

SEPTEMBER 2026

DATA-DRIVEN IMPROVEMENTS TO TRIGA REACTOR OPERATIONS

TRTR Annual Conference

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Digital Twin Implementation at NETL

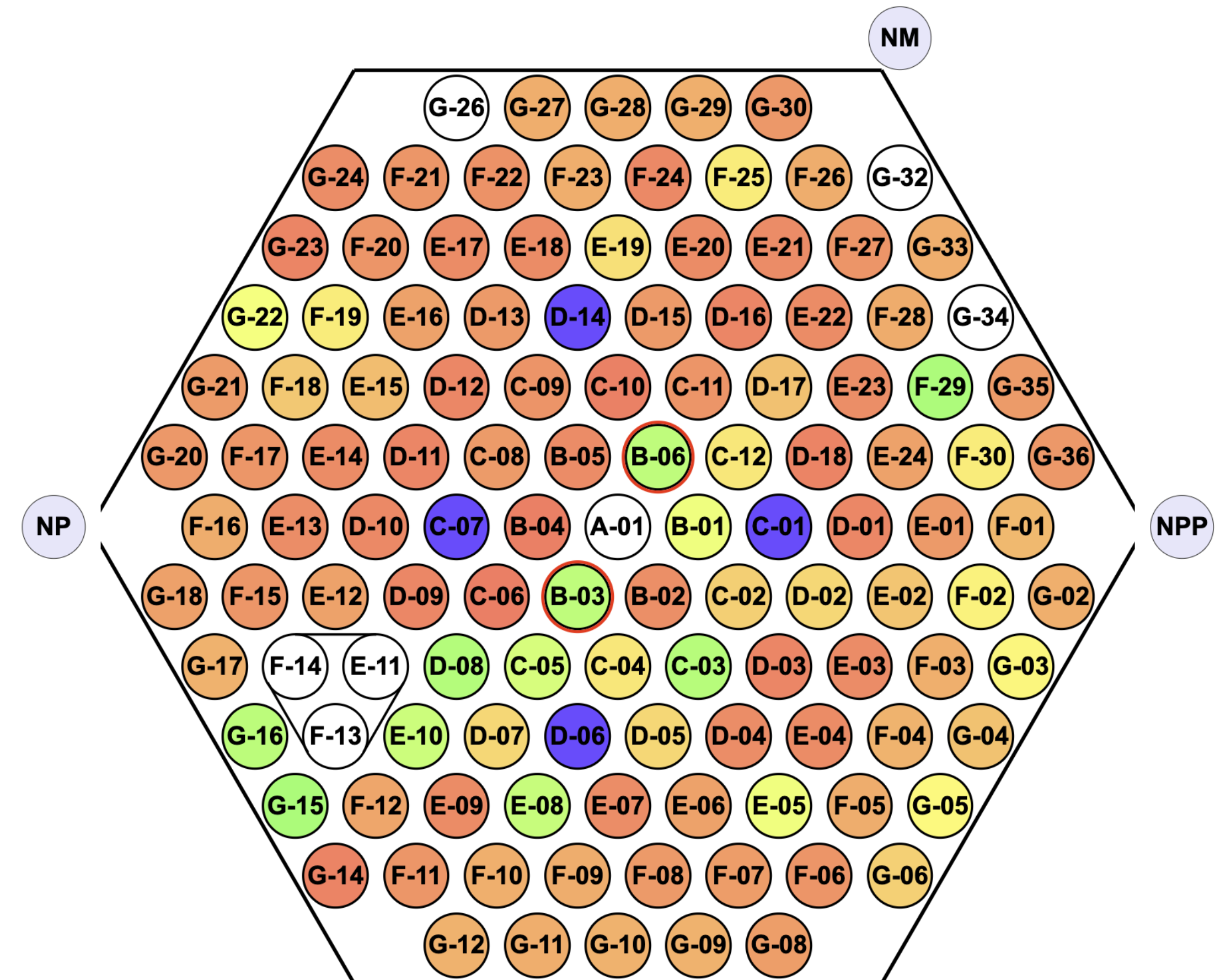
- Data sources: fission chambers, thermocouples, control rod drives
- Shared platform: synchronized reactor data, historical records, and analysis
- Applications: **rod calibration, digital logbooks, camera analytics, and experiment management**



AUTOMATIC ROD CALIBRATION

Background

- Operators recalibrate the control rods after **every core change**.
- The process uses preset rod withdrawals and timed power benchmarks.
- Manual timing and calculation introduce avoidable sources of error.



