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Lithium Ion Battery Risk Reduction Testing in Support of Robotic Lander Vehicles

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Robotic Missions of Interest

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- Lunar Equator – Science Instrument Package
- Lunar Pole – Science Instrument Package
- Lunar Crater
  - Rim
  - Floor – Permanently Shadowed Regions
    - Stationary Lander - ASRG
    - Rover - ASRG
- NEO (Near Earth Object) – Asteroid, etc.
- Mars

Power System Challenges

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- Mass Constrained
  - Lithium Ion energy density
- Thermal Environment
  - -200° C to +170° C
- Mission Duration
  - 6 Years – 75 Cycles
- Sun Light Availability
  - ASRG – Advanced Stirling Radioisotope Generator
  - Solar Array
    - Dust?

Most Power Challenged Missions

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- Lunar Equator
  - Solar Array Battery System
  - Lithium Ion energy density
  - -200° C to +170° C
  - 6 Years – 75 Cycles
- Lunar Polar Crater Floor - PSR
  - ASRG ~ 140 watt maximum
  - Lithium Ion energy density supplement
  - -200° C to +20° C
  - 6 months – 100 Cycles

Lunar Equator Mission

Test Article Packaging

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Option	Cell Type	Temp	Test Case	# Cells	VDC	Period
SAB	VES 180	Nominal	Pack (1) ES41-10-ILN-TA-003	4	14	RT-6yr
SAB	VES 180	Nominal	Pack (1a) ES41-10-ILN-TA-004	4	14	A-8 mo
SAB	VES 180	Off-Nom	Pack (1*) ES41-10-ILN-TA-005	4	14	RT-6yr
SAB	Lithion NCP55-2	Nominal	Pack (2) ES41-10-ILN-TA-006	4	14	RT-6yr
SAB	Lithion NCP55-2	Nominal	Pack (2a) ES41-10-ILN-TA-007	4	14	A-8 mo
SAB	Lithion NCP55-2	Off-Nom	Pack (2*) ES41-10-ILN-TA-008	4	14	RT-6yr
ASRG	A123 APR18650M1A	Nominal	Battery (3) ES41-10-ILN-TA-001	20	28	RT
ASRG	A123 APR18650M1A	Off-Nom	Battery (3a) ES41-10-ILN-TA-002	20	28	RT

Lunar Polar Crater Floor

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- PSR – indicates use of radioisotope power
  - 140 watt ASRG output unable to cover power peaks
    - Thrusters – 750 W
    - Science Instruments – 450 W
- Thermal Subsystem Control
  - -200° C to +20° C
- Lithium Ion ($LiFePO_4$) Battery Supplement
  - 10 cell Battery

Lunar Polar Crater Floor

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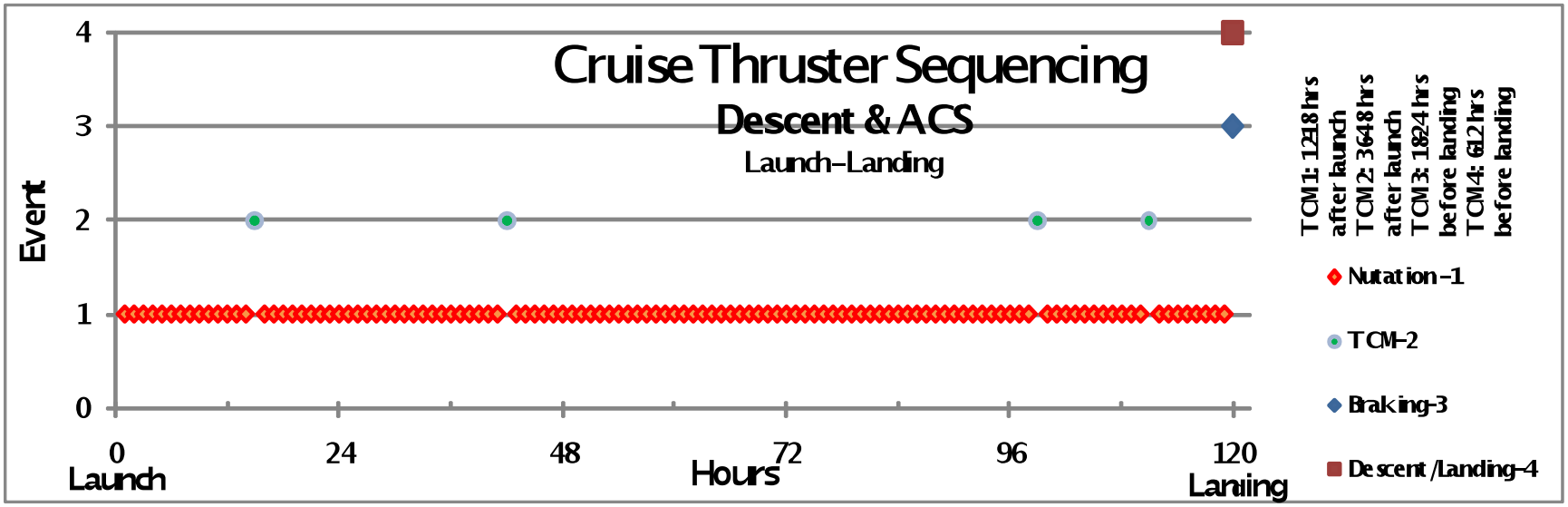

Lunar Polar Crater Floor

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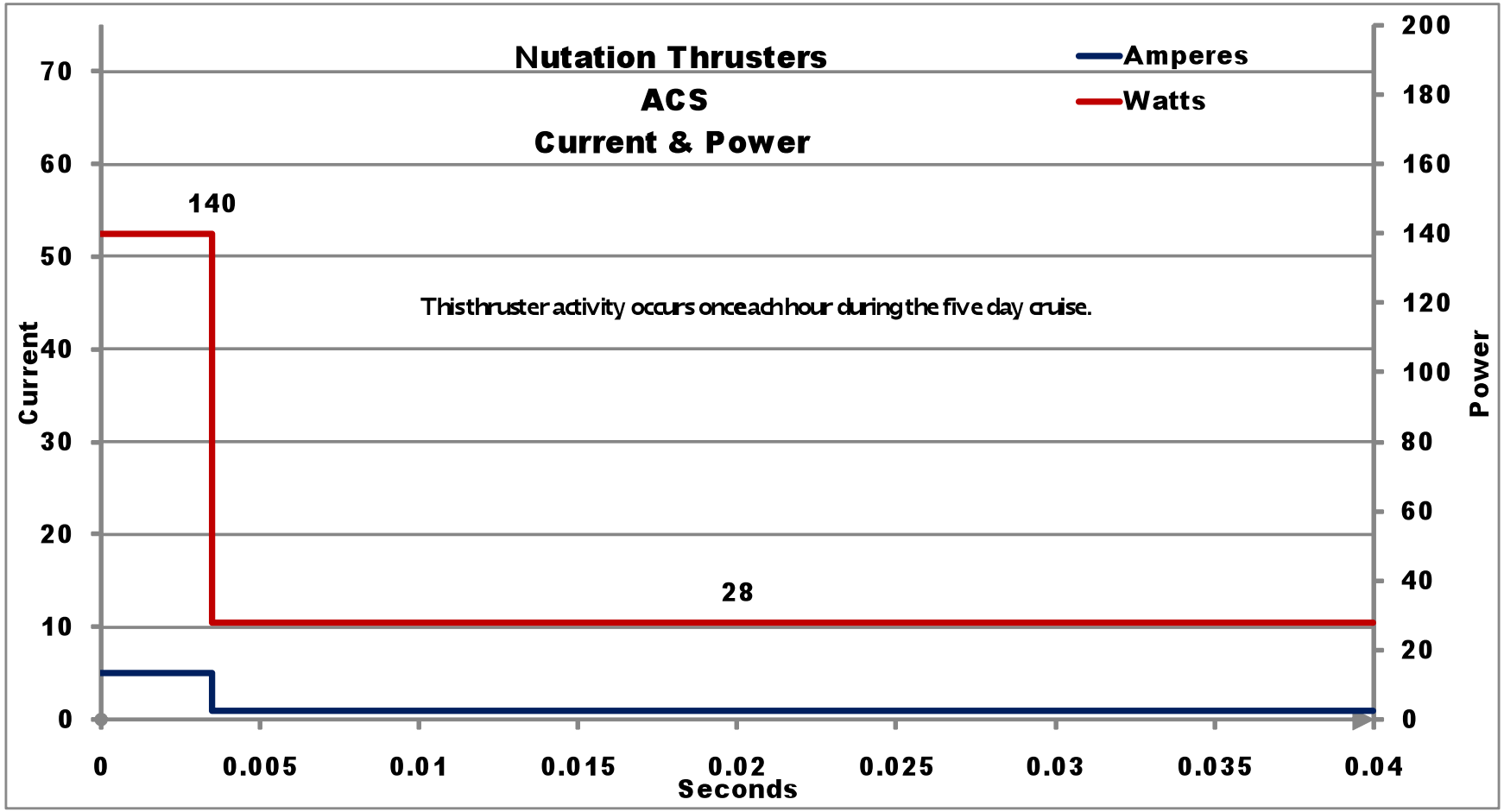

Lunar Polar Crater Floor

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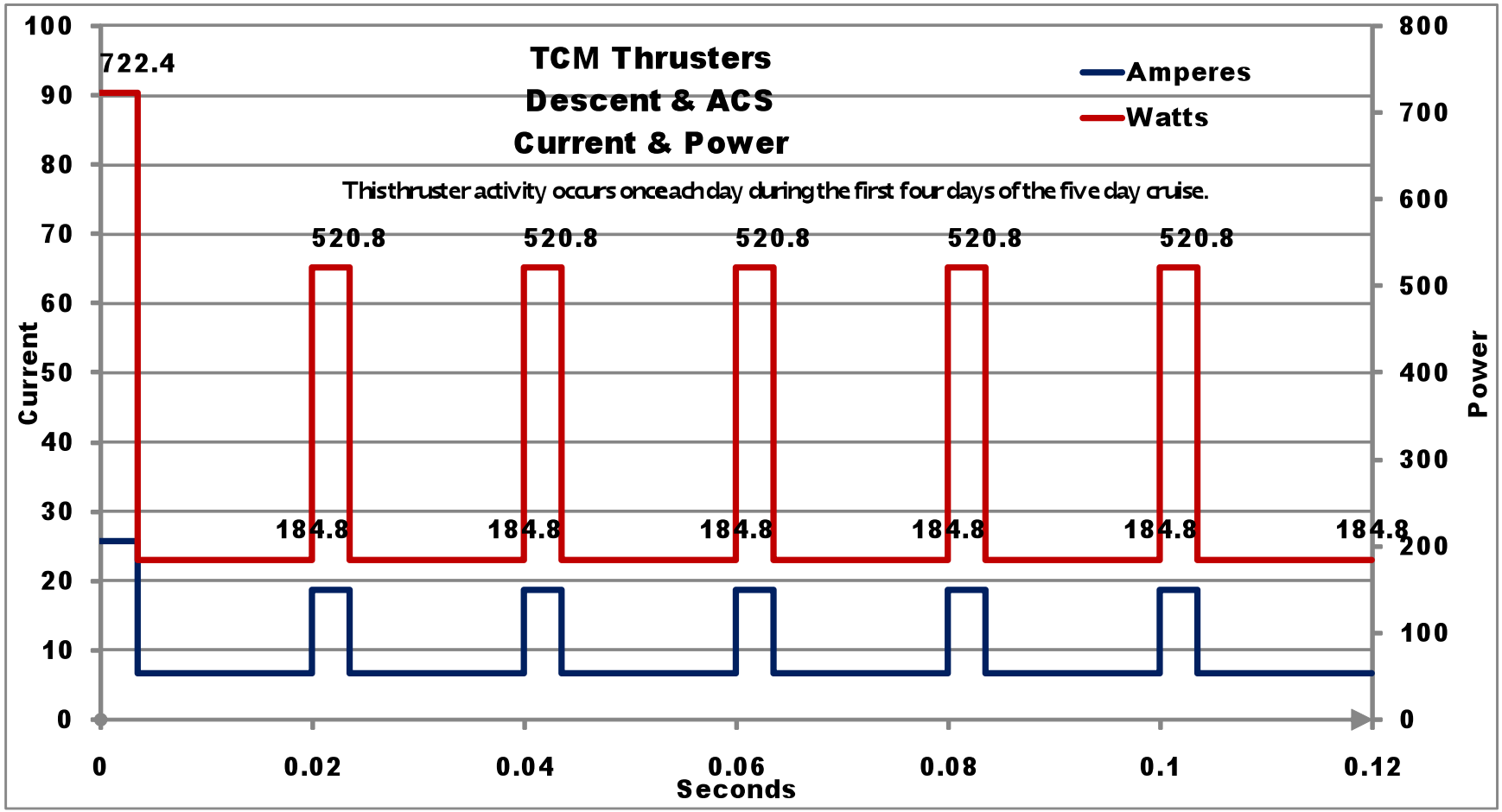

Lunar Polar Crater Floor

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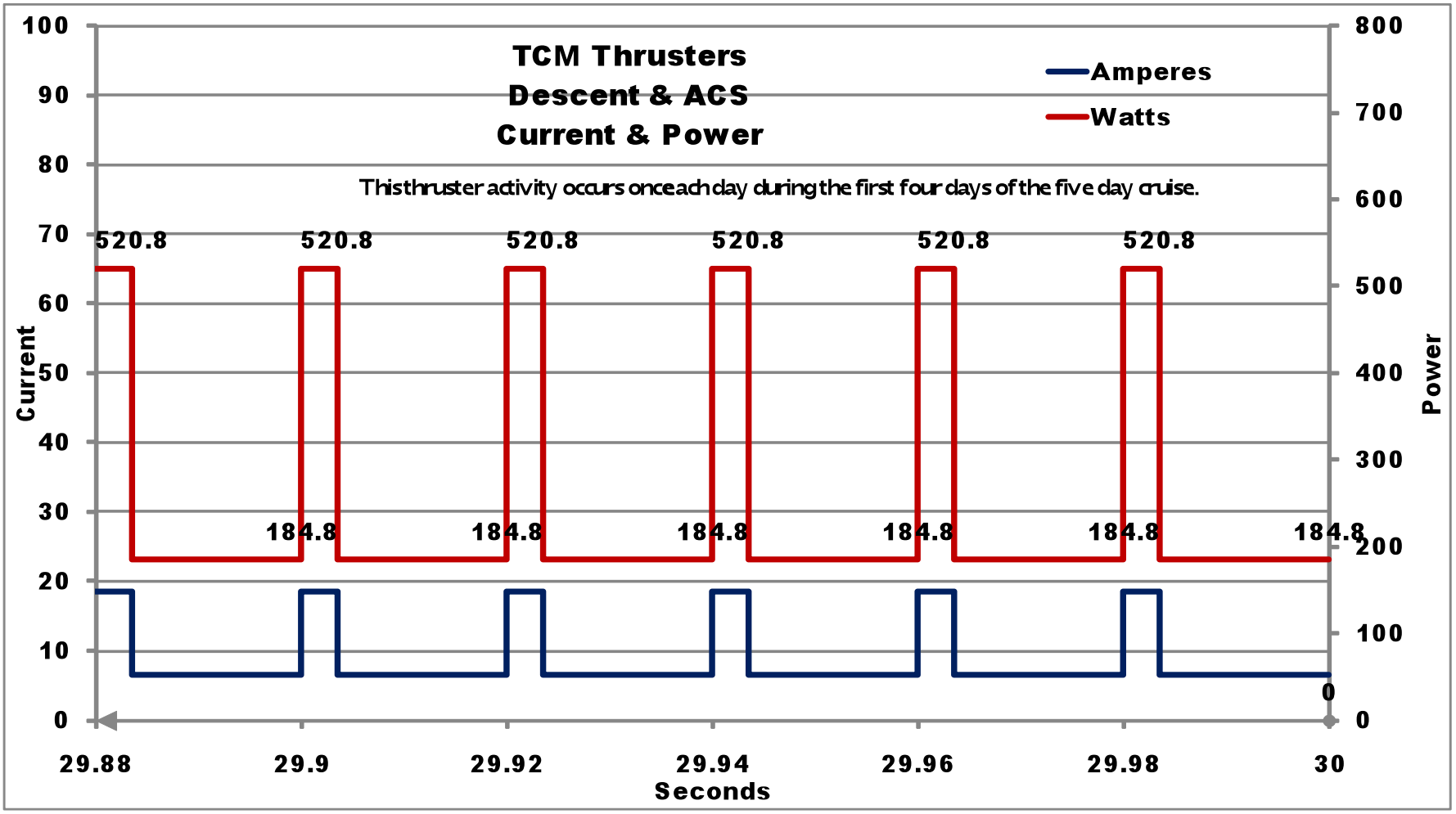

Lunar Polar Crater Floor

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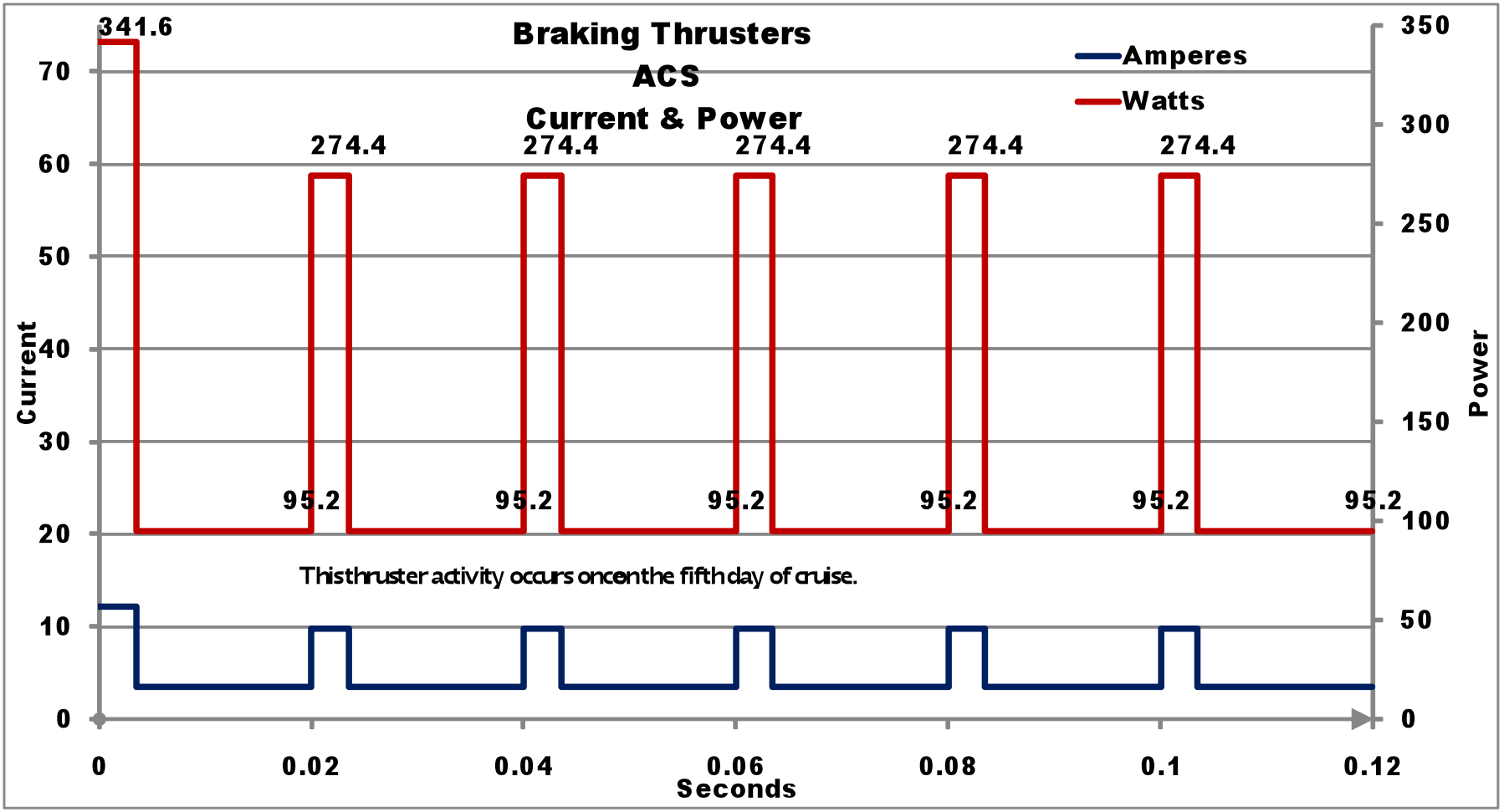

