On-Orbit Operation of the Adiabatic Demagnetization Refrigerator on the Astro-H/Hitomi Soft X-ray Spectrometer Instrument

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ADR Requirements and Design

- ADR cools the Soft X-ray Spectrometer microcalorimeter array to 50 mK
- ADR uses a cryogenic system consisting, in part, of a 4.5 K Joule-Thomson (JT) cryocooler and a ~1.3 K superfluid helium tank
- SXS is designed to meet science goals even if there is a failure of the liquid helium or a failure of the JT cryocooler
- ADR has two operating modes

Cryogen mode 2-stage ADR cools the detectors, and rejects heat to the liquid helium

Cryogen-free mode 3-stage ADR cools the helium tank and detectors, and rejects heat to 4.5 K JT cooler

Performance Requirements

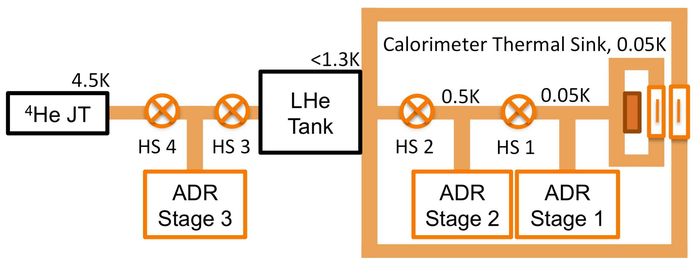
	Cryogen Mode	Cryogen-free Mode
Detector operating temperature (K)	0.05	0.05
Detector temperature stability (μK rms)	2.5	2.5
Detector housing temperature stability (mK)	1.0	1.0
Detector heat load (μW)	0.27	0.47
Minimum observing efficiency	90%	90%
Typical hold time (hours)	24	15
Typical recycle time (hours)	1	2
Maximum heat sink load (mW)	0.2 (avg)	30 (peak)
Maximum magnetic field at detectors (mT)	10	10

Physical Design Parameters

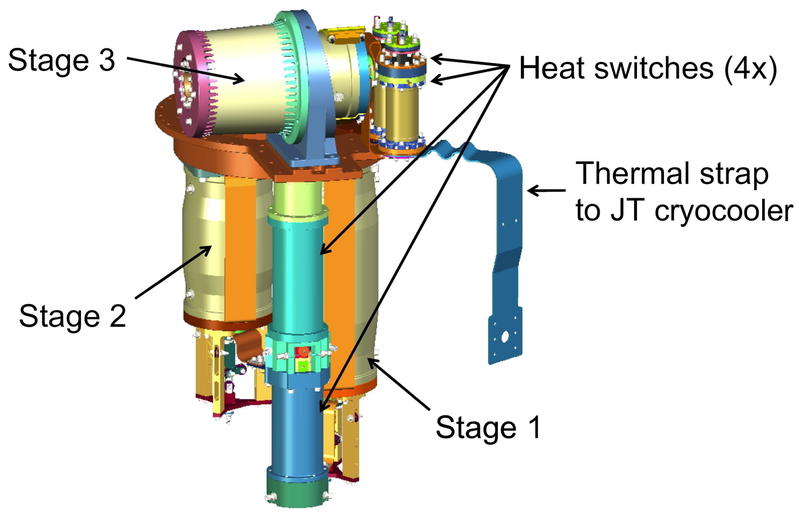
	Stage 1	Stage 2	Stage 3
Refrigerant type	CPA	GLF	GLF
Refrigerant mass (g)	270	147	147
Maximum magnetic field (T)	2	3	3
Maximum magnet voltage (V)	±1	±1	±1
Magnet inductance (H)	250	200	200

Operating Parameters (Cryogen Mode)

	Stage 1	Stage 2
Hold temperature (K)	0.05	0.50
Demagnetization temperature (K)	0.75	1.40
Maximum reject temperature (K)	1.60	1.55



Schematic of the Astro-H Cryogenic System (4.5 K and Below)
The four heat switches HS1-HS4 are all active gas-gap