Calibration Process

Operators use the three rods not under calibration to establish criticality at 2 W.

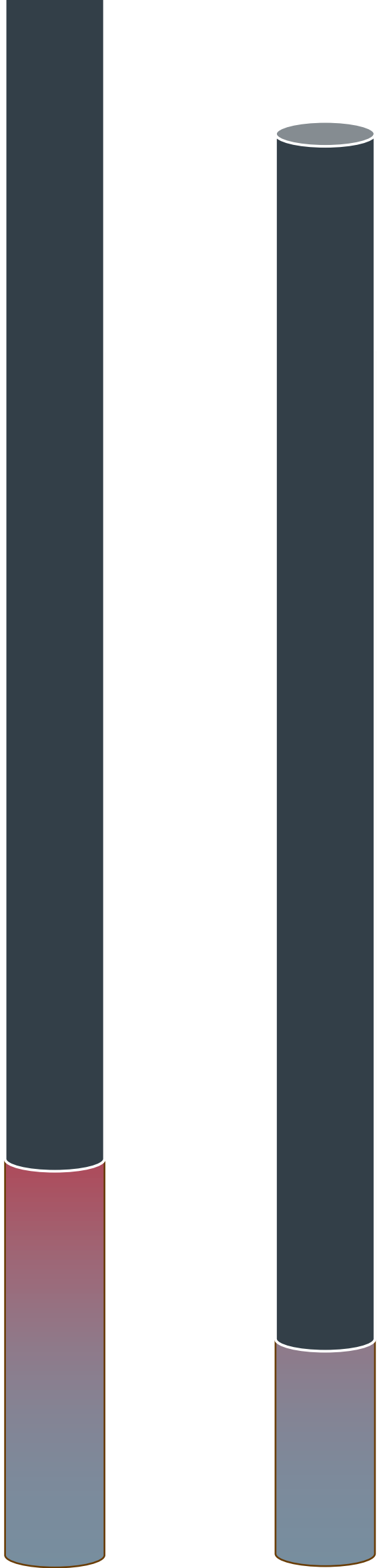
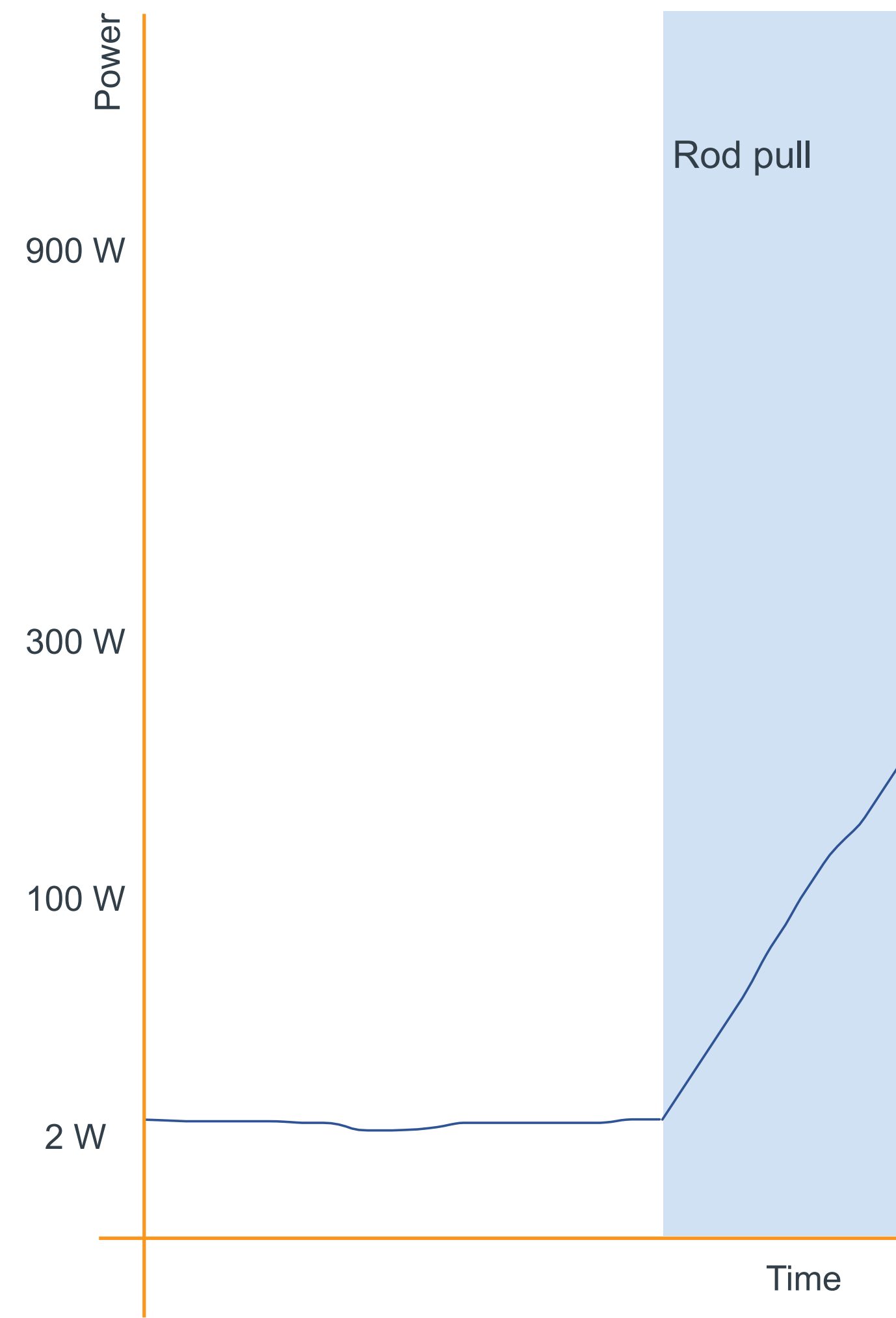