Lunar Polar Crater Floor

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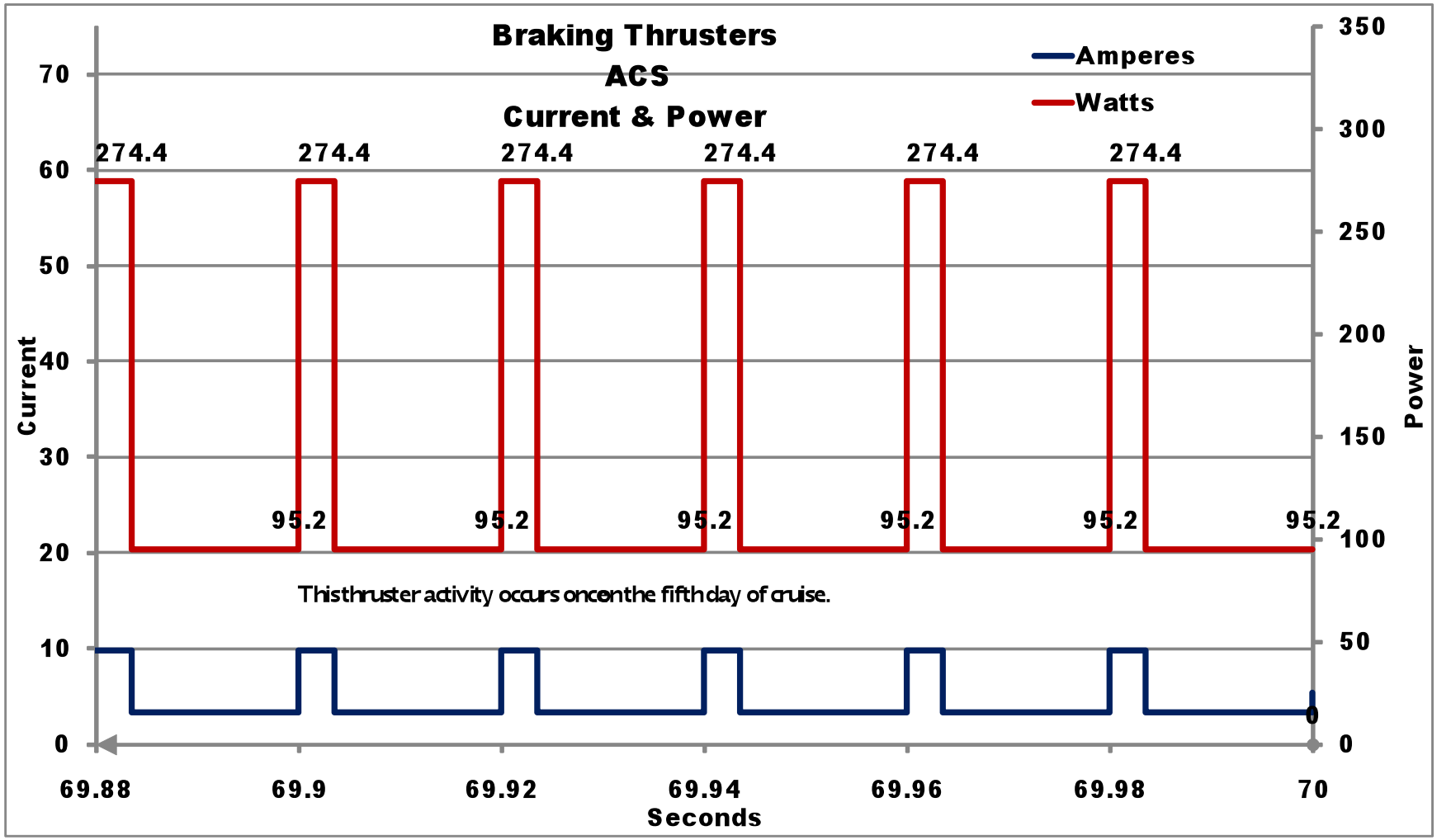

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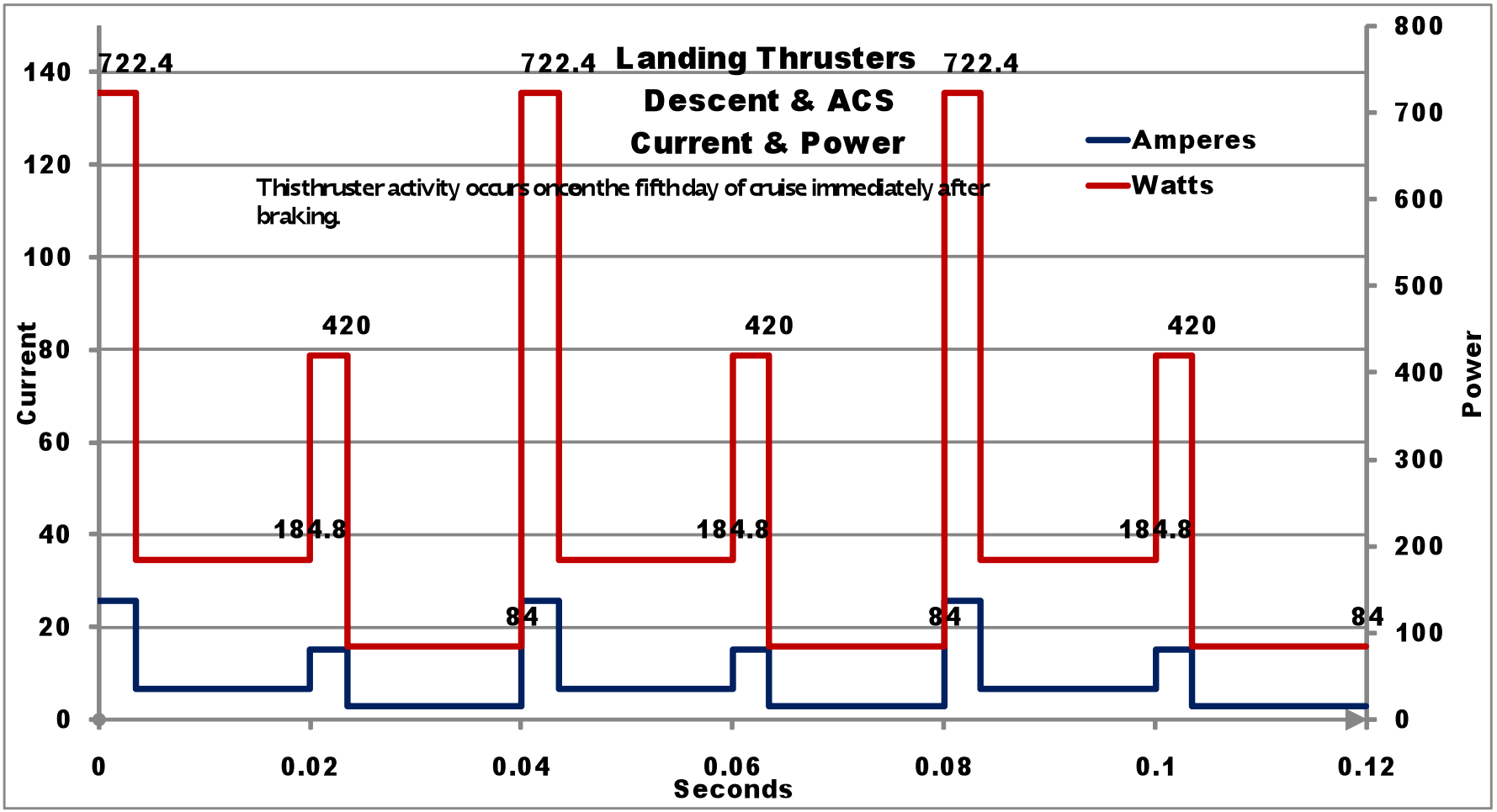

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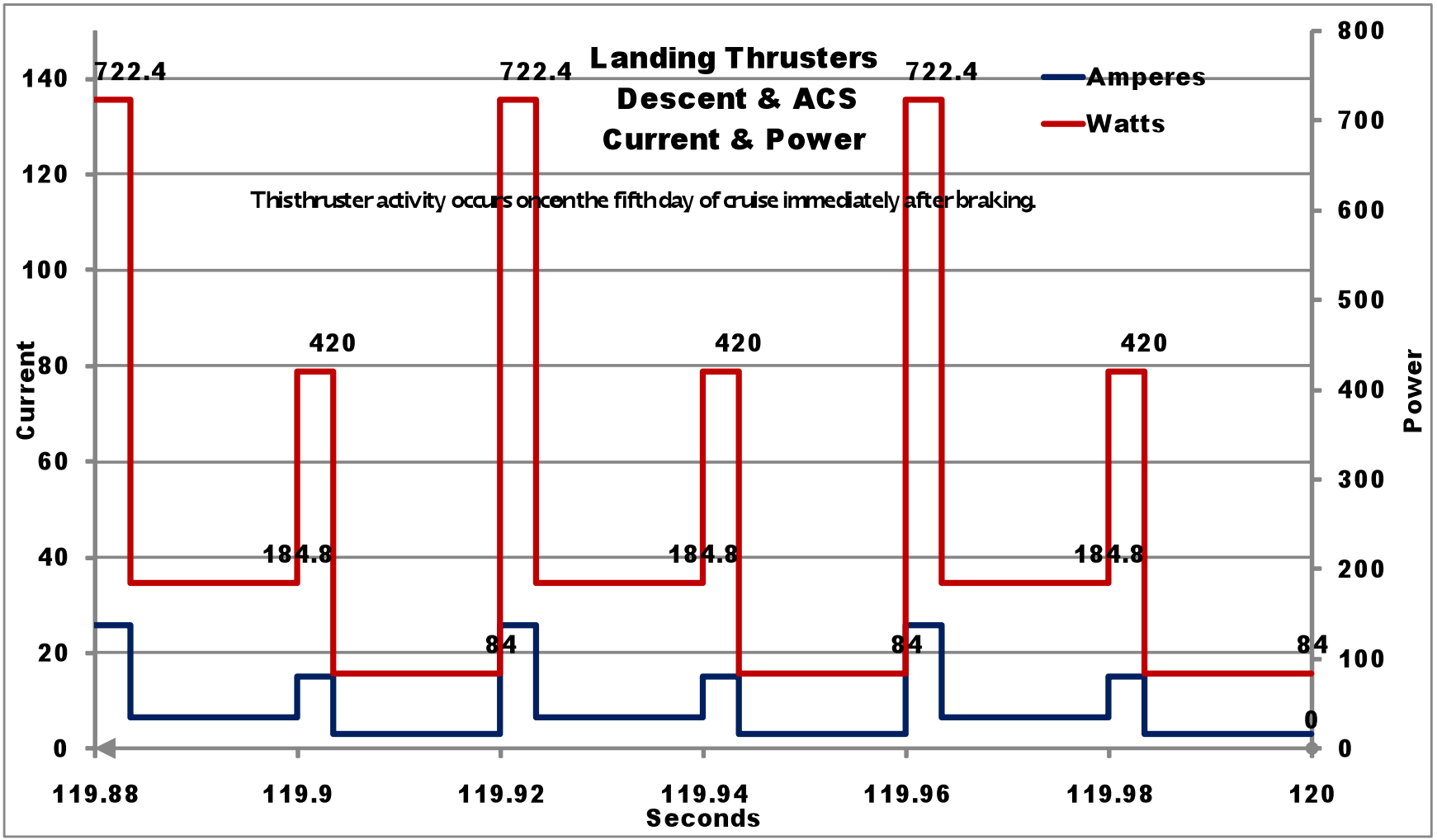

ILN/LPV ASRG/$LiFePO_4$ Battery Risk Reduction Testing

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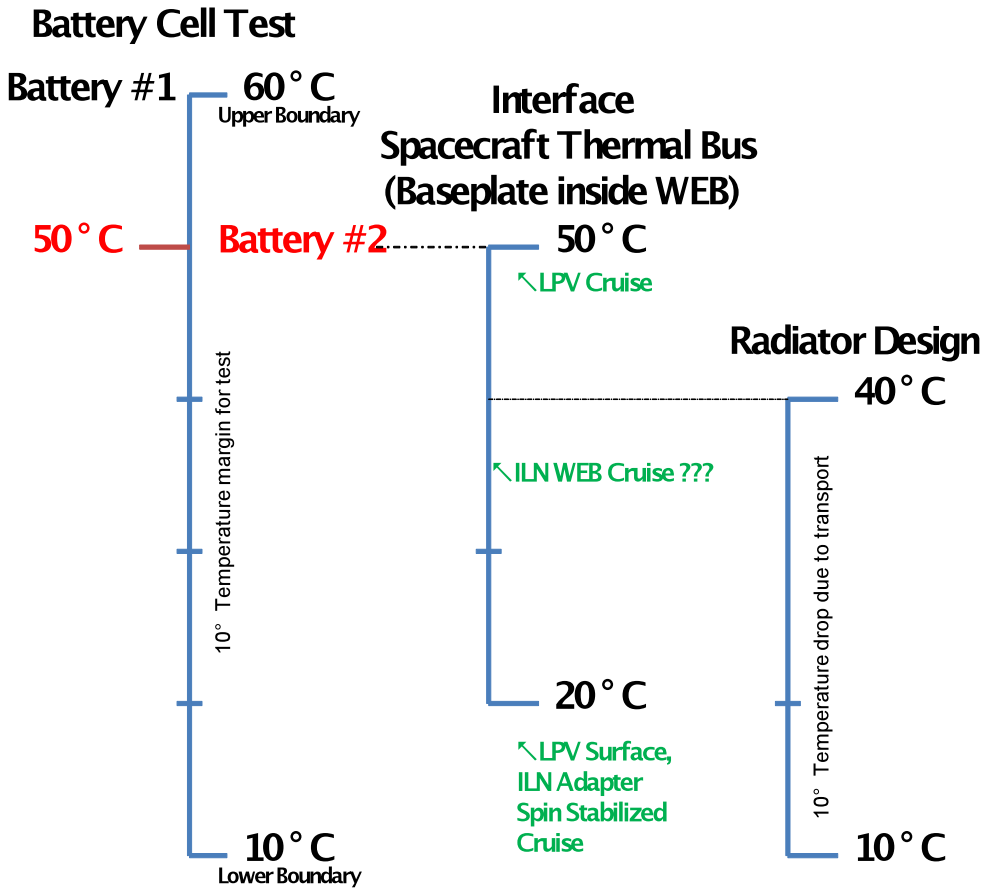
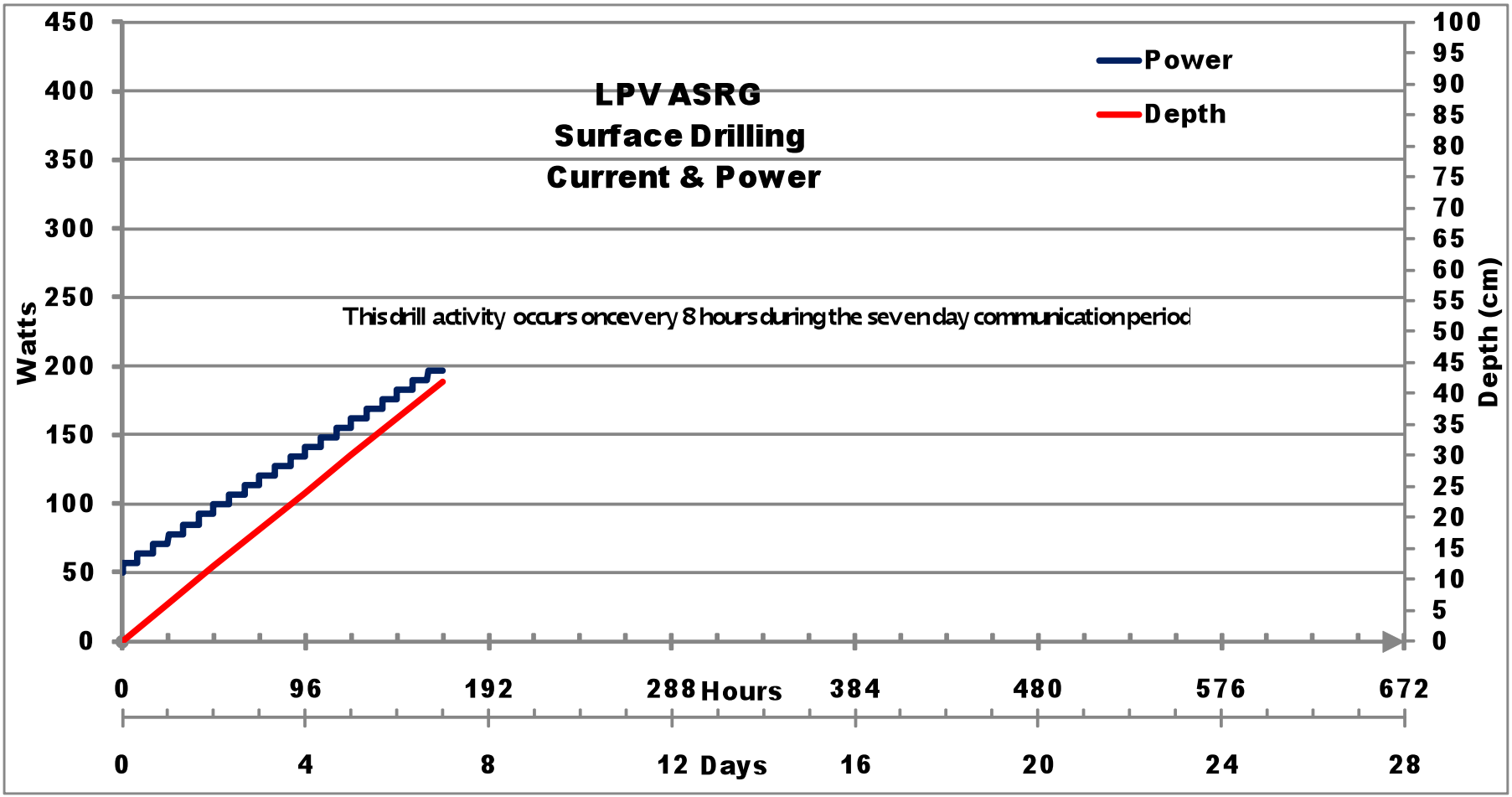
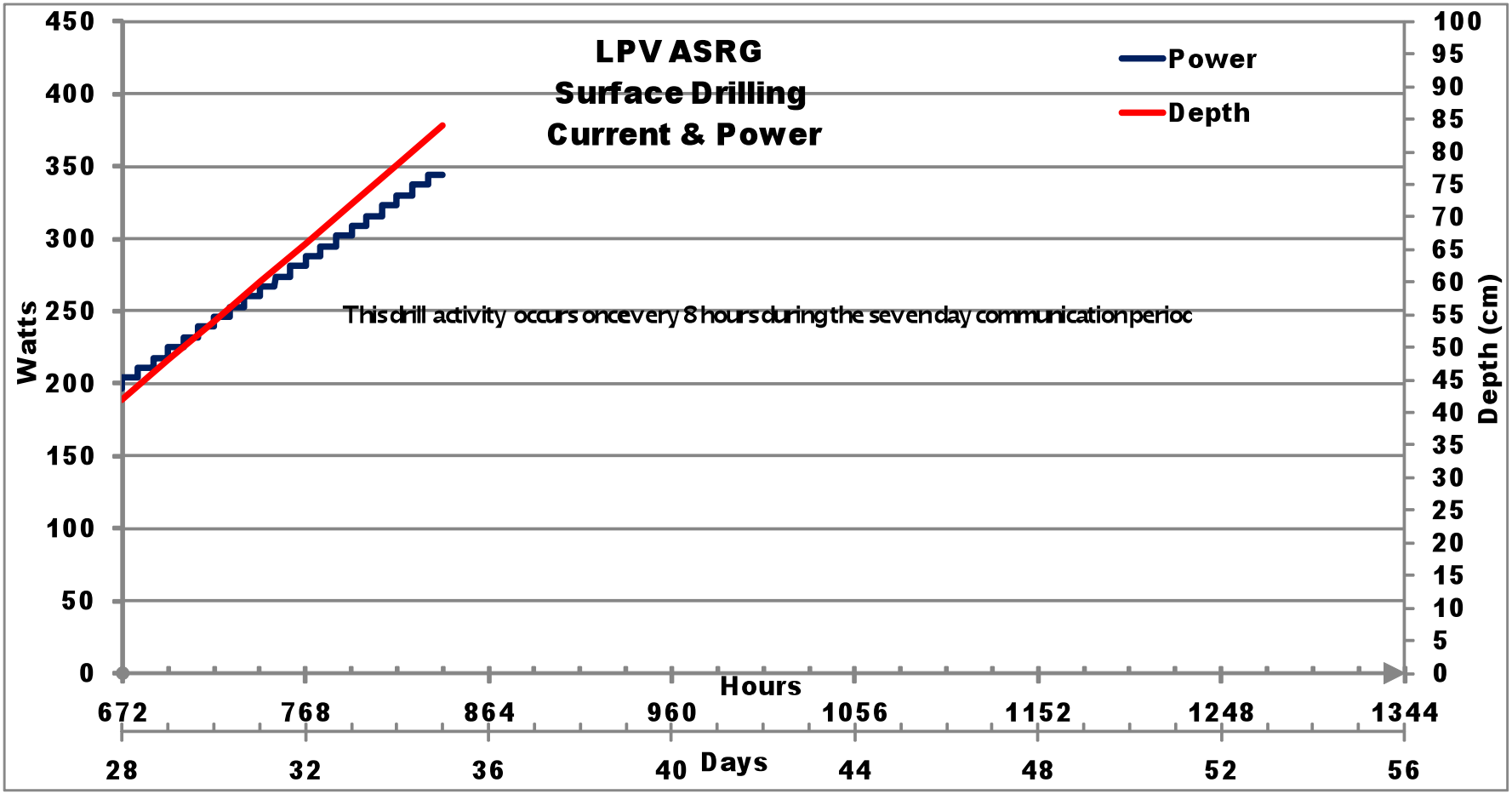



