. **Keeping in-house drives cost down and decreases delivery timelines.**
3. **Deliver Off-The-Shelf (OTS) 20793 solutions pre-tested to satisfy 20793 requirements.**
    - Design based on 20793 driven guidelines for battery and associated electronics,
    - Fully or marginally successful abuse testing reports per design,
    - Qualification testing (TVAC, shock, vibration, electrical) available per design,
    - Acceptance testing conducted in-house, prior to shipment.

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# Growing Market Drives Significance

- **The space economy is growing to >$1T by the 2030s; this is driven by the commoditization of commercialized space industry. Key players in the growth here are:**
  - Continued dominance of existing Tier 1 private firms such as SpaceX and Blue Origin.
  - Sustained participation from traditional government contract entities like Boeing, NGC, and LMCo.
  - Introduction of new critical players such as Intuitive Machines with their lunar rover contract with NASA.
  - New up and coming companies like Starlink, Firefly Space (launch provider), Axiom (space station provider), and Vast (space station provider)
- **The space economy trends drive the needs for cost effective energy storage solutions (est. $25B market by 2032) that are suitable for a commoditization model which seeks to reduce the overall cost of space exploration by drastically decreasing the overall price entry barrier**
- **Commercialization of crewed spaceflight drastically increases the need for JSC 20793-Revision D compliant batteries with reduced cost and short delivery timeframe:**
  - i.e., there is an increasing need for a virtually non-existent market offering of a 20793 rated battery that is off-the-shelf (OTS) delivery and commoditized price tag.
  - Balancing the push for reduced cost with mission risk and safety is very difficult for energy storage systems; if the battery fails, so does the mission.
- **The scalable KULR ONE Space (K1-S) architecture seeks to provide a solution for this rapidly growing market vertical and to be the first OTS 20793 rated battery to market. Without this capability, space design teams requiring batteries must:**
  - Contract battery design efforts to expensive 3rd party firms or,
  - Build their own battery team from the ground up.

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# K1S 100 Series Specification

K1S 100, ISO View

K1S 100, Side View

**K1S 100, Samsung 18650-30Q**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 3.0 | Ah |
| Cell Stored Energy | 10.8 | Wh |
| Series | 4 | # |
| Parallel | 2 | # |
| Pack Max Voltage | 16.8 | V |
| Pack Nominal Voltage | 14.4 | V |
| Pack Capacity | 6.0 | Ah |
| Pack Energy | 86.4 | Wh |
| 2C Current | 12.0 | A |
| 2C Power | 172.8 | W |

**K1S 100, MOLICEL 18650-M35A**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 3.5 | Ah |
| Cell Stored Energy | 12.6 | Wh |
| Series | 4 | # |
| Parallel | 2 | # |
| Pack Max Voltage | 16.8 | V |
| Pack Nominal Voltage | 14.4 | V |
| Pack Capacity | 7.0 | Ah |
| Pack Energy | 100.8 | Wh |
| 2C Current | 14.0 | A |
| 2C Power | 201.6 | W |

**K1S 100, Amprius 18650-SA10**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 4.0 | Ah |
| Cell Stored Energy | 14.4 | Wh |
| Series | 4 | # |
| Parallel | 2 | # |
| Pack Max Voltage | 16.8 | V |
| Pack Nominal Voltage | 14.4 | V |
| Pack Capacity | 8.0 | Ah |
| Pack Energy | 115.2 | Wh |
| 2C Current | 16.0 | A |
| 2C Power | 230.4 | W |

- **The K1S 100 series comes in a** 10 cm x 10 cm x 10 cm form factor and is suitable for use in 2U and up CubeSat / SmallSat or larger.
- **Electrical Configurability:** 4S-2P (specification above) and (2S-4P, not shown above)
- **Power and Communications:** Space-rated Glenair Connector
- **Thermal:** -10 to 50 °C (cell dependent, heaters not installed in this revision)
- **Vibration / Shock:** NASA SLS Environment / GEVS / Vulcan Centaur
- **Safety:** In-line with JSC 20793 Revision D. Off-the-shelf 20793 coming Spring 2025 (requires flight acceptance testing prior to delivery).
- **Quality:** All packs constructed with NASA JSC WI-37A screened cells, regardless of cell selection. Packs constructed with MOLICEL 18650-M35A are constructed with cells that have an associated NASA Initial Lot Assessment (ILA) and Lot Acceptance Testing (LAT).

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# K1S 200 Series

K1S 200, Front View

K1S 200, Side View

**K1S 200, Samsung 18650-30Q**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 3.0 | Ah |
| Cell Stored Energy | 10.8 | Wh |
| Series | 4 | # |
| Parallel | 4 | # |
| Pack Max Voltage | 16.8 | V |
| Pack Nominal Voltage | 14.4 | V |
| Pack Capacity | 12.0 | Ah |
| Pack Energy | 172.8 | Wh |
| 2C Current | 24.0 | A |
| 2C Power | 345.6 | W |