To be calibrated



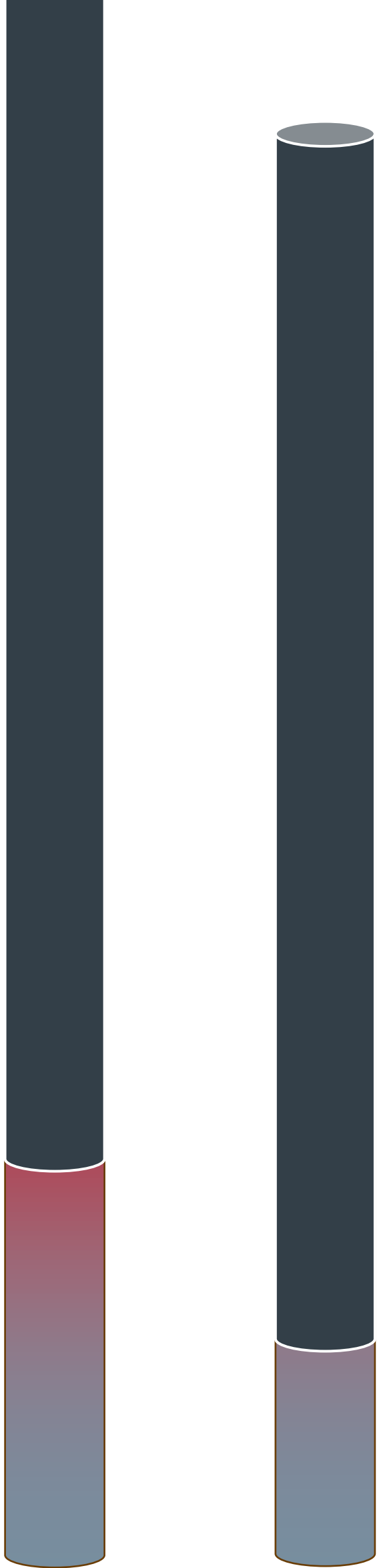
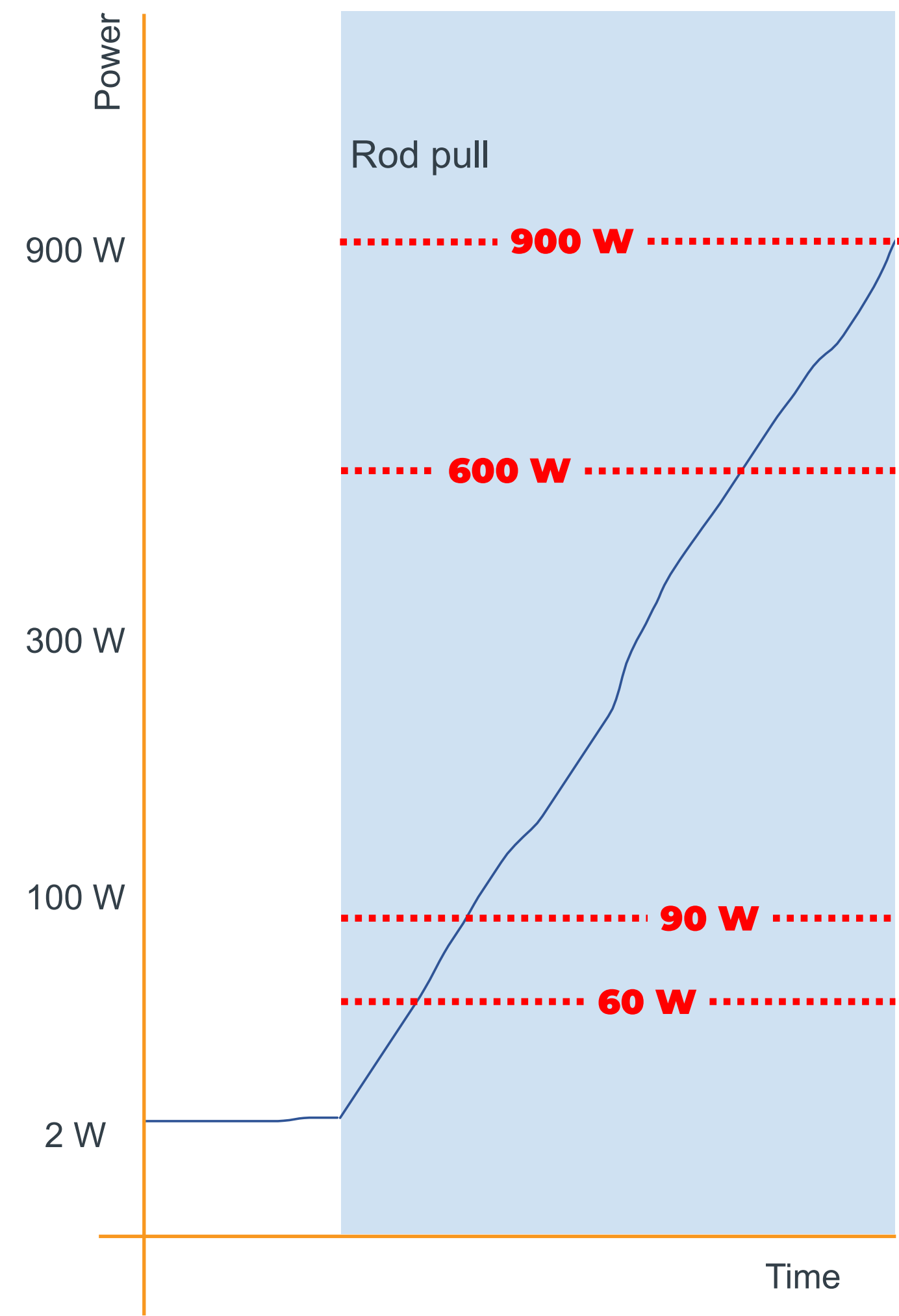
Calibration Process

Operators withdraw the rod under calibration by a preset increment, causing reactor power to rise.