LPV ASRG
Surface Drilling
Current & Power
Power
Depth
This drill activity occurs once every 8 hours during the seven day communication period
Watts
Depth (cm)
450
400
350
300
250
200
150
100
50
0
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
96
192
288
Hours
384
480
576
672
0
4
8
12 Days
16
20
24
28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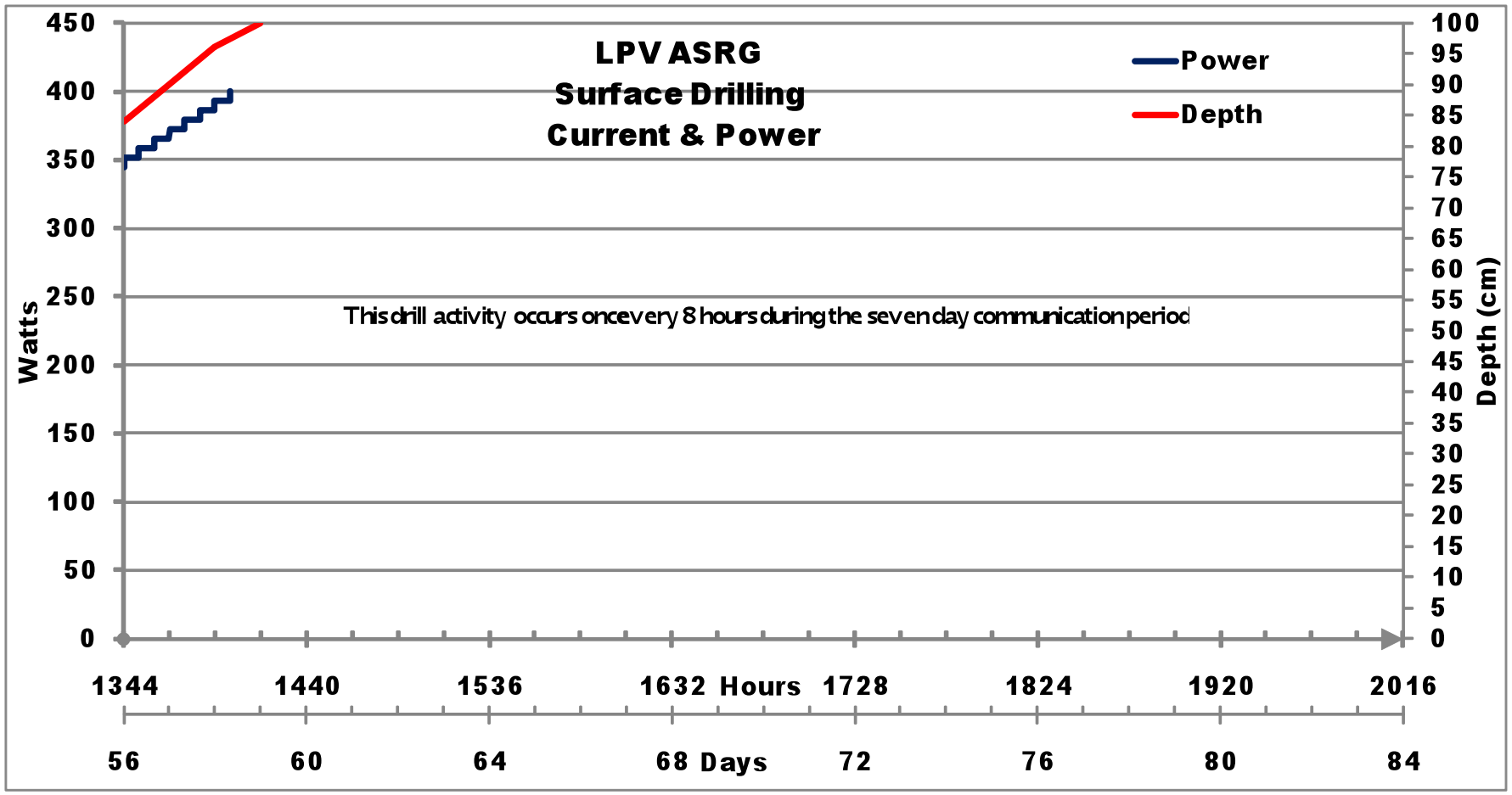

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75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1344
1440
1536
1632 Hours
1728
1824
1920
2016
56
60
64
68 Days
72
76
80
84

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A123 APR18650M1A Cell

Test battery ES41-10-ILN-TA-001 (10S2P)
2.2 Ahr

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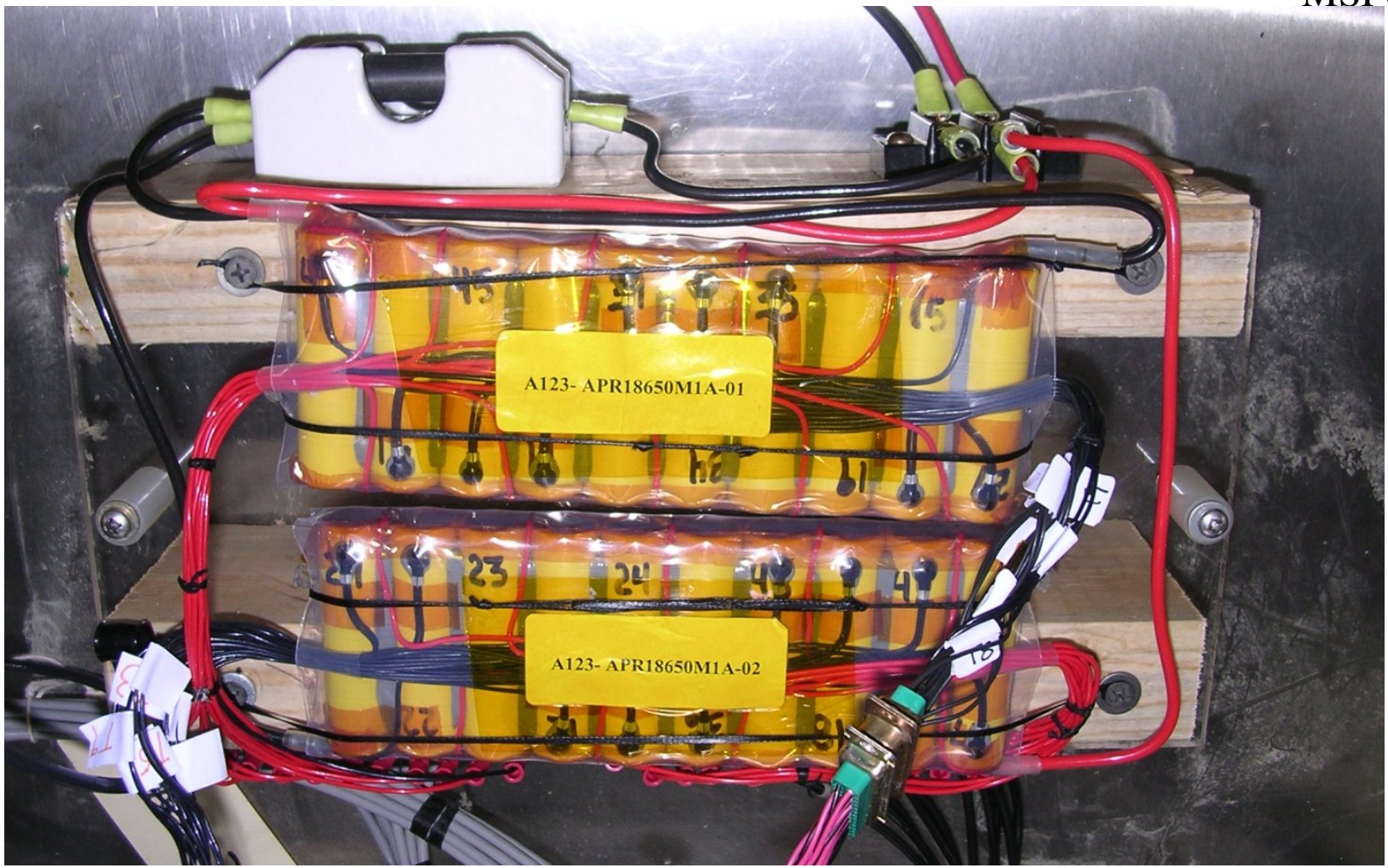
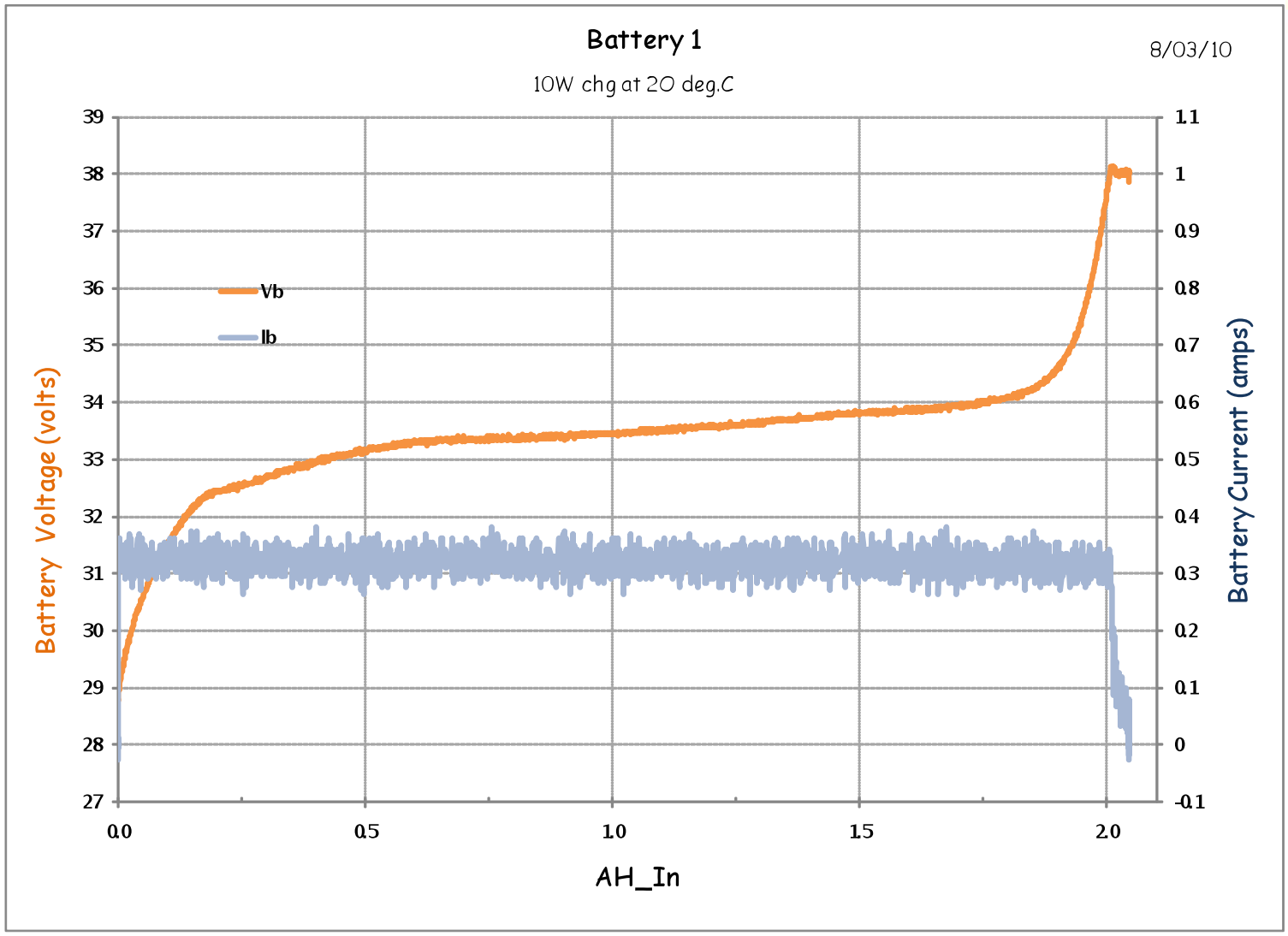


Typical Battery Recharge



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Typical Battery Recharge

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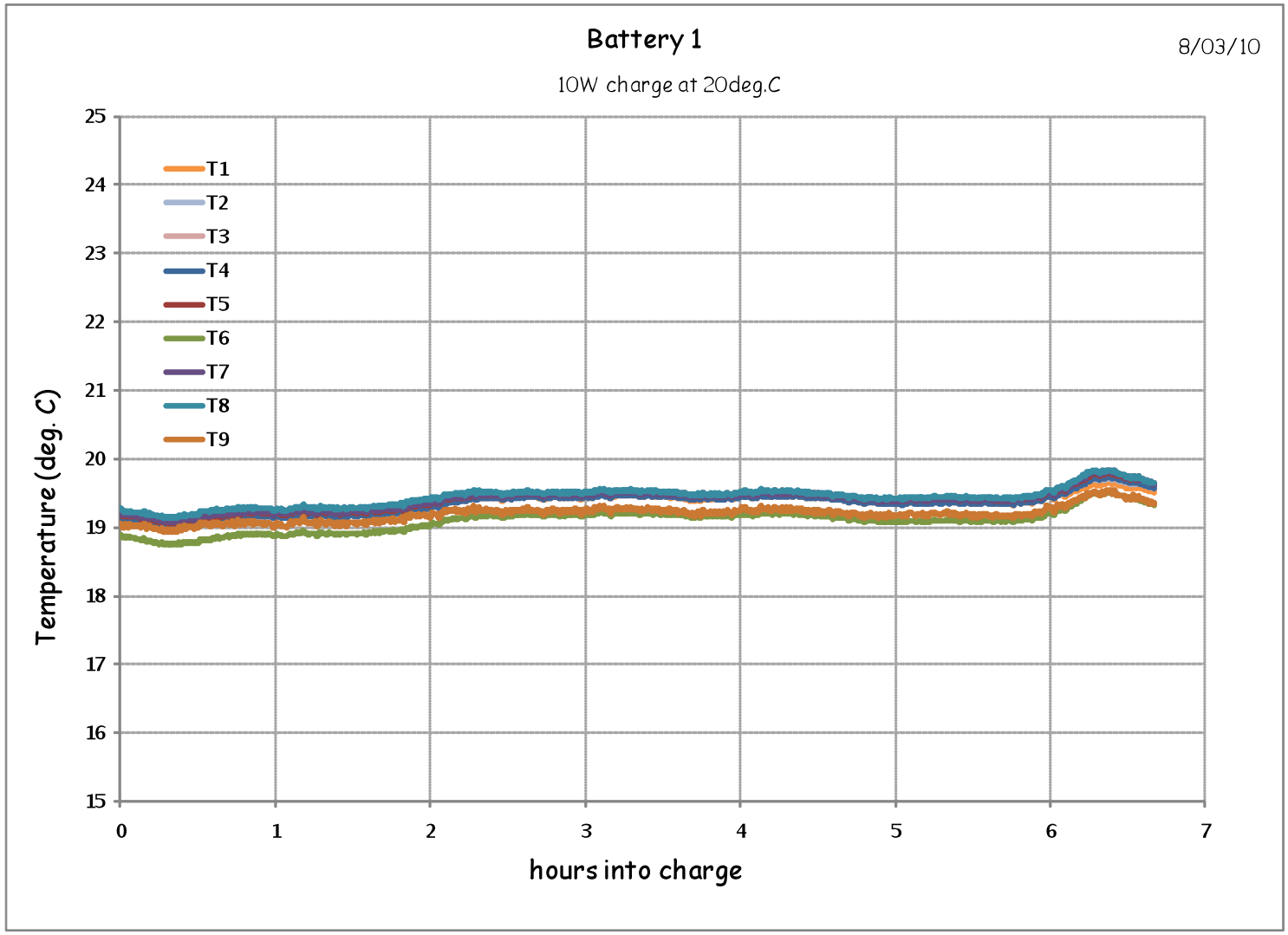
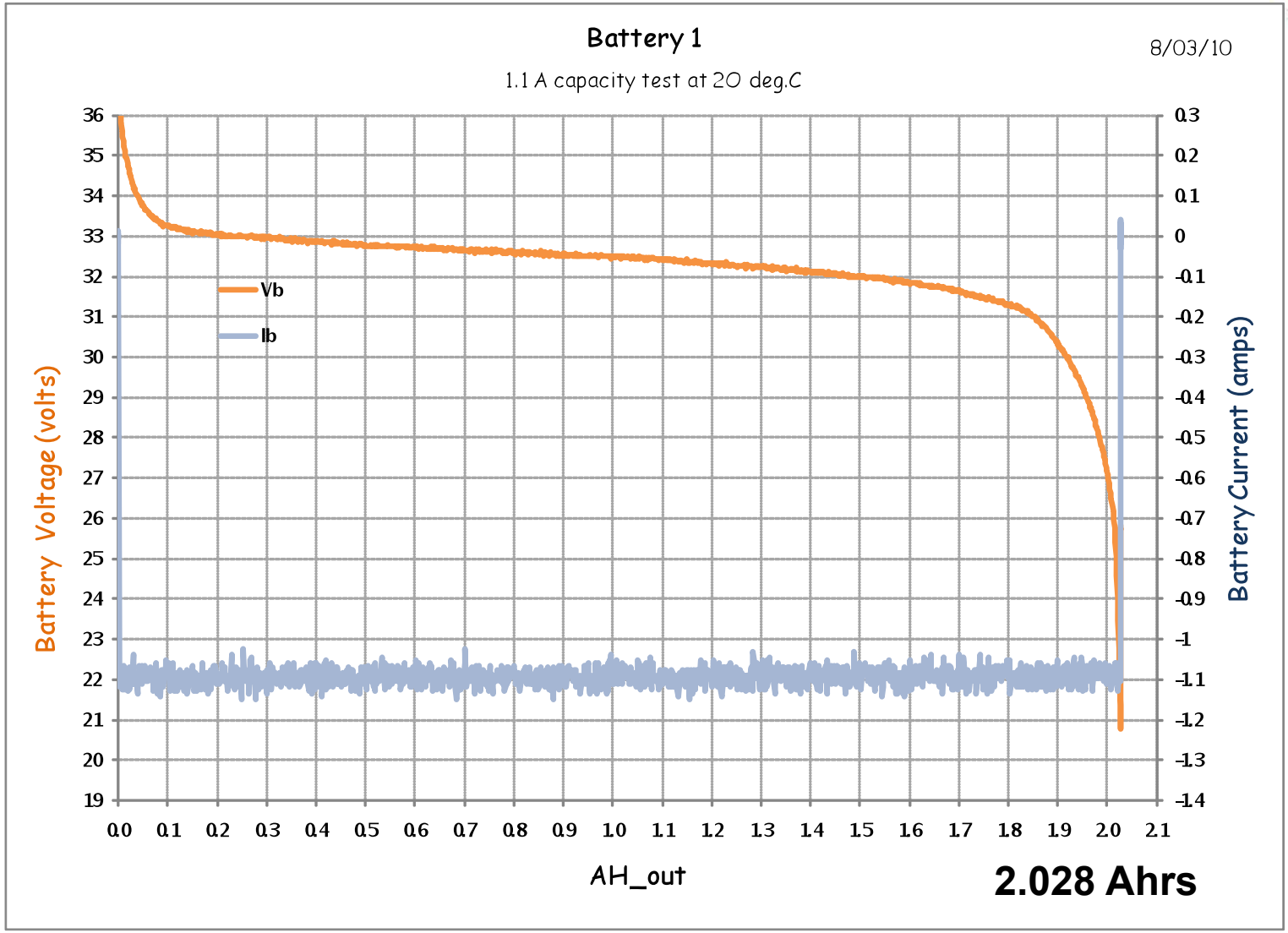


Initial Battery Capacity



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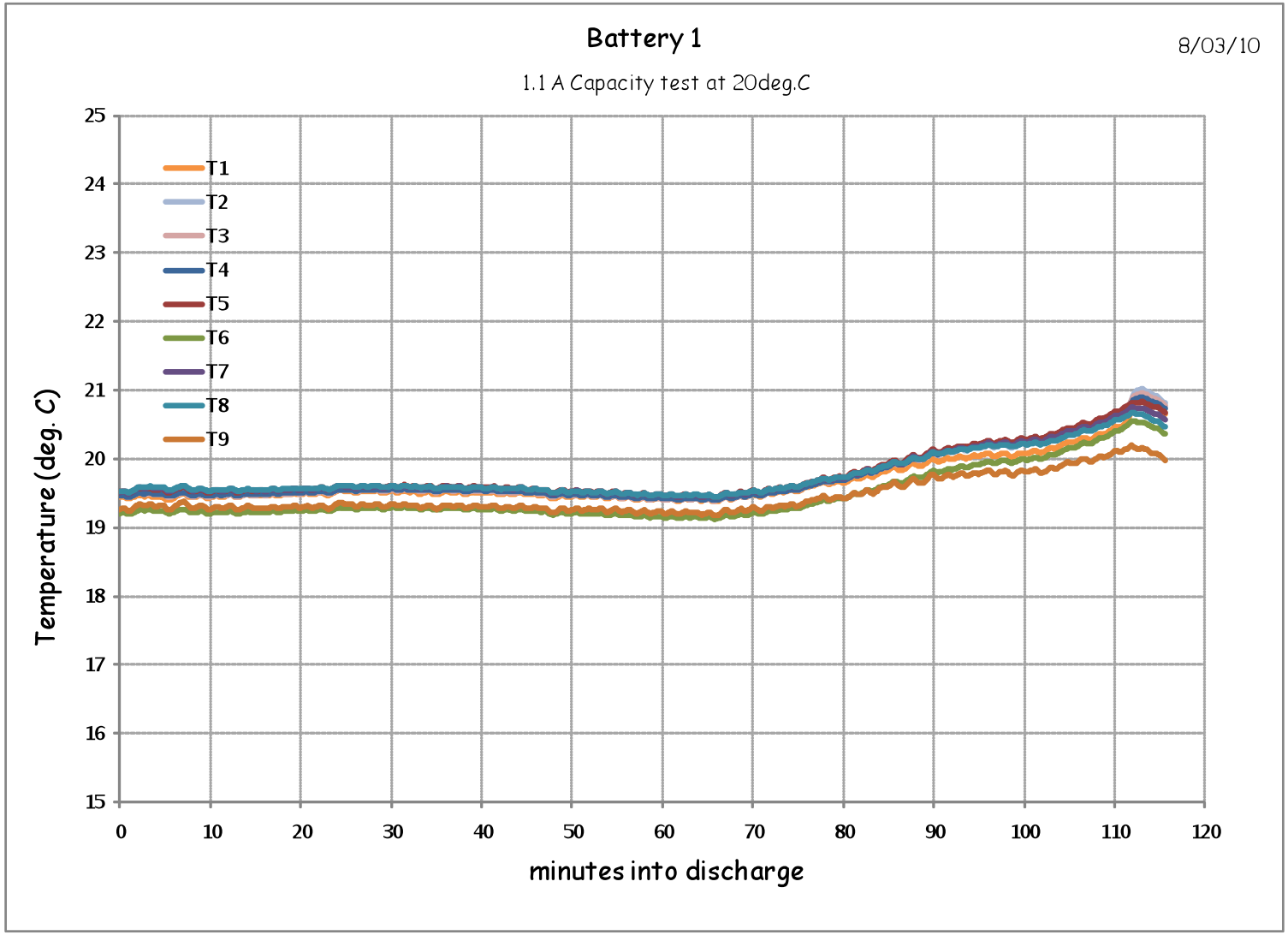