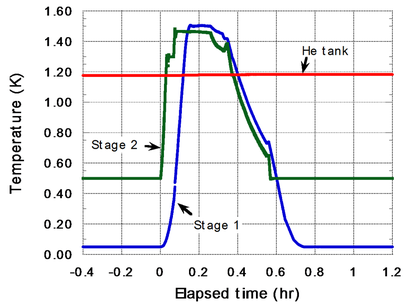


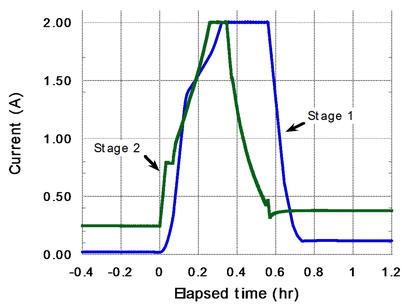
Solid Model of the 3-Stage ADR

ADR Recycling

Recycling process optimized for shortest duration

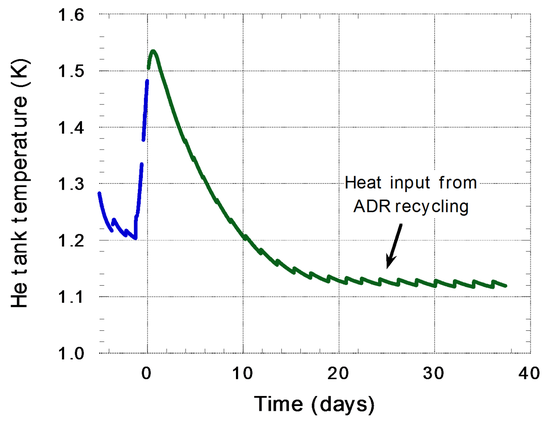
1. Both stages are magnetized to temperature above He tank
2. Heat switches HS1 and HS2 are powered on
3. Both stages are magnetized to full current, flowing heat to He tank
4. HS2 is powered off
5. Stage 2 is demagnetized, cooling Stage 1 to 0.75 K
6. HS1 is powered off
7. Stage 1 is demagnetized to 0.05 K, and Stage 2 to 0.5 K



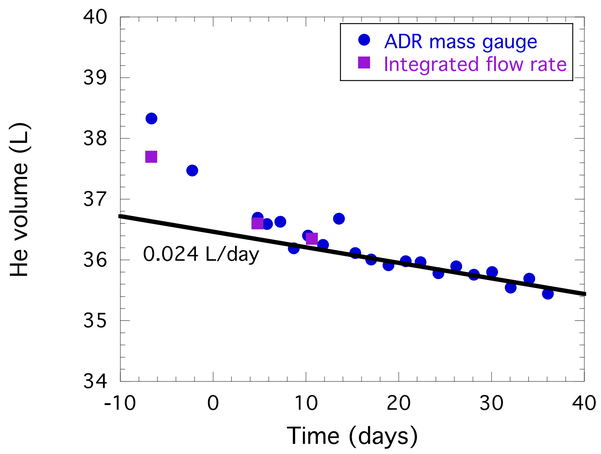


ADR Mass Gauging

- Each ADR recycle rejects ~11.2 J to the helium tank
- The temperature rise and heat input can be used to determine the helium volume
- The mass loss rate was 0.024 liters/day (±10%)
- The predicted lifetime for 36 liters was 4.2 years

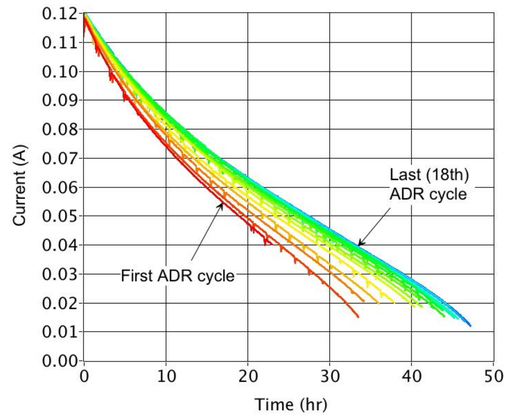


Helium tank temperature from before launch through the end of the mission, and helium volume as determined from ADR mass gauging



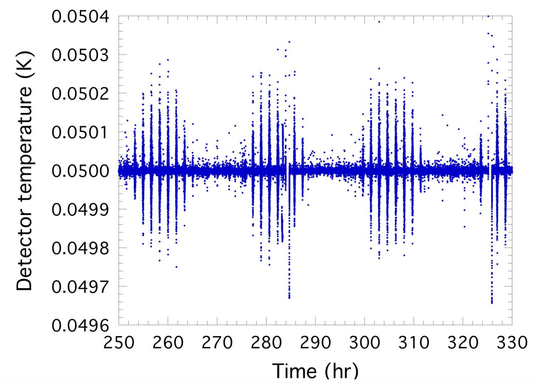
Detector Cooling On Orbit

- Hitomi launched with ~36 liters of liquid helium
- ADR operations began on Day 5
- ADR was operated only in Cryogen Mode
- ADR was recycled 18 times before operations ended on Day 38
- Heat load continually decreased as He tank cooled, eventually yielding a **hold time of 48 hours**



Demagnetization curves for Stage 1 at 50 mK

- On orbit, cosmic ray heating appeared as random impulses outside of the South Atlantic Anomaly (SAA), but as a significant disturbance during passes through the SAA
- Hitomi passed through some portion of the SAA on 8-9 (out of ~15) orbits each days



Orbit Operation Summary

- SXS instrument operated flawlessly through 38 days on orbit
- ADR was cycled 18 times
  - ❖ Recycle operation requires <0.8 hours
  - ❖ Hold time ~48 hours, with stability of ~1 μK rms at 50 mK
- Duty cycle in excess of 98%
- Total heat load to 50 mK was ~0.8 μW
  - ❖ Inferred detector heat load was ~0.4 μW
- Time average heat output to the helium tank was <0.07 mW

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