**K1S 200, MOLICEL 18650-M35A**

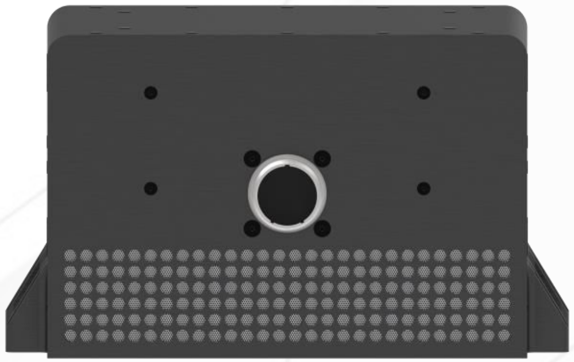
| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 3.5 | Ah |
| Cell Stored Energy | 12.6 | Wh |
| Series | 4 | # |
| Parallel | 4 | # |
| Pack Max Voltage | 16.8 | V |
| Pack Nominal Voltage | 14.4 | V |
| Pack Capacity | 14.0 | Ah |
| Pack Energy | 201.6 | Wh |
| 2C Current | 28.0 | A |
| 2C Power | 403.2 | W |

**K1S 200, Amprius 18650-SA10**

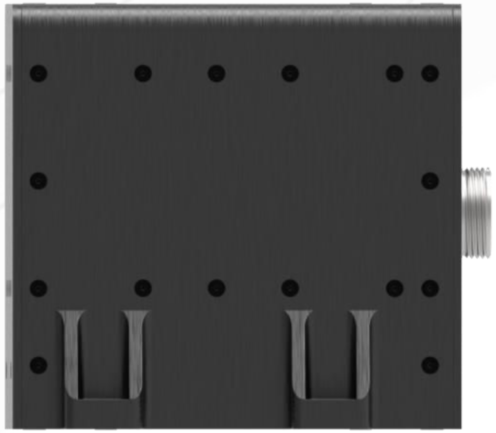
| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 4.0 | Ah |
| Cell Stored Energy | 14.4 | Wh |
| Series | 4 | # |
| Parallel | 4 | # |
| Pack Max Voltage | 16.8 | V |
| Pack Nominal Voltage | 14.4 | V |
| Pack Capacity | 16.0 | Ah |
| Pack Energy | 230.4 | Wh |
| 2C Current | 32.0 | A |
| 2C Power | 460.8 | W |

- **The K1S 200 series comes in a** 10 cm x 10 cm x 20 cm form factor and is suitable for use in 2U and up CubeSat / SmallSat or larger.
- **Electrical Configurability:** 4S-4P (specification above) and (4S-4P, not shown above)
- **Power and Communications:** Space-rated Glenair Connector
- **Thermal:** -10 to 50 °C (cell dependent, heaters not installed in this revision)
- **Vibration / Shock:** NASA SLS Environment / GEVS / Vulcan Centaur
- **Safety:** In-line with JSC 20793 Revision D. Off-the-shelf 20793 coming Spring 2025 (requires flight acceptance testing prior to delivery).
- **Quality:** All packs constructed with NASA JSC WI-37A screened cells, regardless of cell selection. Packs constructed with MOLICEL 18650-M35A are constructed with cells that have an associated NASA Initial Lot Assessment (ILA) and Lot Acceptance Testing (LAT).

# K1S 400 Series



K1S 400, Front View



K1S 400, Side View

**K1S 400, Samsung 18650-30Q**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 3.0 | Ah |
| Cell Stored Energy | 10.8 | Wh |
| Series | 8 | # |
| Parallel | 4 | # |
| Pack Max Voltage | 33.6 | V |
| Pack Nominal Voltage | 28.8 | V |
| Pack Capacity | 12.0 | Ah |
| Pack Energy | 345.6 | Wh |
| 2C Current | 24.0 | A |
| 2C Power | 691.2 | W |

**K1S 400, MOLICEL 18650-M35A**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 3.5 | Ah |
| Cell Stored Energy | 12.6 | Wh |
| Series | 8 | # |
| Parallel | 4 | # |
| Pack Max Voltage | 33.6 | V |
| Pack Nominal Voltage | 28.8 | V |
| Pack Capacity | 14.0 | Ah |
| Pack Energy | 403.2 | Wh |
| 2C Current | 28.0 | A |
| 2C Power | 806.4 | W |

**K1S 400, Amprius 18650-SA10**

| Description | | |
|---|---|---|
| Cell Voltage (Max) | 4.2 | V |
| Cell Voltage (Nominal) | 3.6 | V |
| Cell Capacity | 4.0 | Ah |
| Cell Stored Energy | 14.4 | Wh |
| Series | 8 | # |
| Parallel | 4 | # |
| Pack Max Voltage | 33.6 | V |
| Pack Nominal Voltage | 28.8 | V |
| Pack Capacity | 16.0 | Ah |
| Pack Energy | 460.8 | Wh |
| 2C Current | 32.0 | A |
| 2C Power | 921.6 | W |

- **The K1S 400 series comes in a** 12.7 cm x 21.6 cm x 12.4 cm form factor and is suitable for use in 2U and up CubeSat / SmallSat or larger.
- **Power and Communications:** Space-rated Glenair Connector
- **Thermal:** -10 to 50 °C (cell dependent, heaters not installed in this revision)
- **Vibration / Shock:** NASA SLS Environment / GEVS / Vulcan Centaur
- **Safety:** First of the K1S family offered as OTS 20793 rated (flight acceptance testing required prior to delivery)
- **Quality:** All packs constructed with NASA JSC WI-37A screened cells, regardless of cell selection. Packs constructed with MOLICEL 18650-M35A are constructed with cells that have an associated NASA Initial Lot Assessment (ILA) and Lot Acceptance Testing (LAT).