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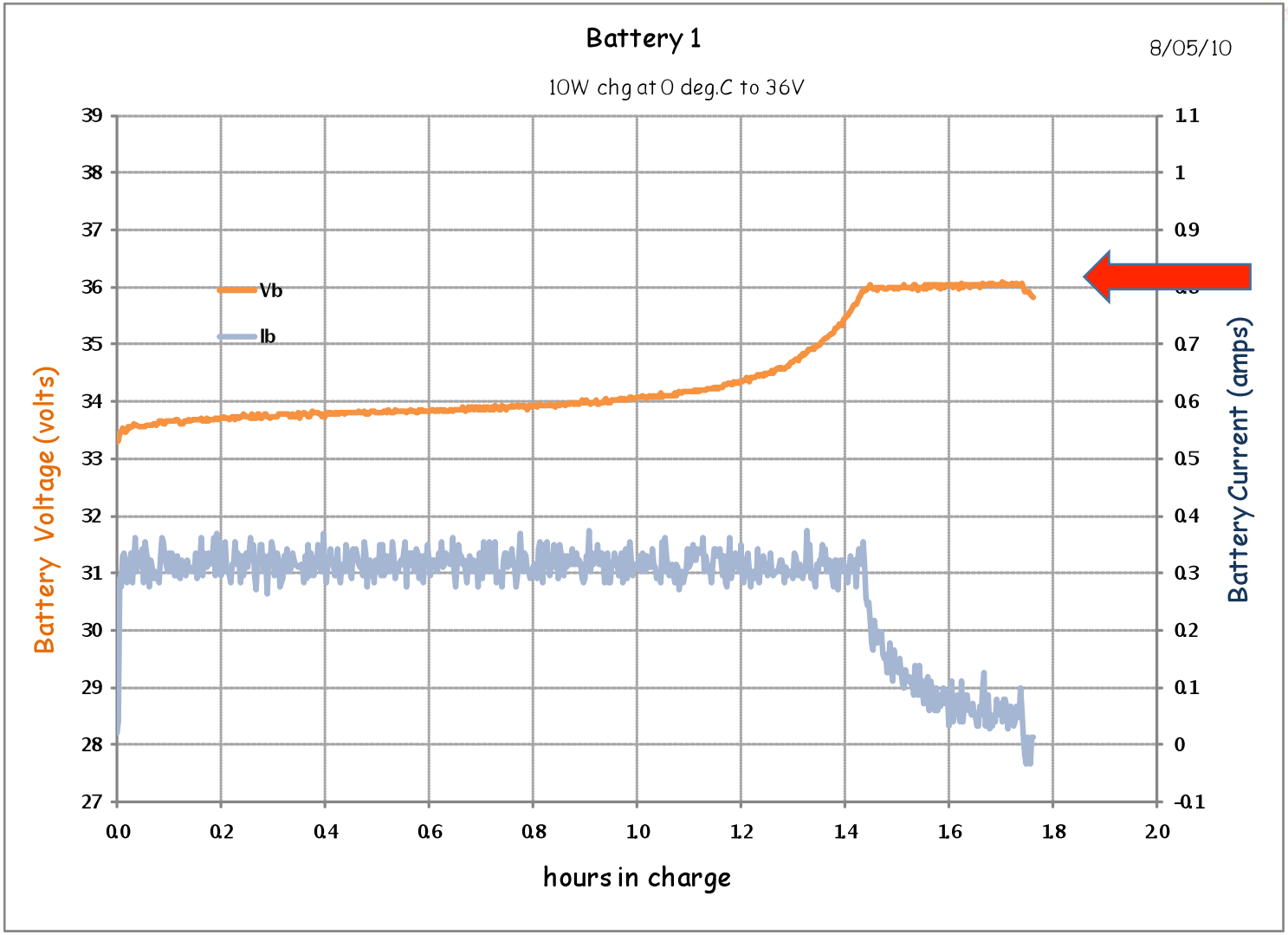
Pulse Power Ability



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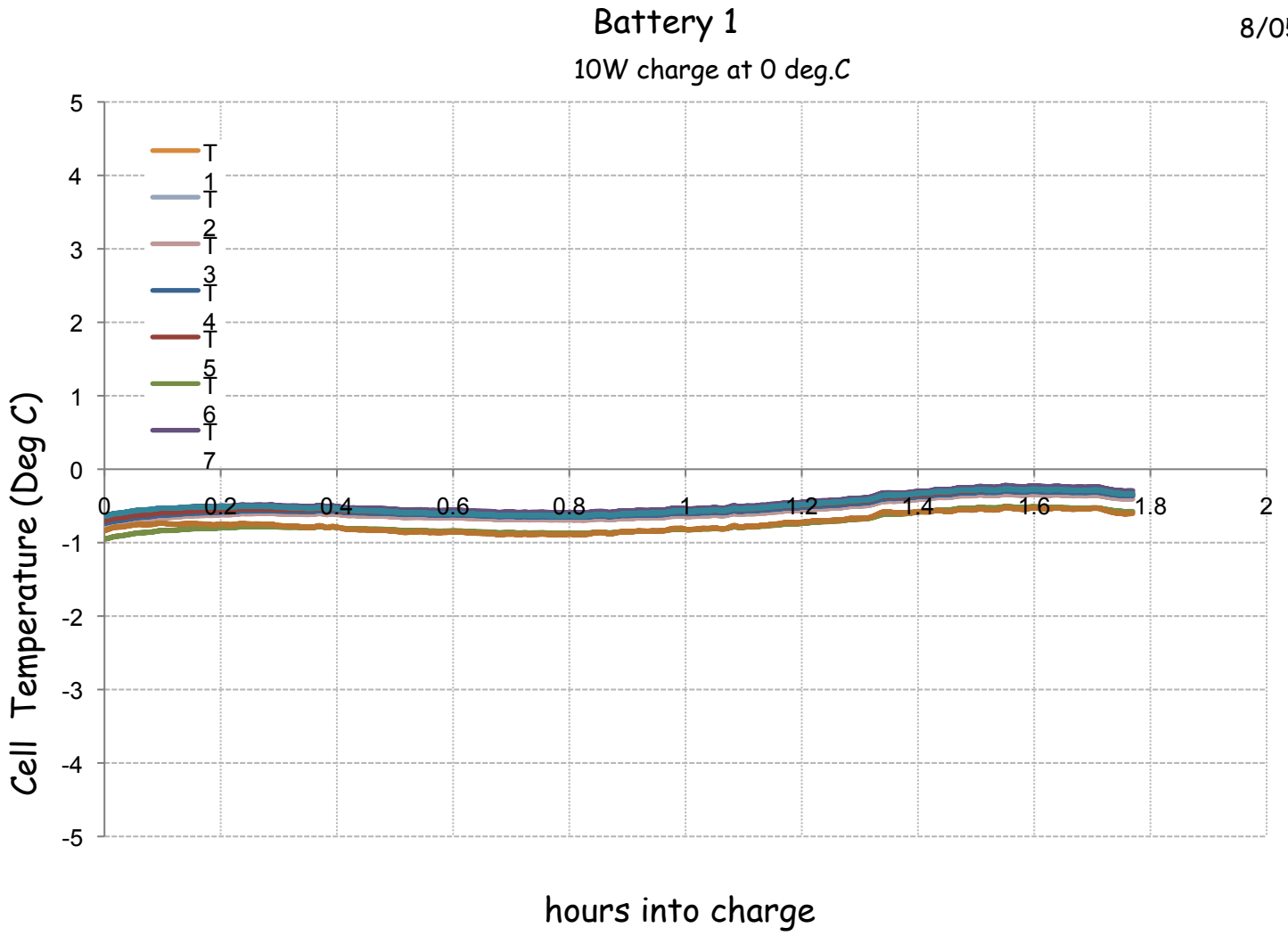

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Pulse Power Ability

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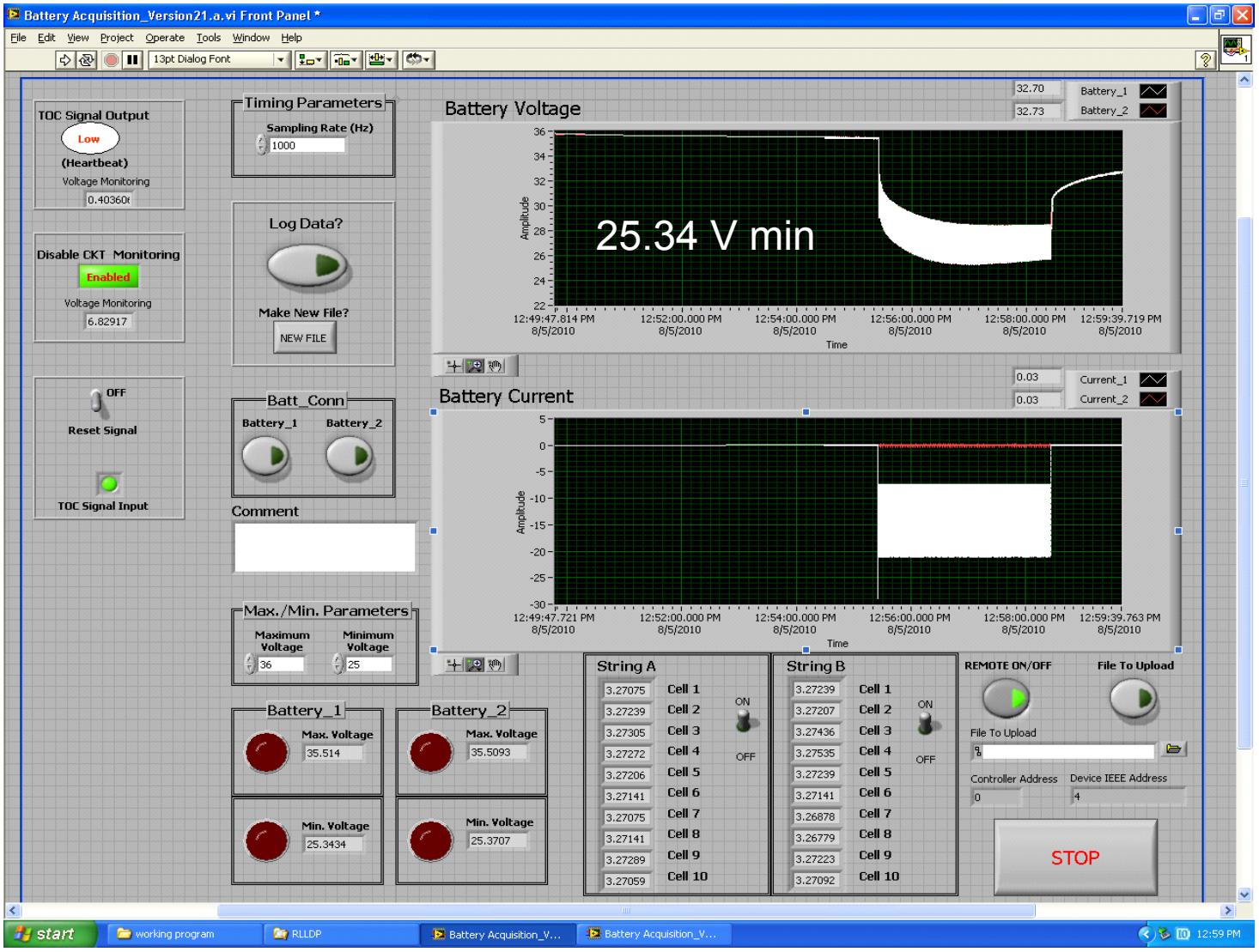
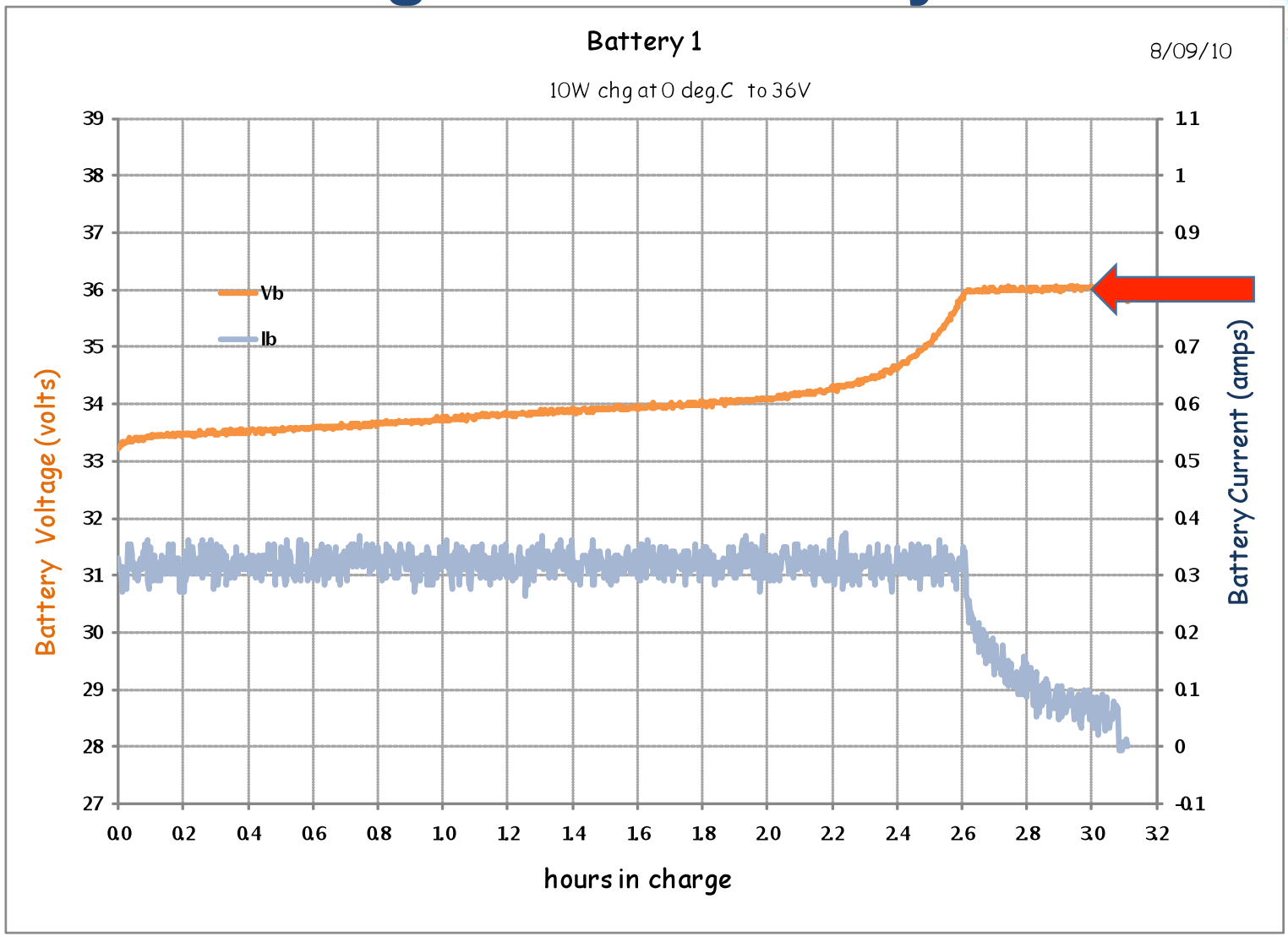


High Power Ability



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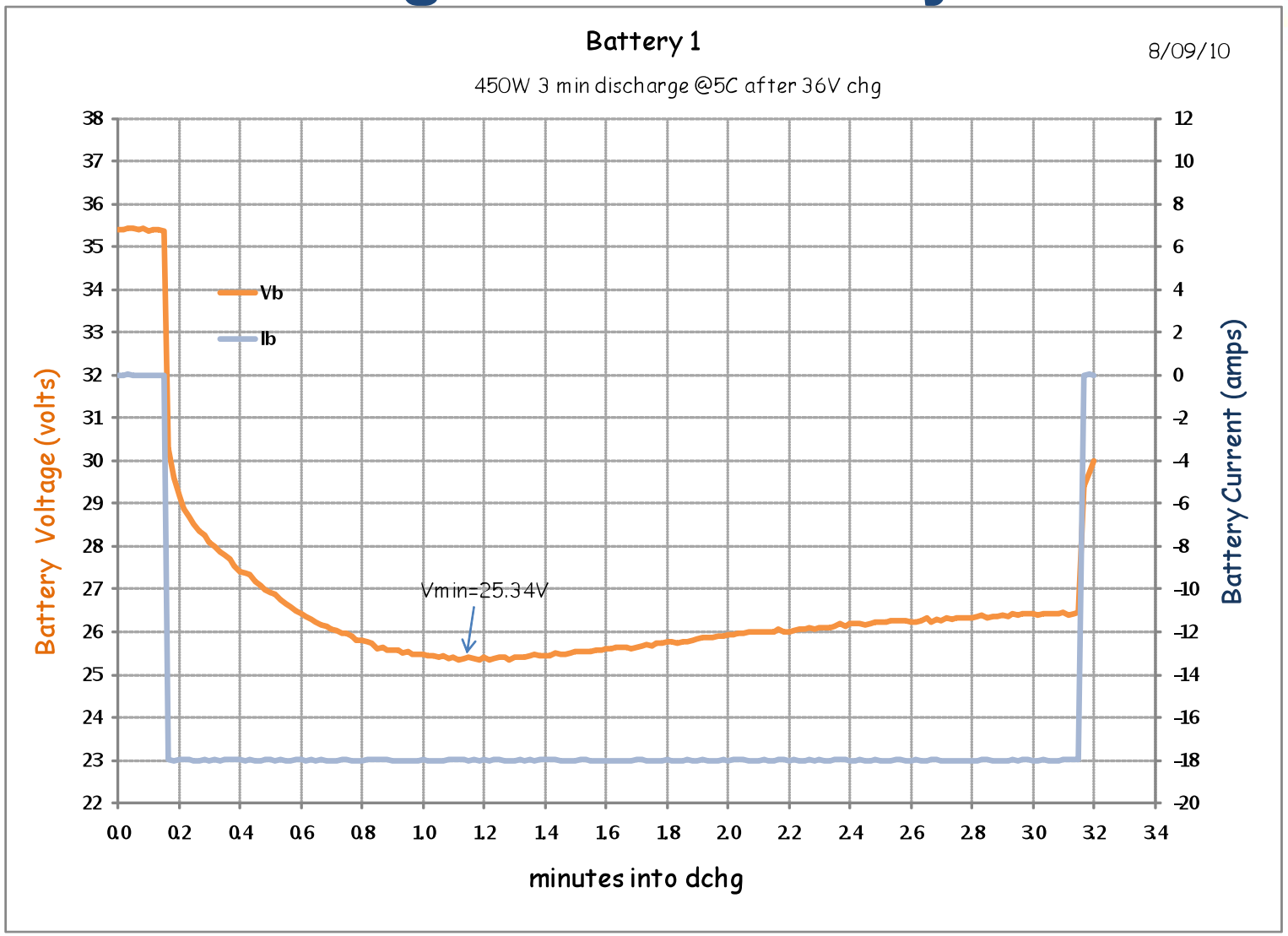

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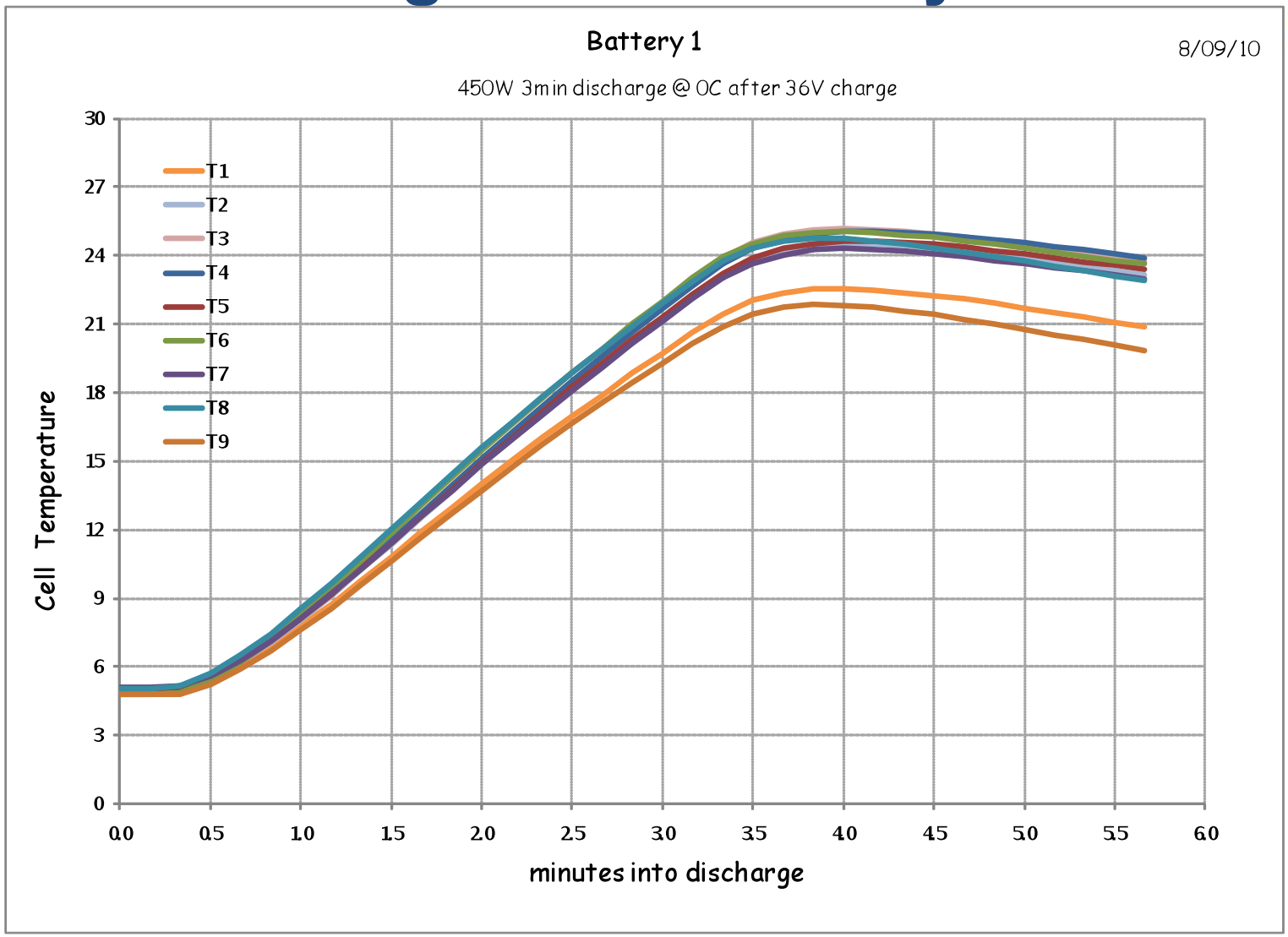

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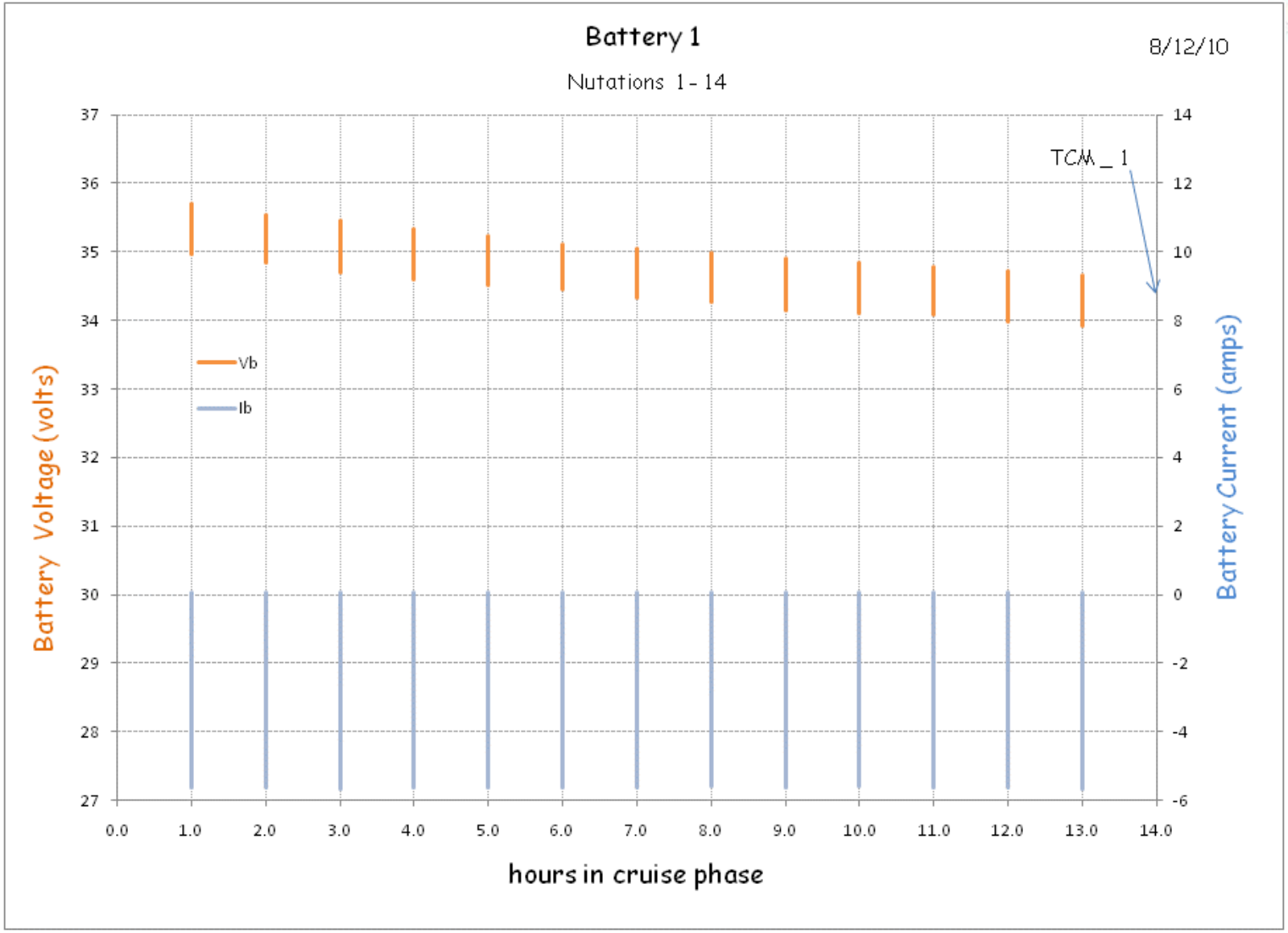
40° C Cruise Phase



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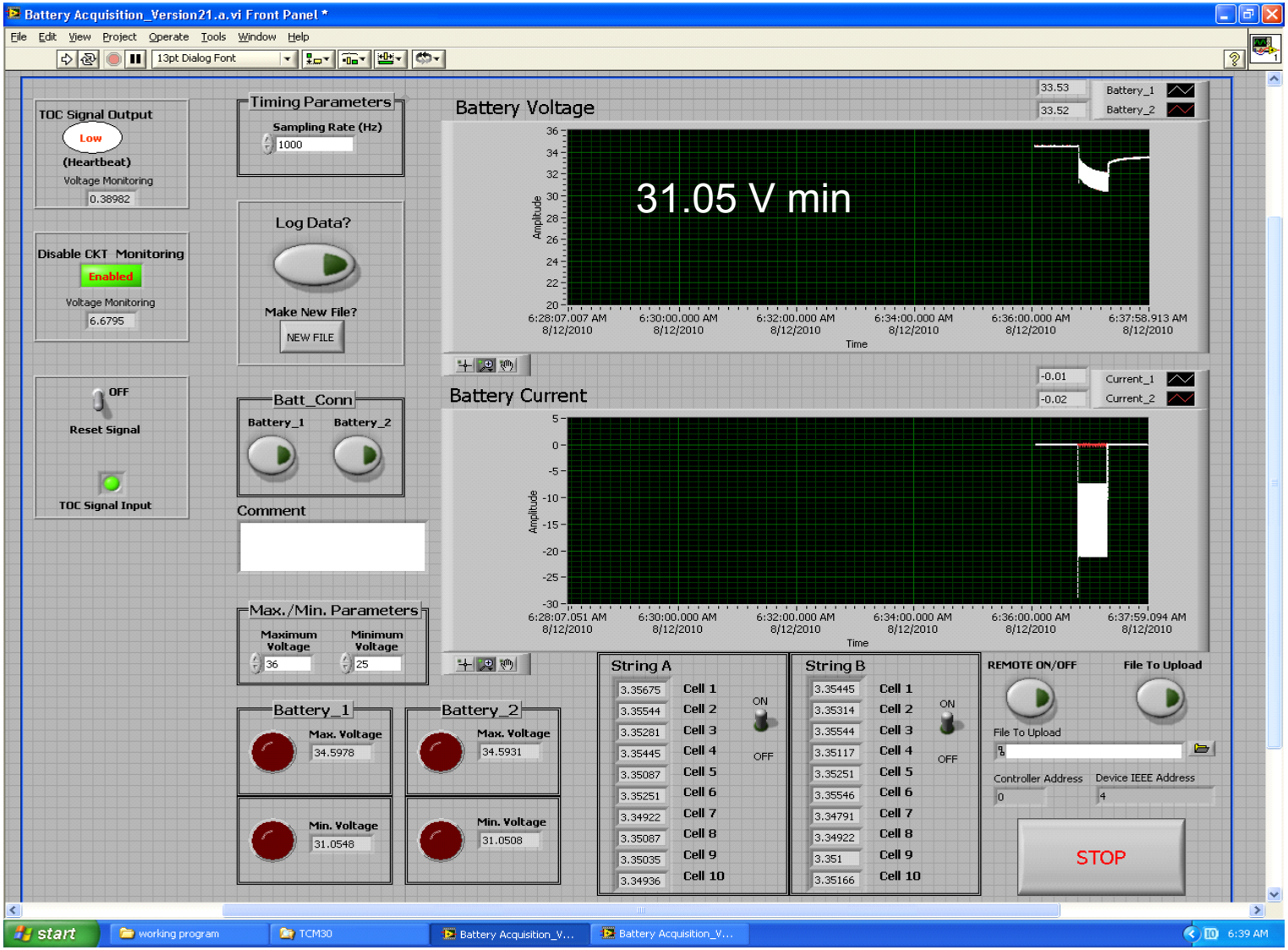

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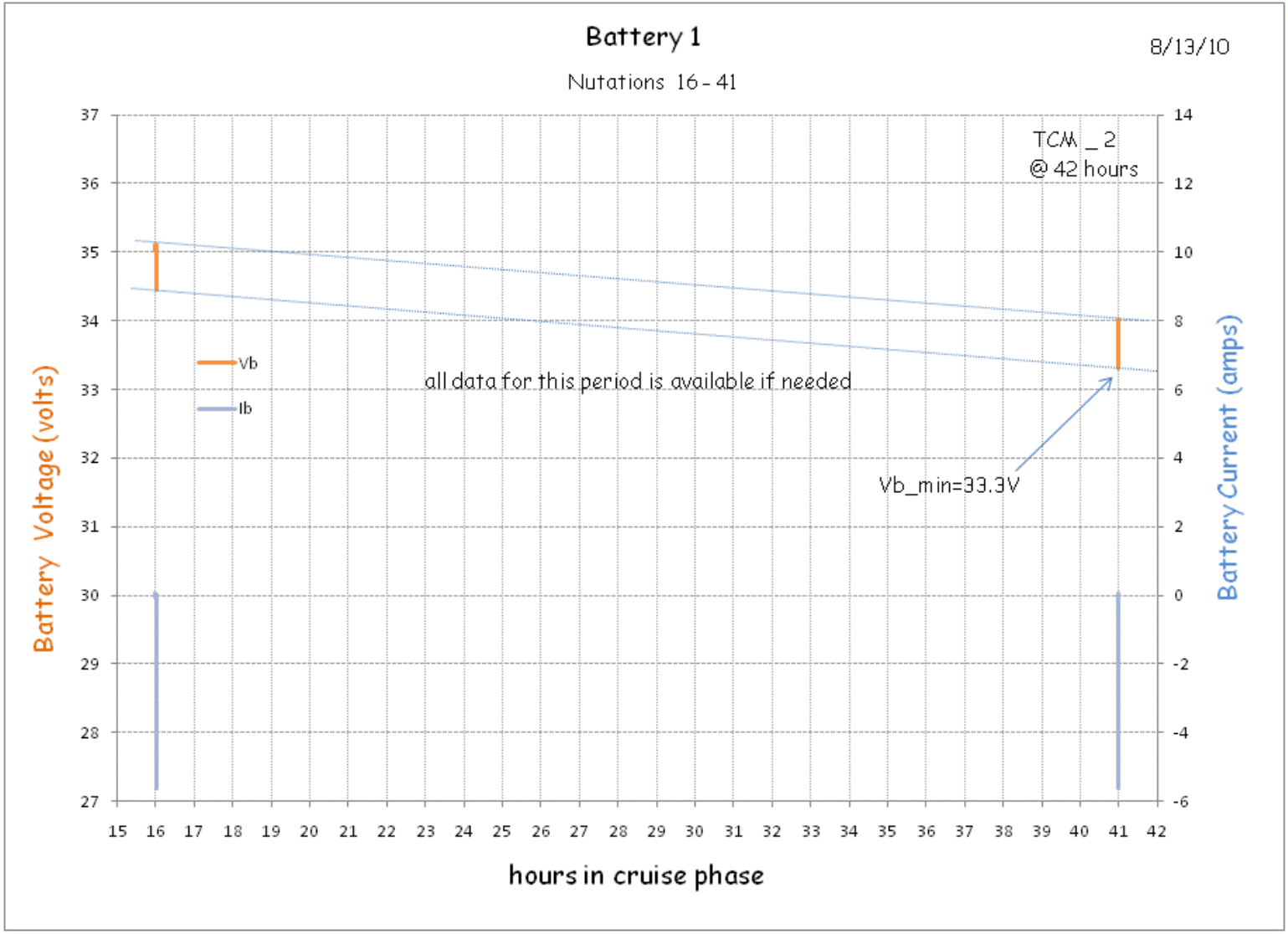

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40° C Cruise Phase

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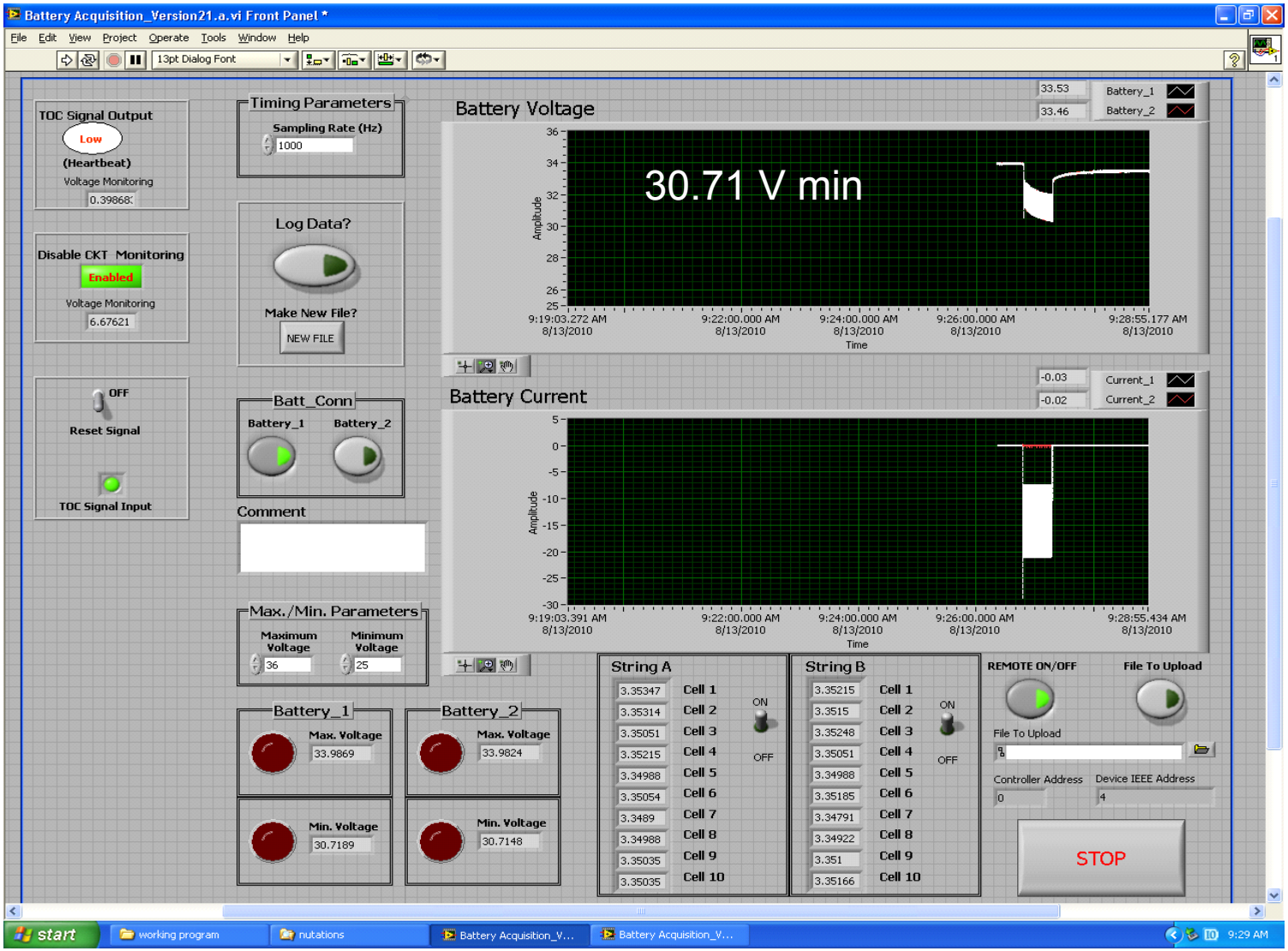

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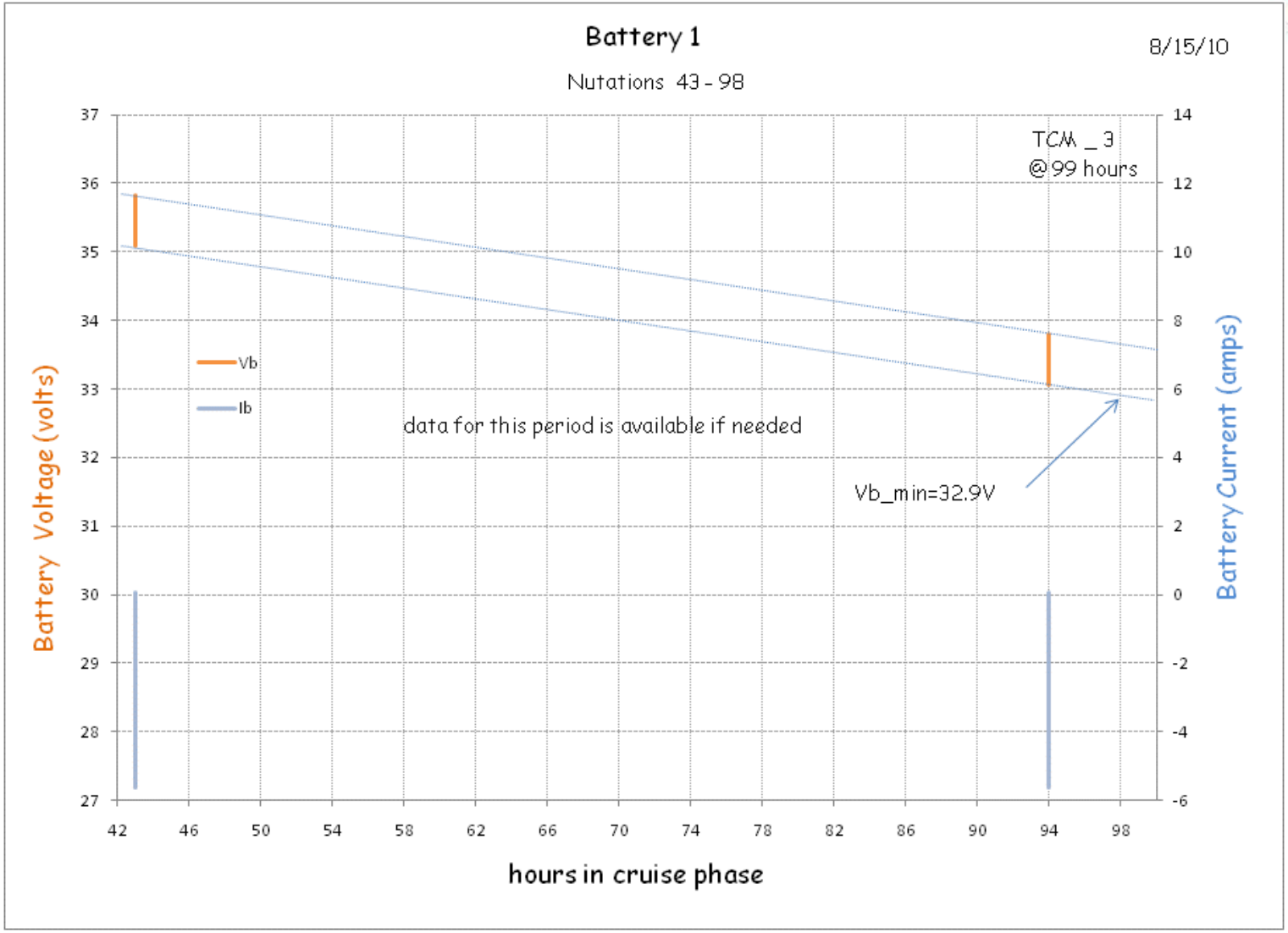

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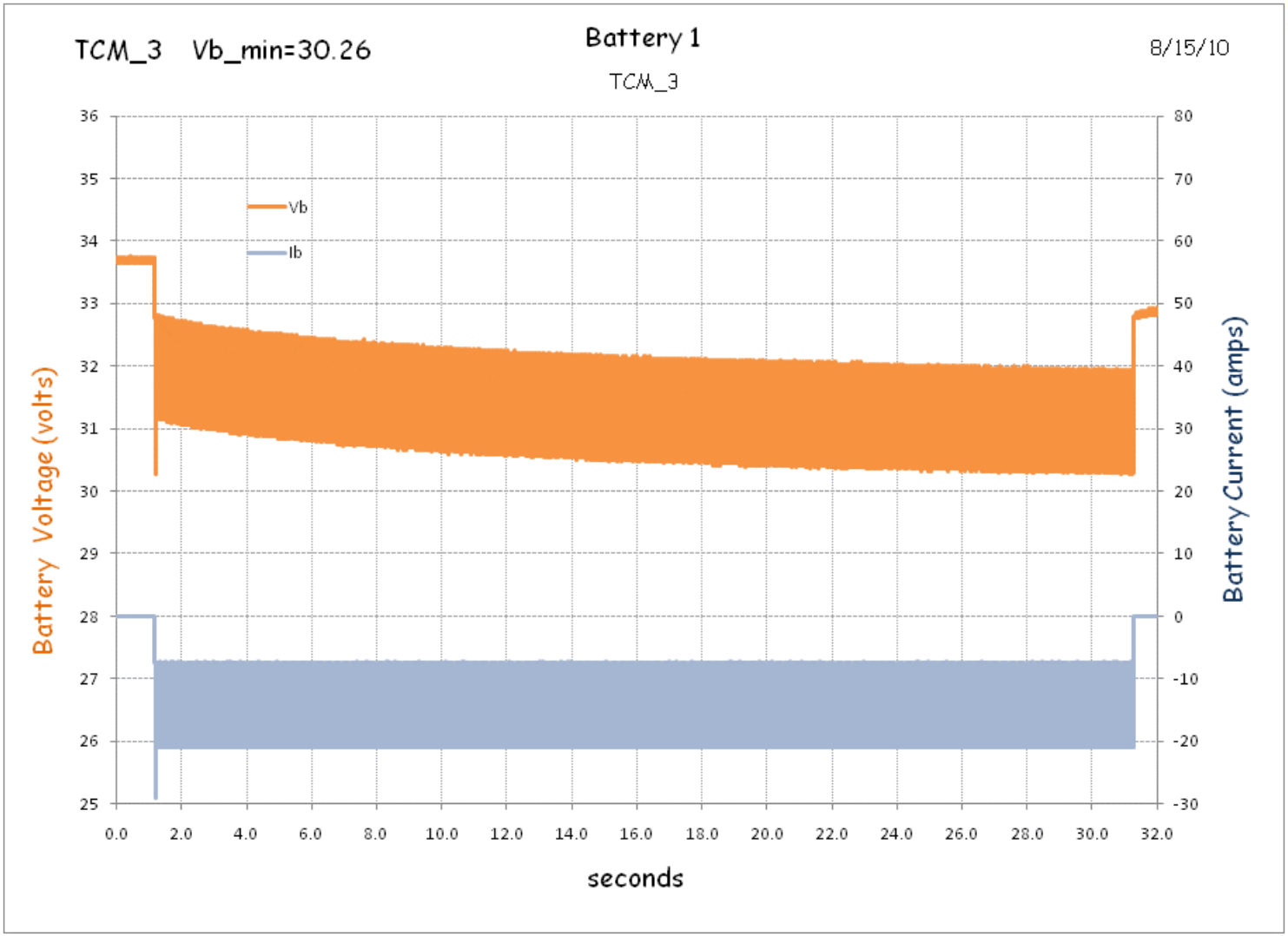

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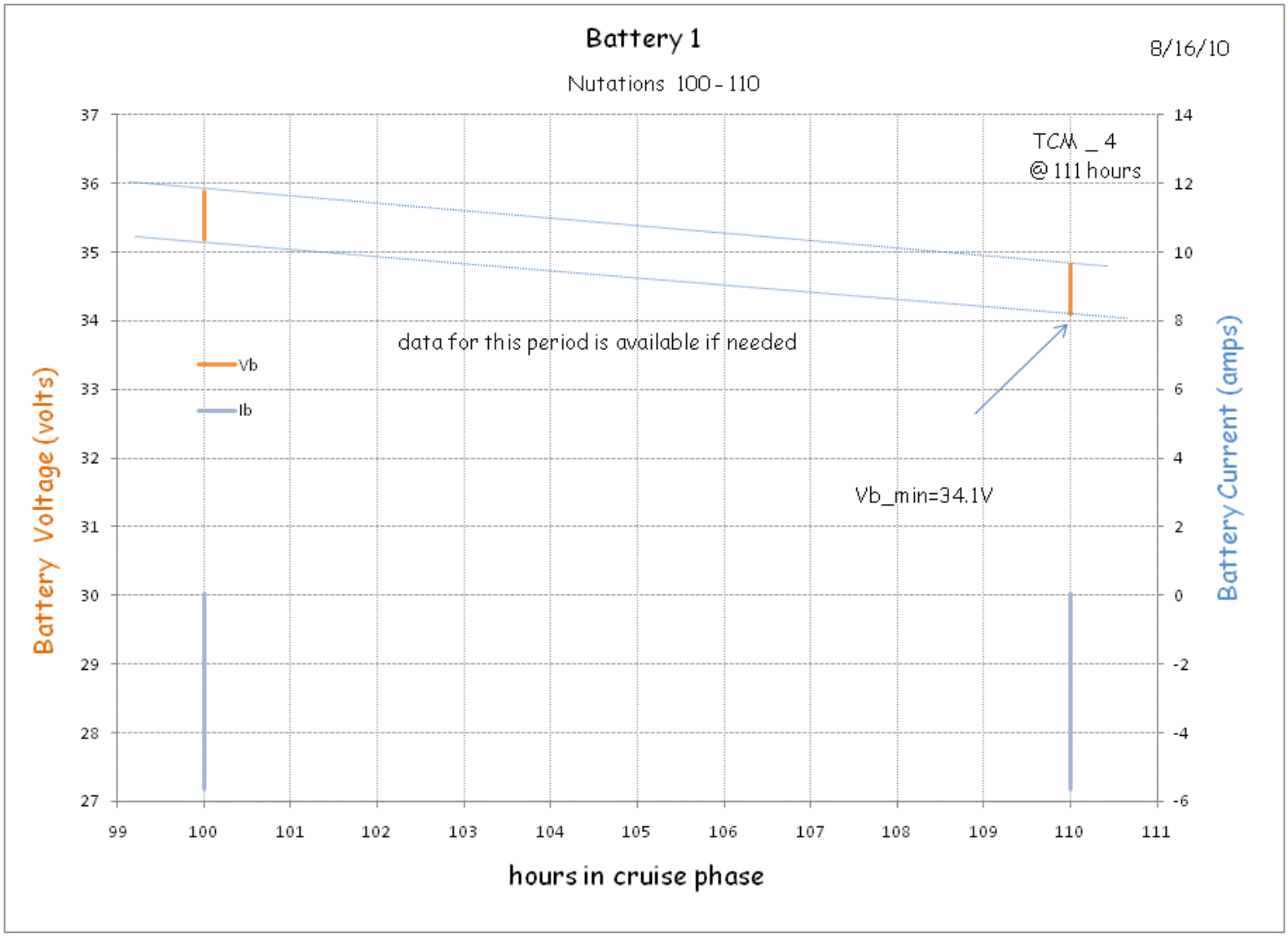

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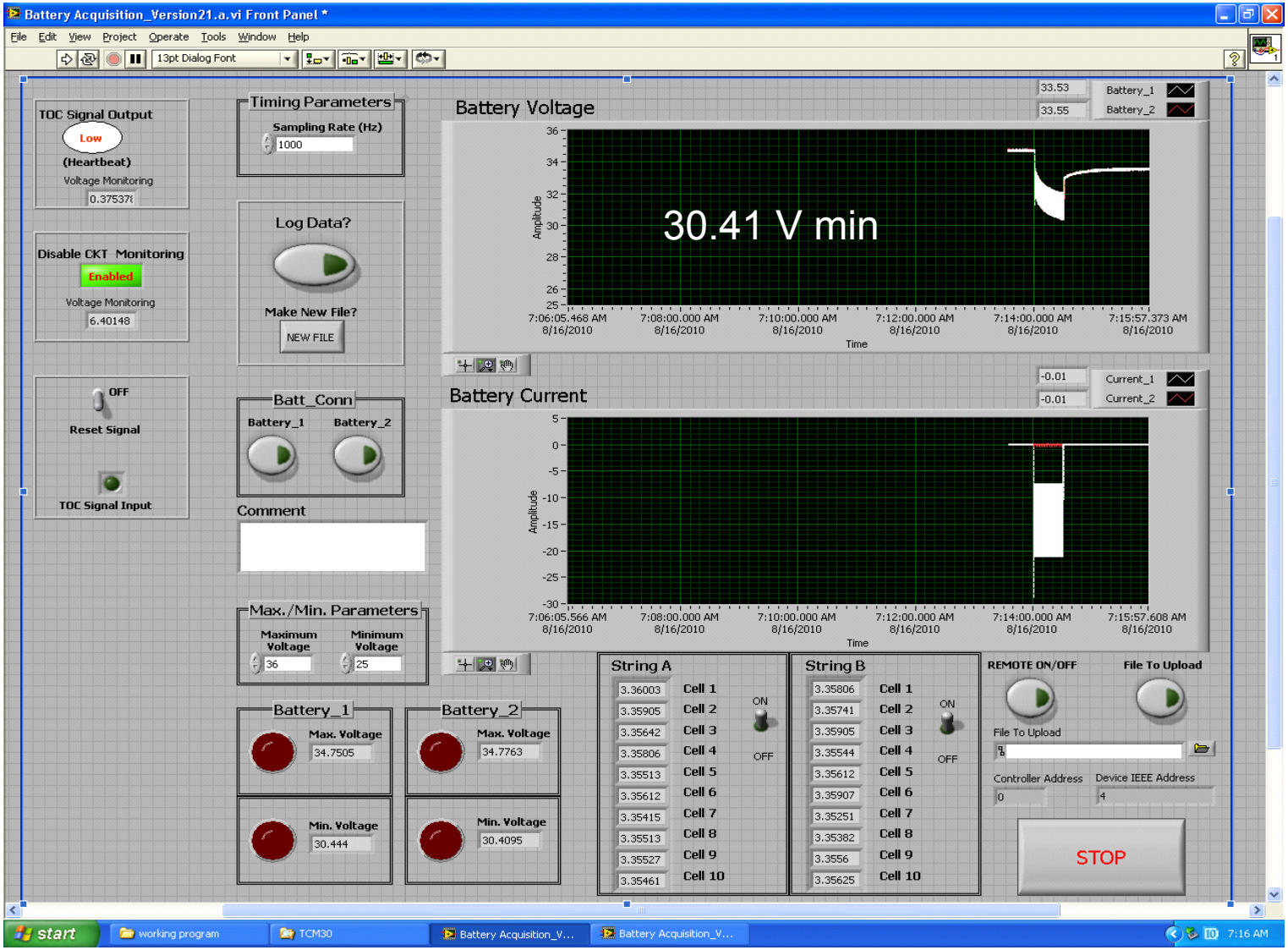

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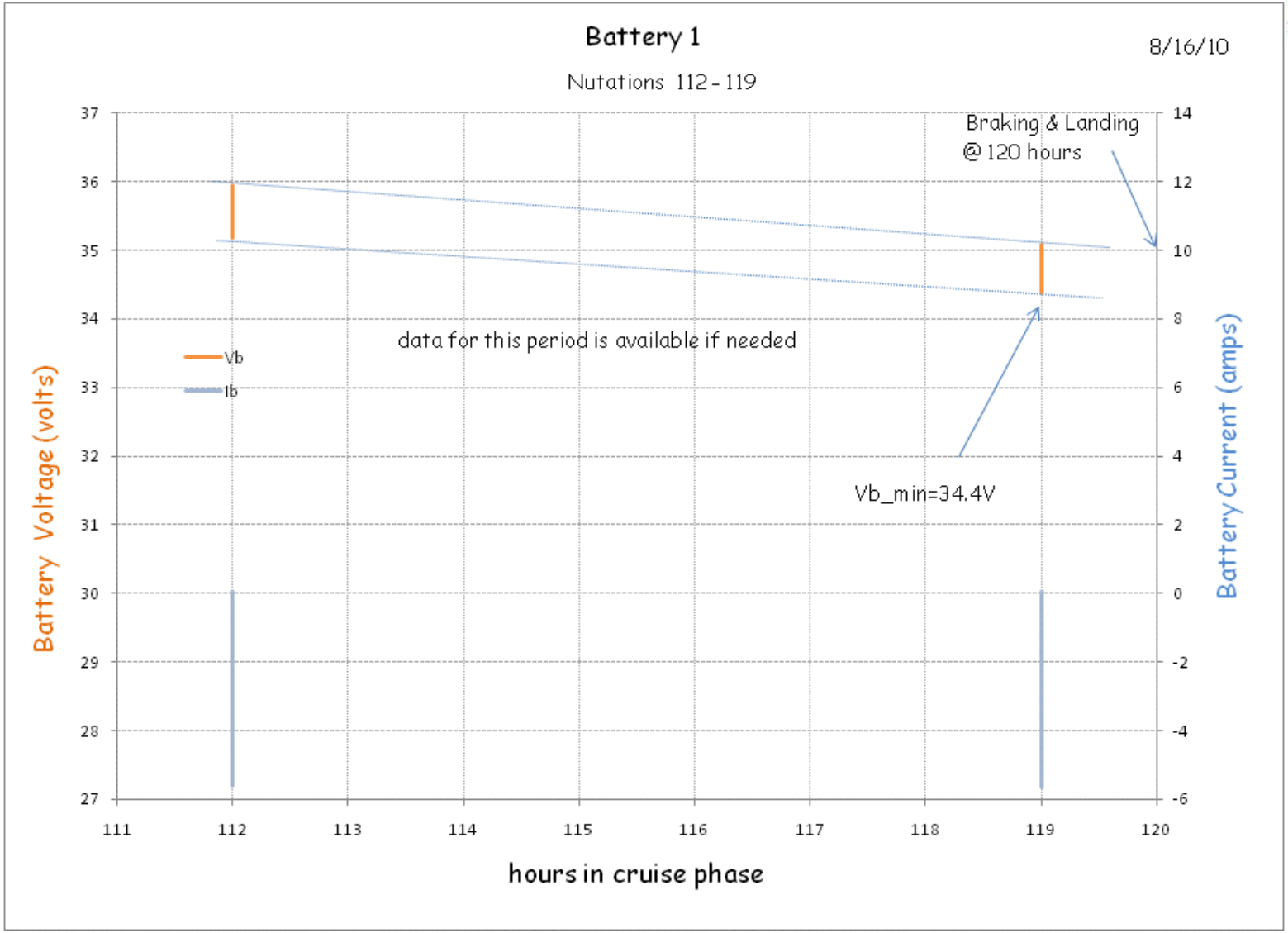

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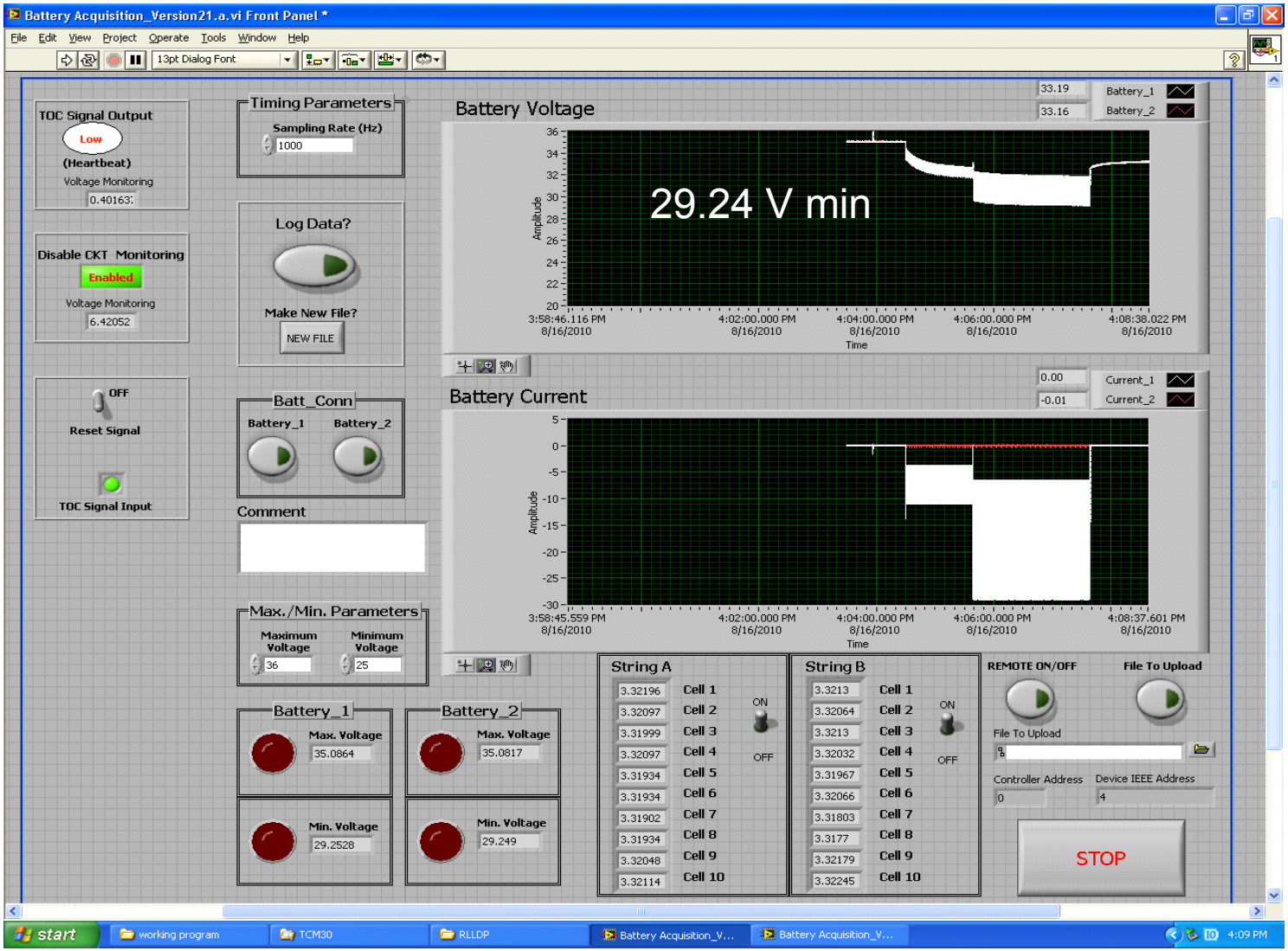
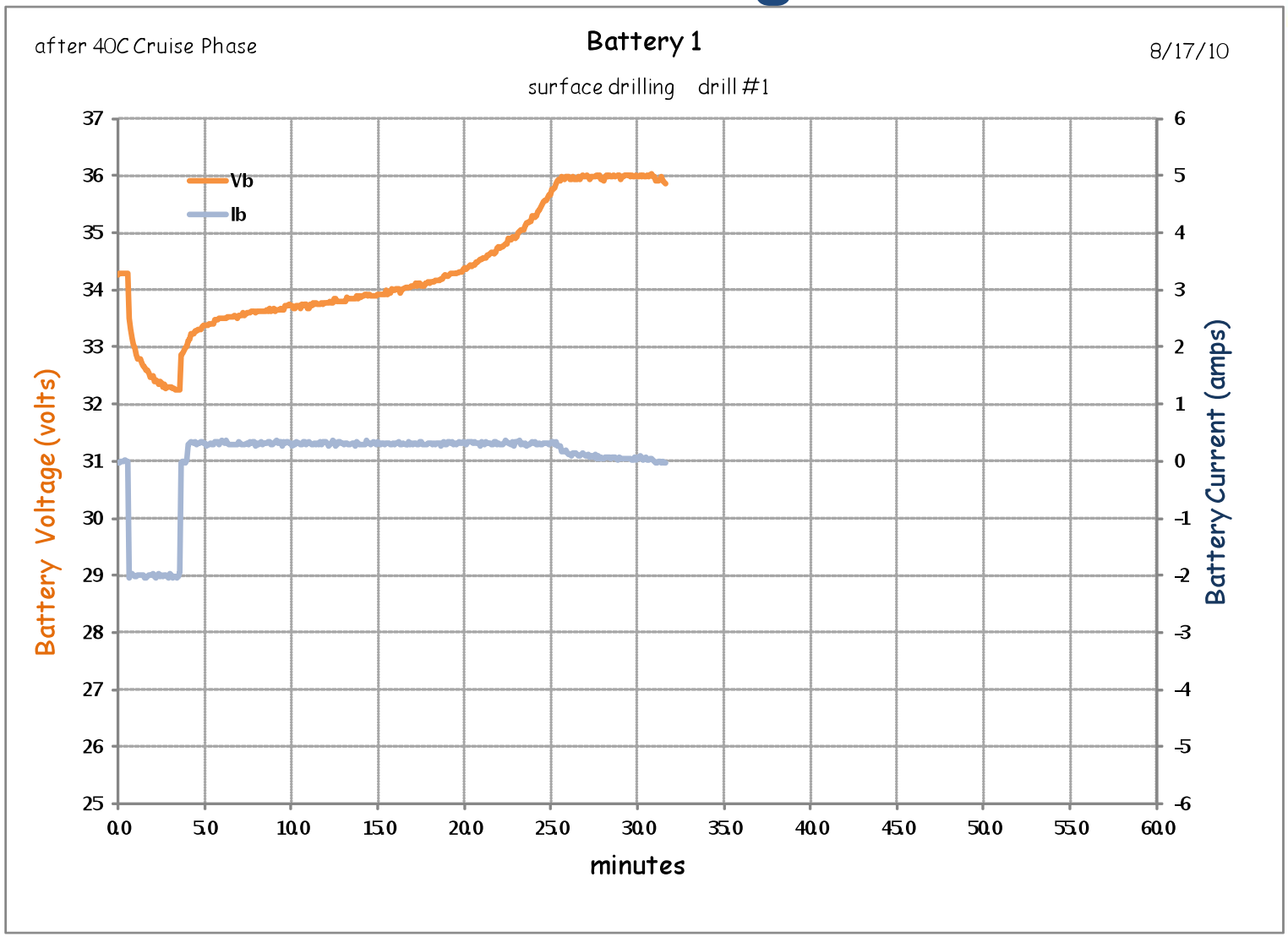


Surface Drilling Phase



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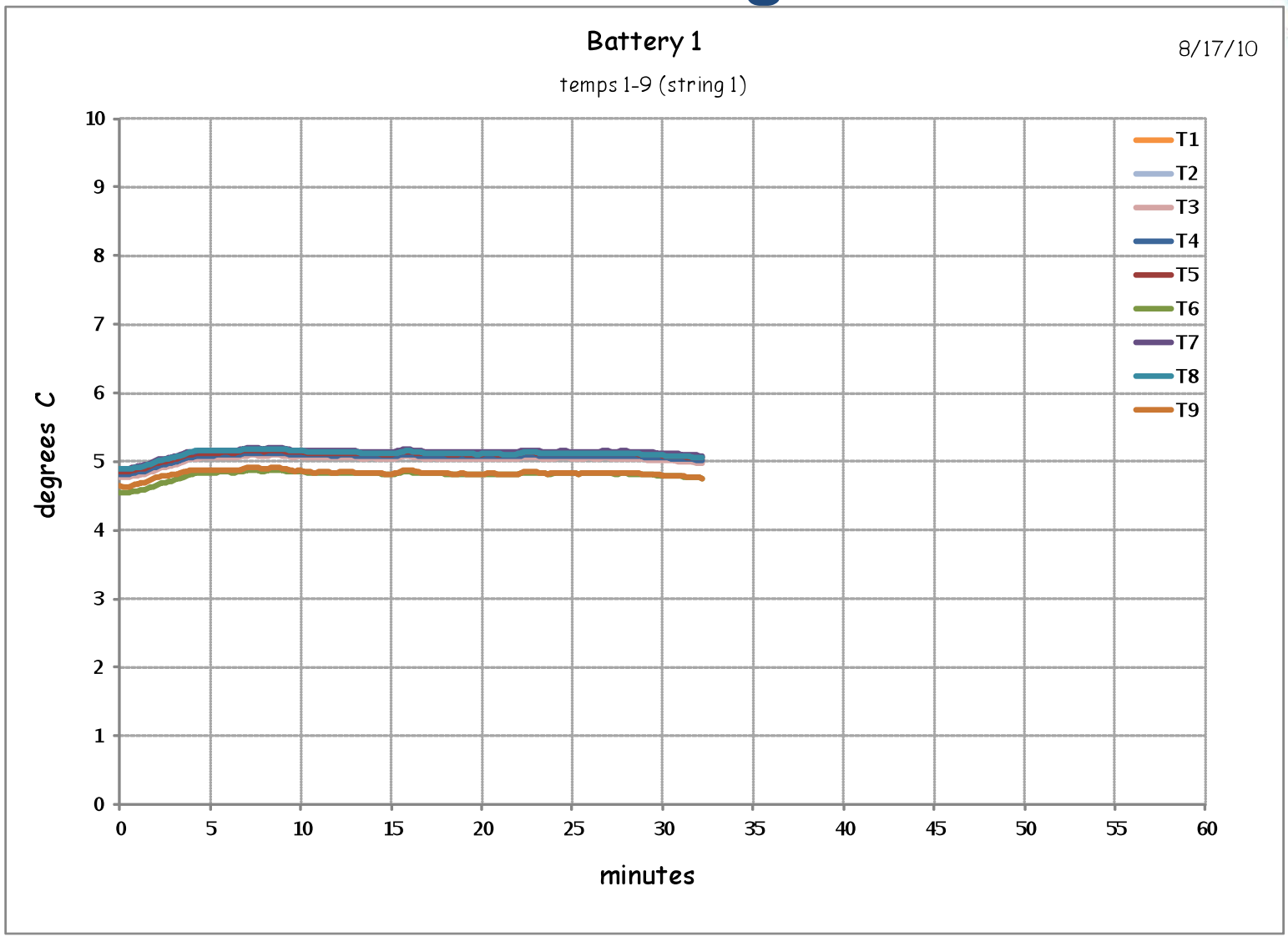

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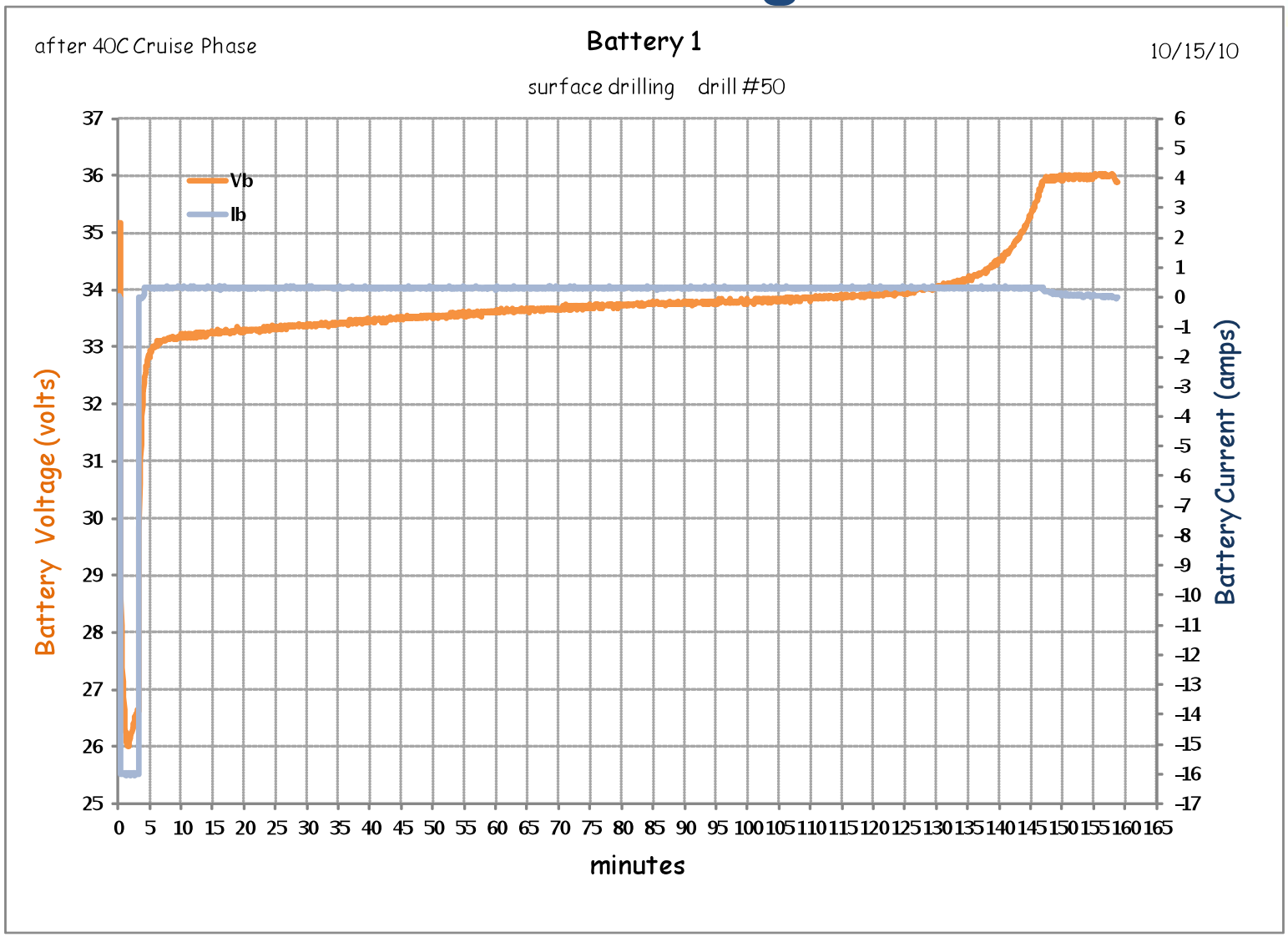

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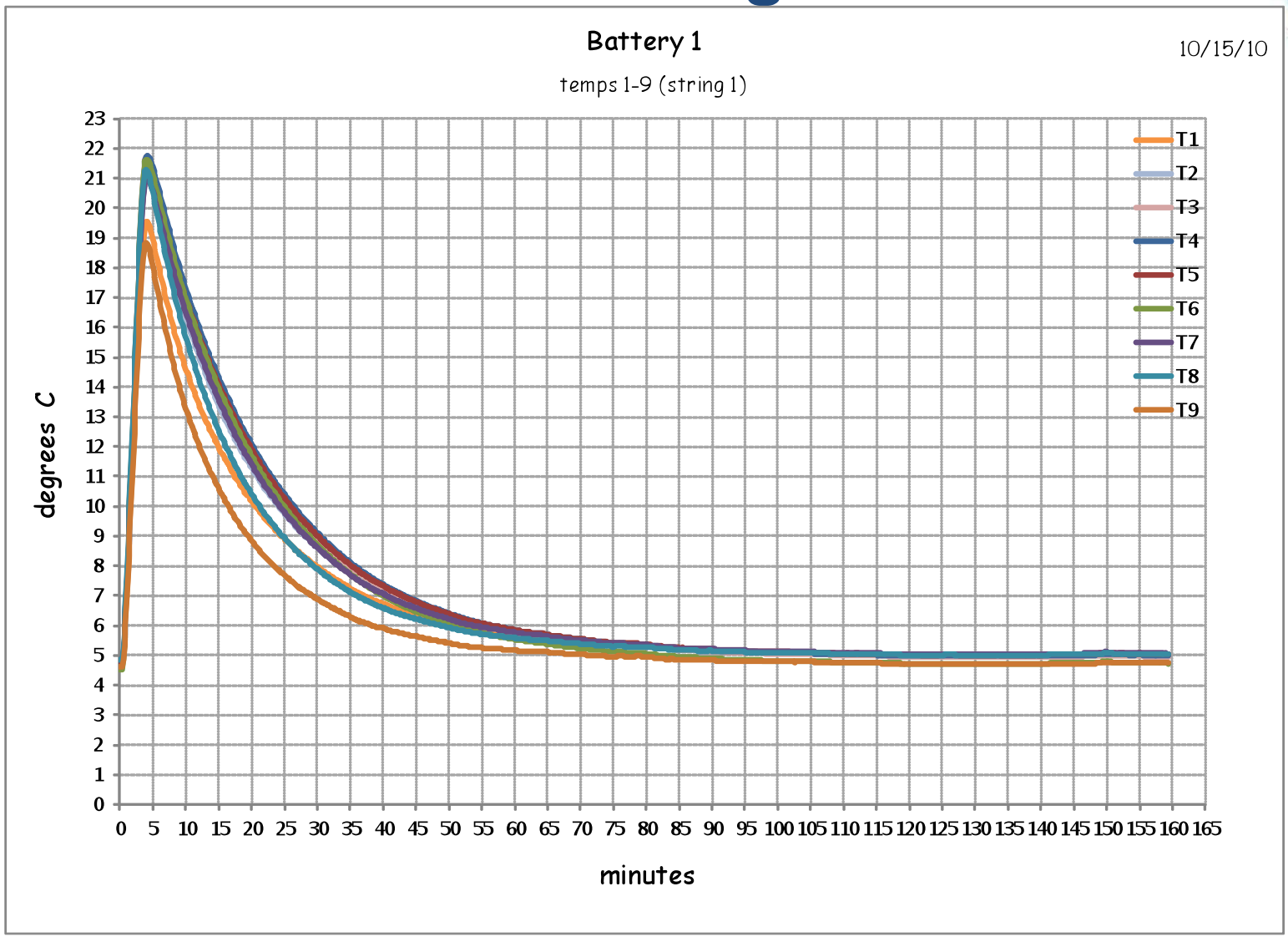

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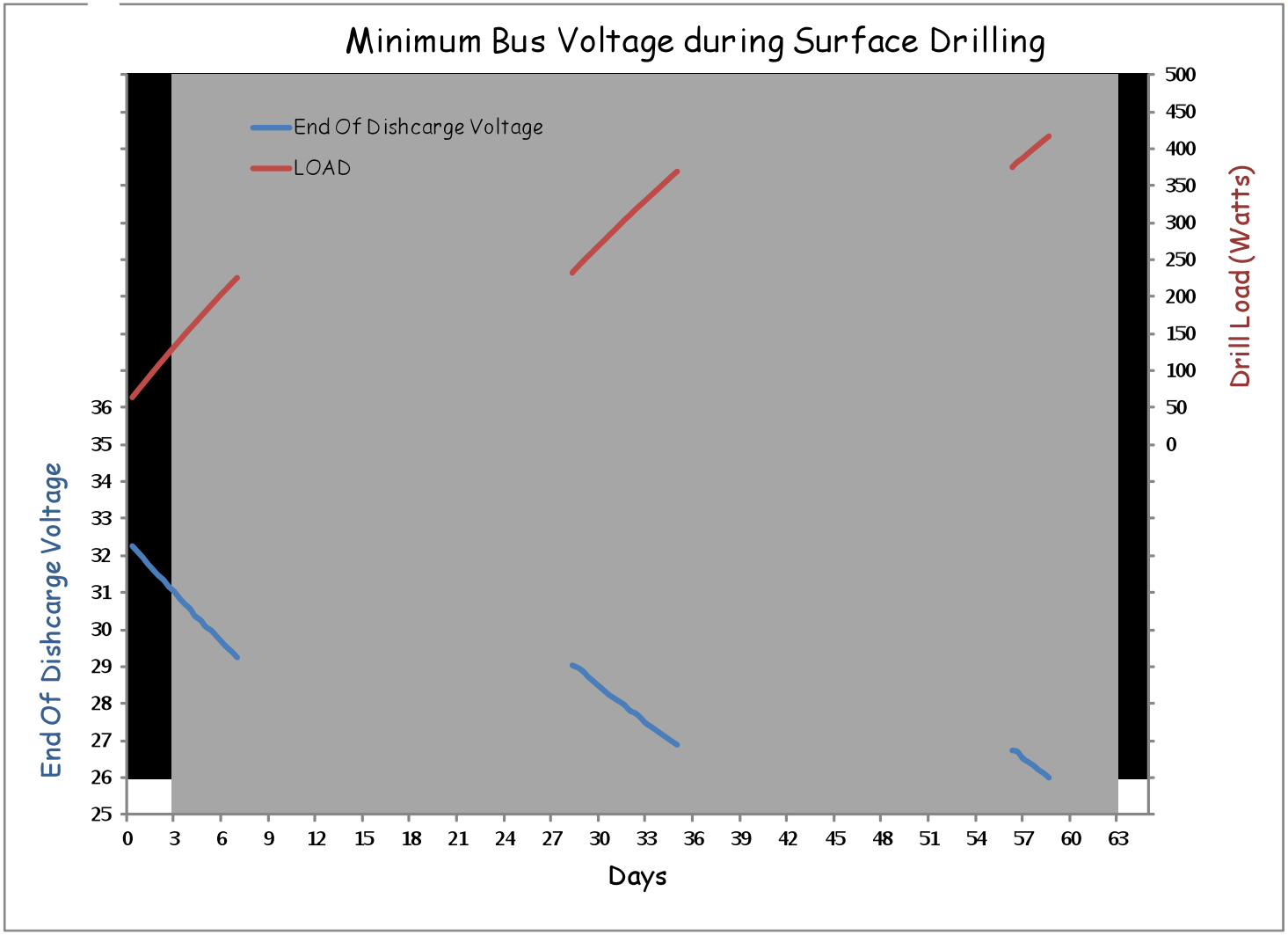

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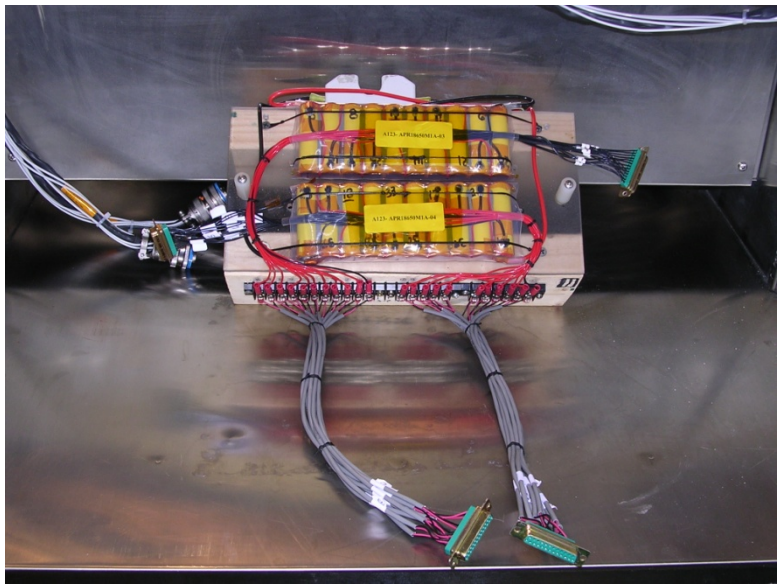

- Second Battery (ES41-10-ILN-TA-001) @ 50° C During 5Day Cruise
- Second Battery Performance Duplicates and Reinforces Performance of First Battery

Lunar Equator Mission

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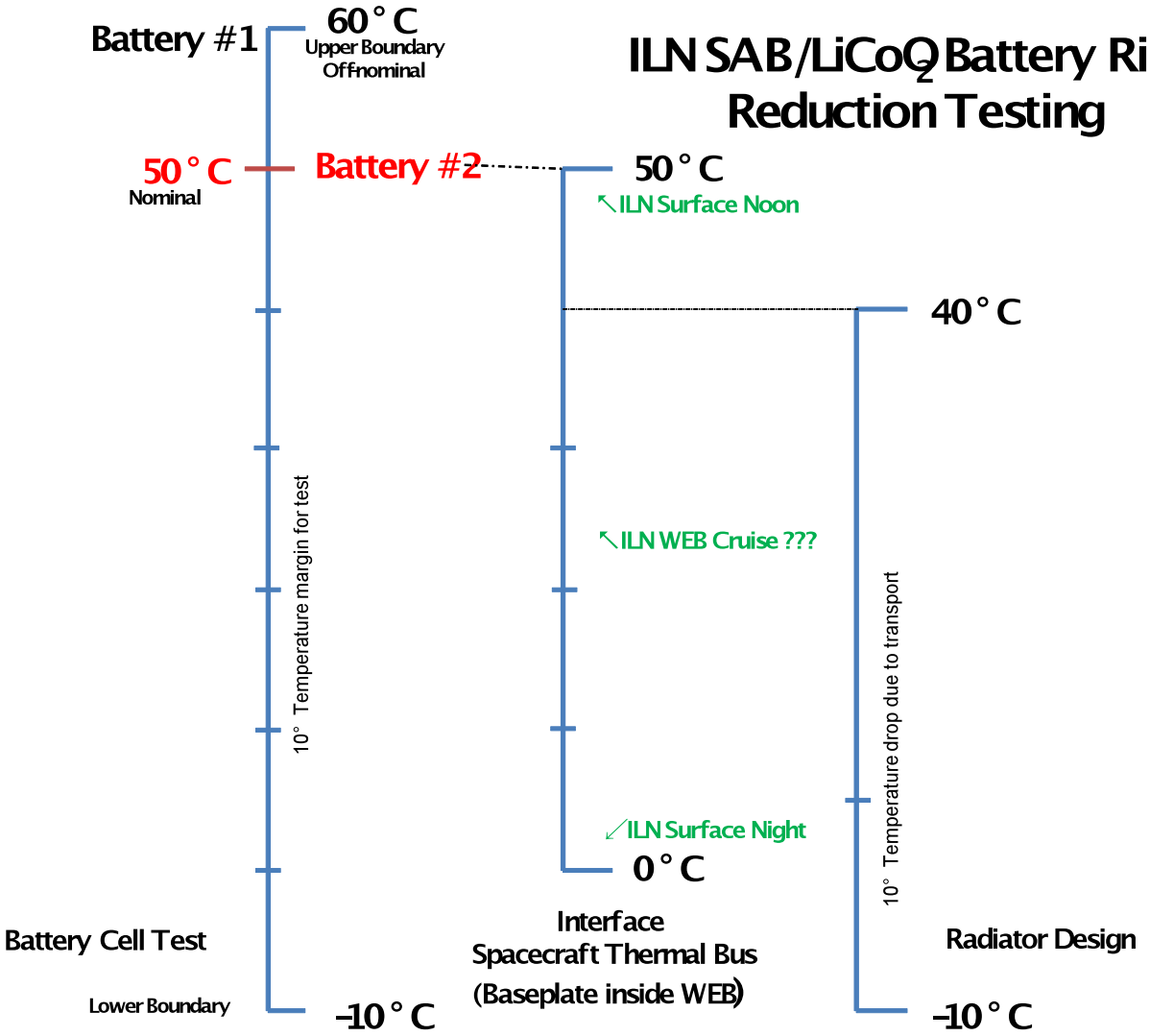
- Solar Array Battery System Indicated
  - 15.5 Days (372 Hours) eclipse darkness
  - 14 Days (336 hours) sunlight
- Thermal Subsystem Control
  - -200° C to +170° C
- Lithium Ion ($LiCoO_2$) Battery - 50 Ahr Blocks
  - 8 cell Battery
  - Very Low Surface Rates
  - Battery Size covers Peaks

Lunar Equator Mission



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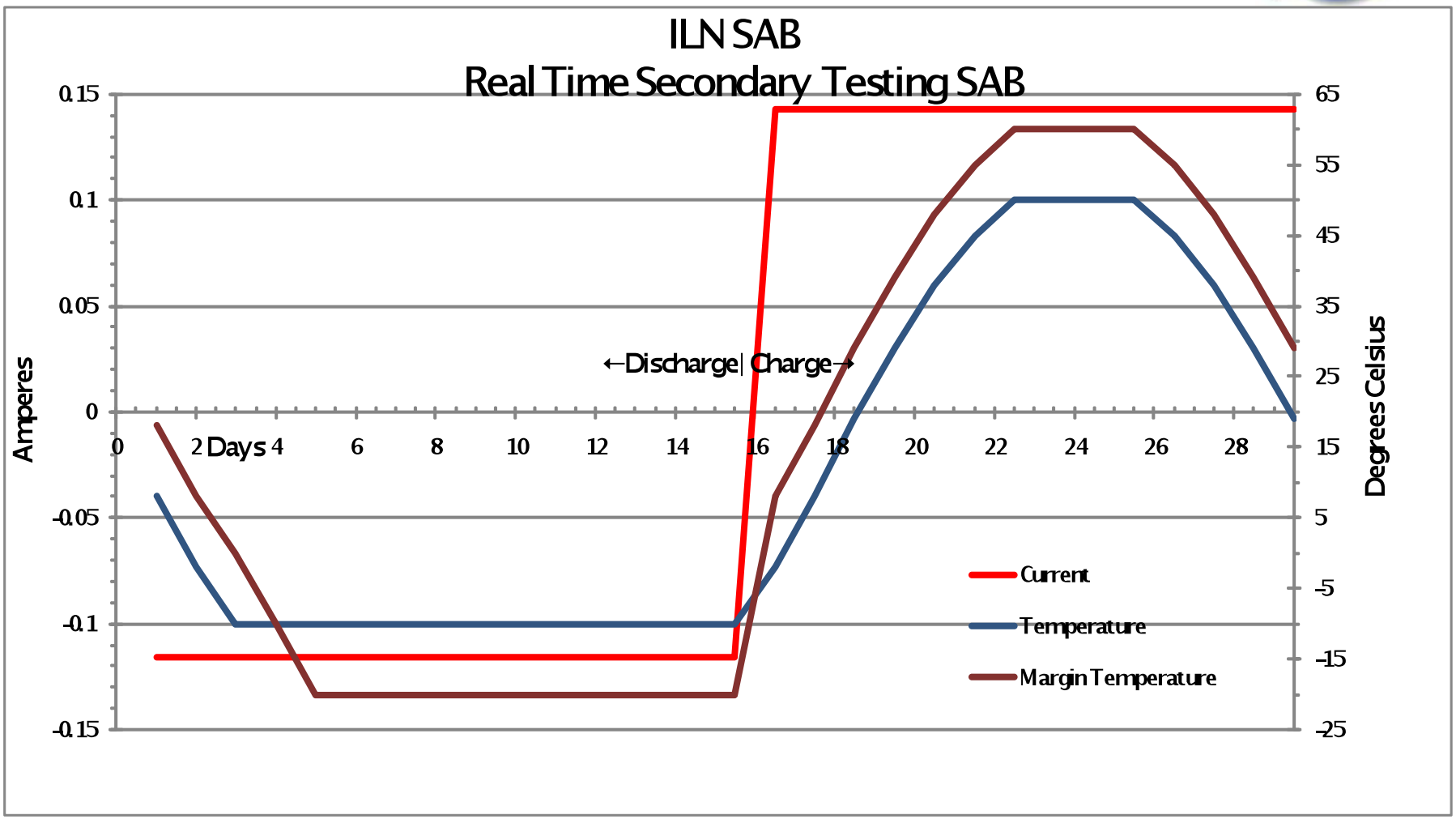

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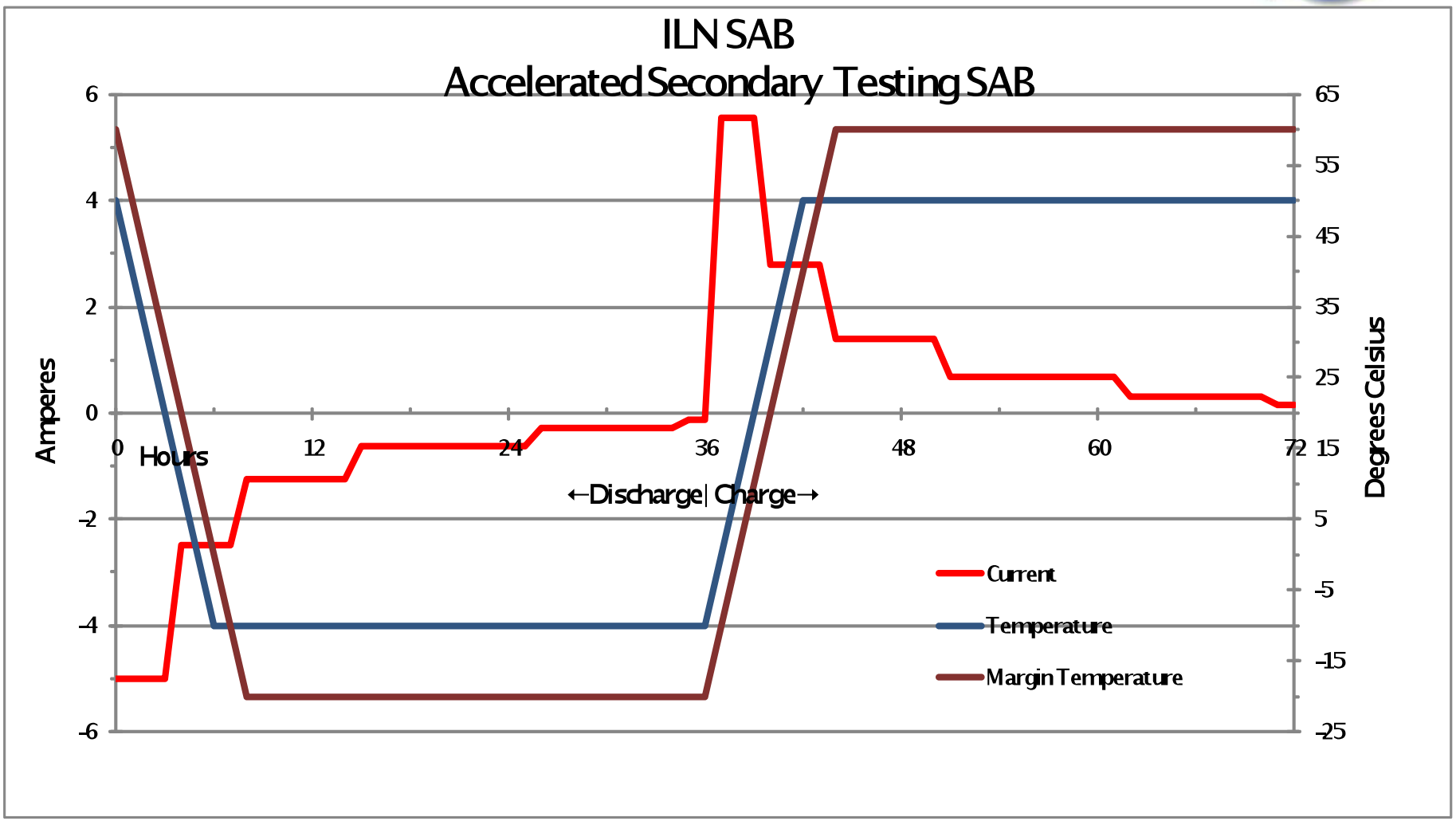

Lunar Equator Mission

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SAFT VES 180

LiNi-$AlCoO_2$

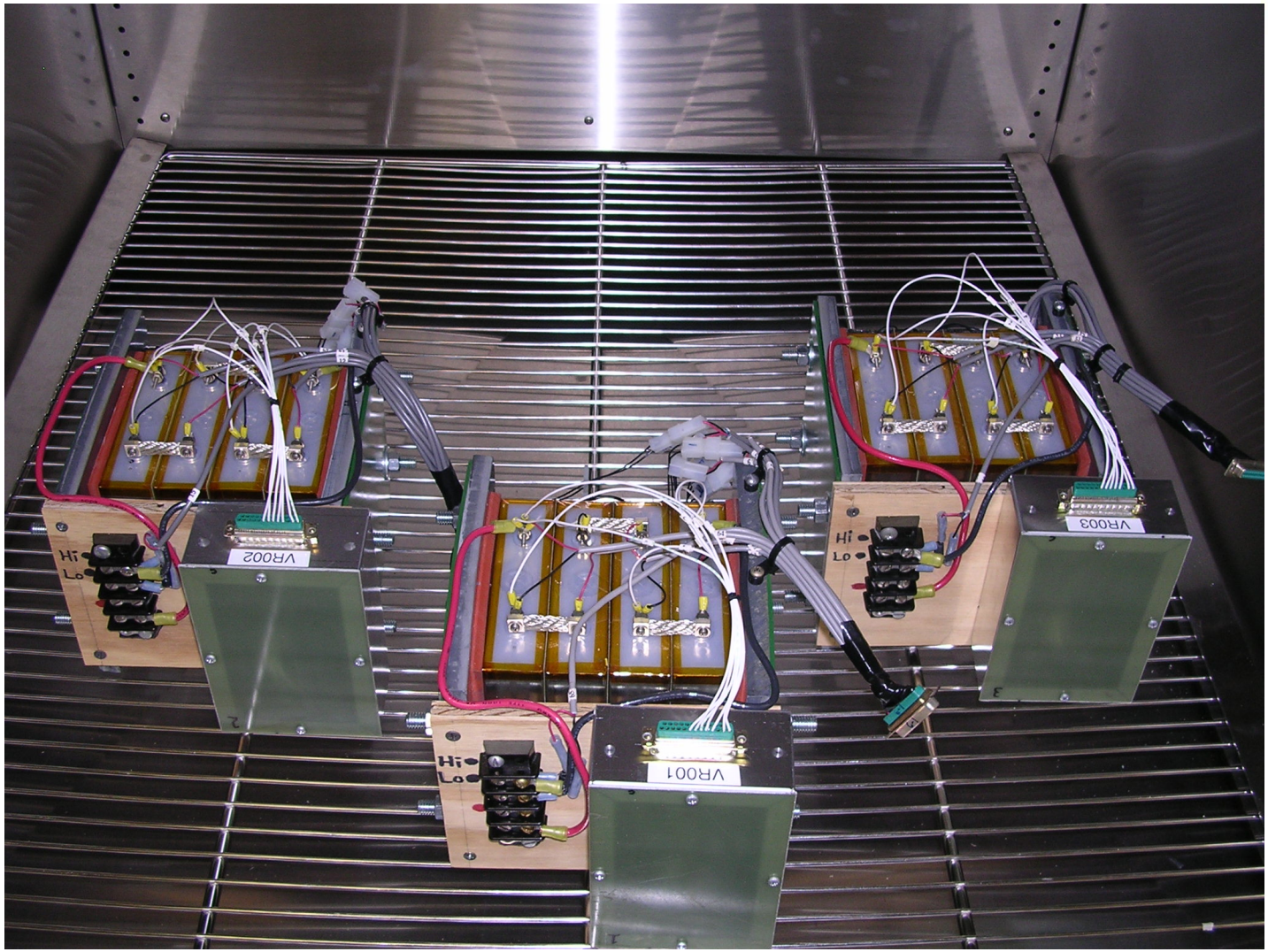
Lithion NCP55-2

Li-CoO_2 SAB

Lunar Equator Mission

MSFC

Lunar Equator Mission



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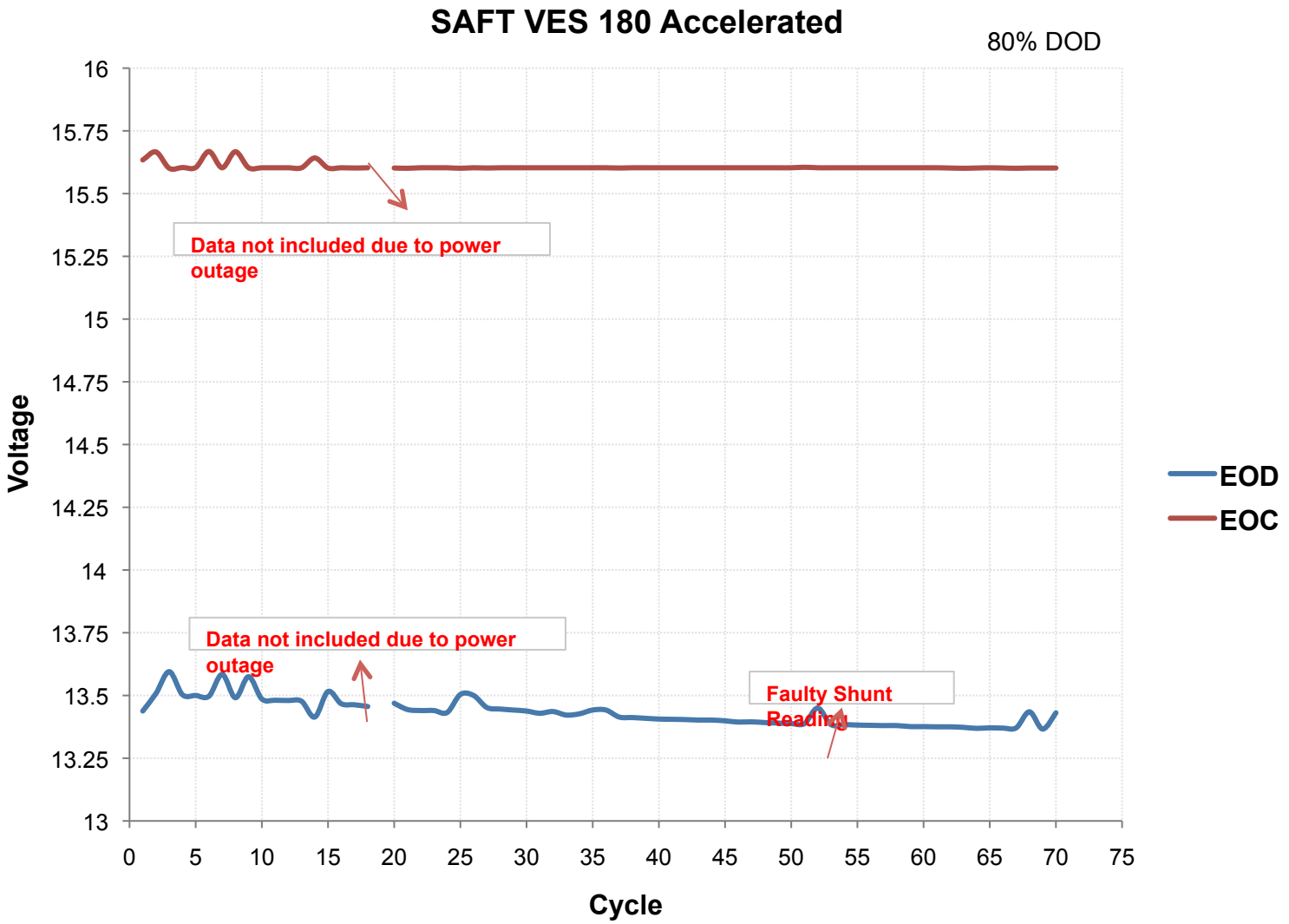

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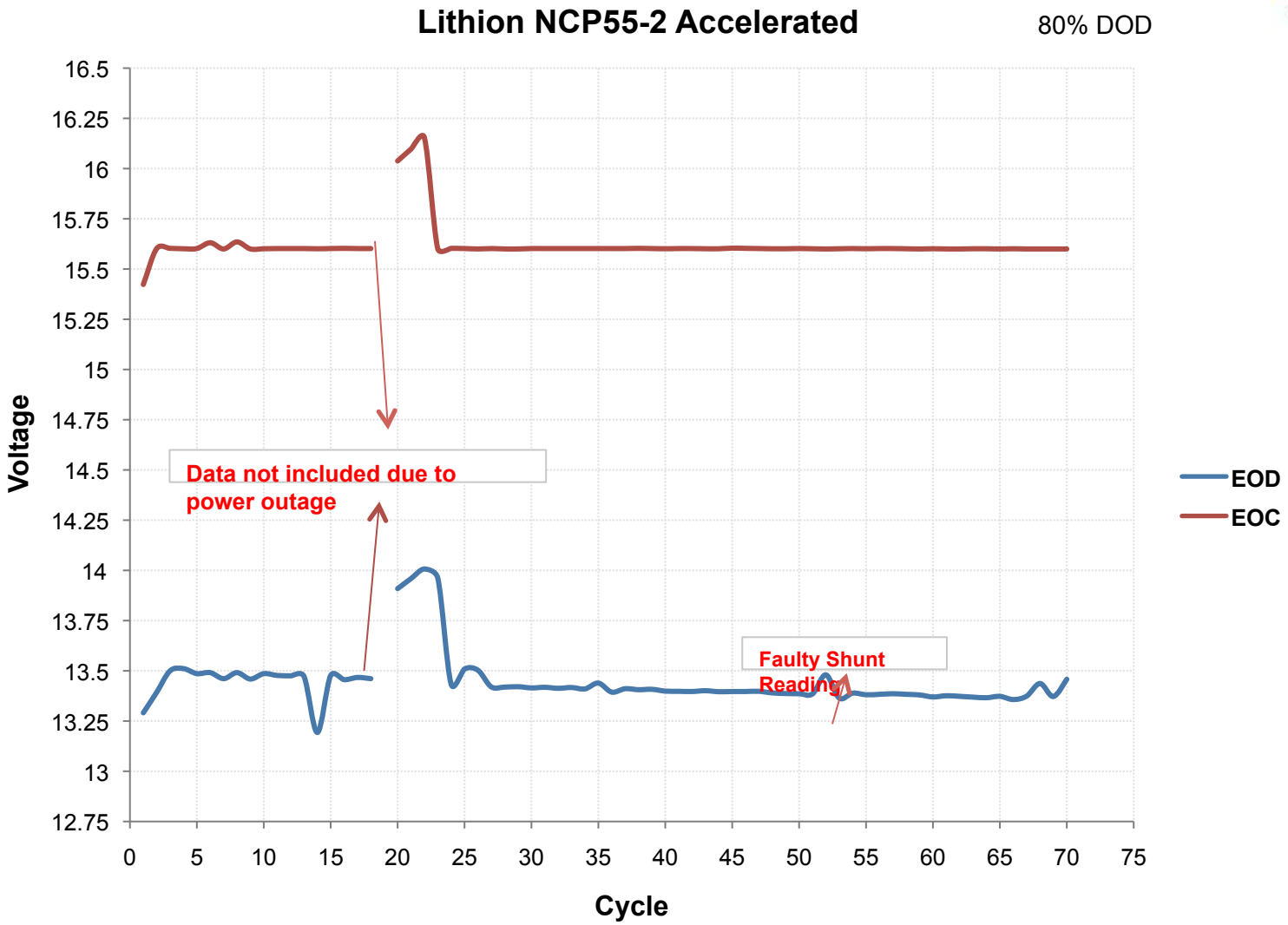

Real Time Lunar Equator

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- In 10th Cycle
  - 15.5 Days (372 Hours) eclipse darkness
  - 14 Days (336 hours) sunlight
  - 26 watt Constant Load
  - 80% DOD
- 50° and 60° C
- No Trending established yet.

Conclusions

MSFC

- Lithium Iron Phosphate ($LiFePO_{4)}$ is a good candidate chemistry to supplement ASRG
  - 16 C rate Capability
  - 0 deg C min operating Temperature
- Lithium Cobalt Oxide ($LiCoO_2$) accelerated testing successful for Lunar Equator application.
  - +50 deg C maximum battery temperature
  - -10 deg C minimum battery temperature
- Real time testing at +50° C and +60° C maximum
  - 9 completed cycles
  - No trending yet established