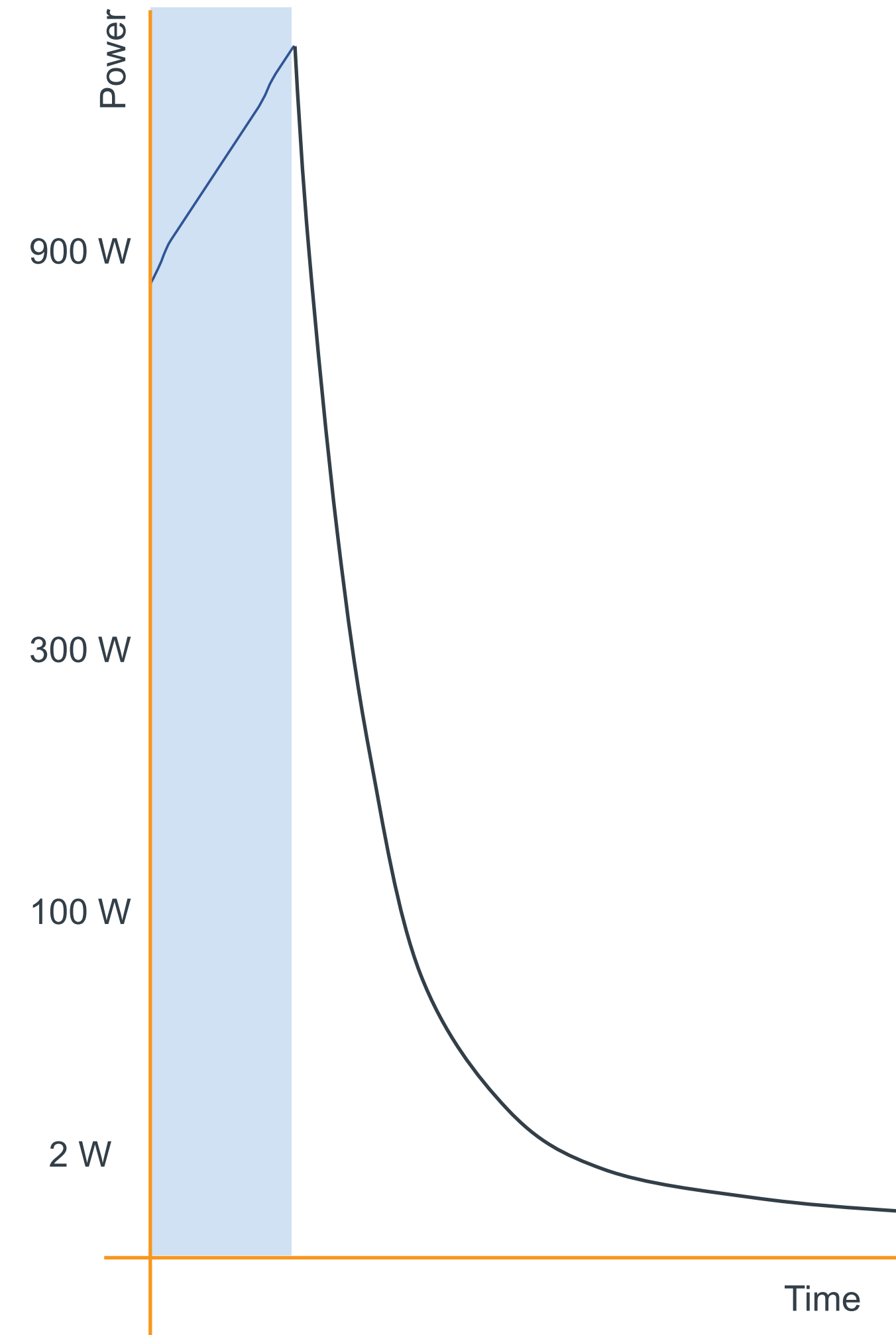
Background

Operators with stopwatches measure the time it takes for the power to reach 4 benchmarks: 60 watts, 90 watts, 600 watts, and 900 watts



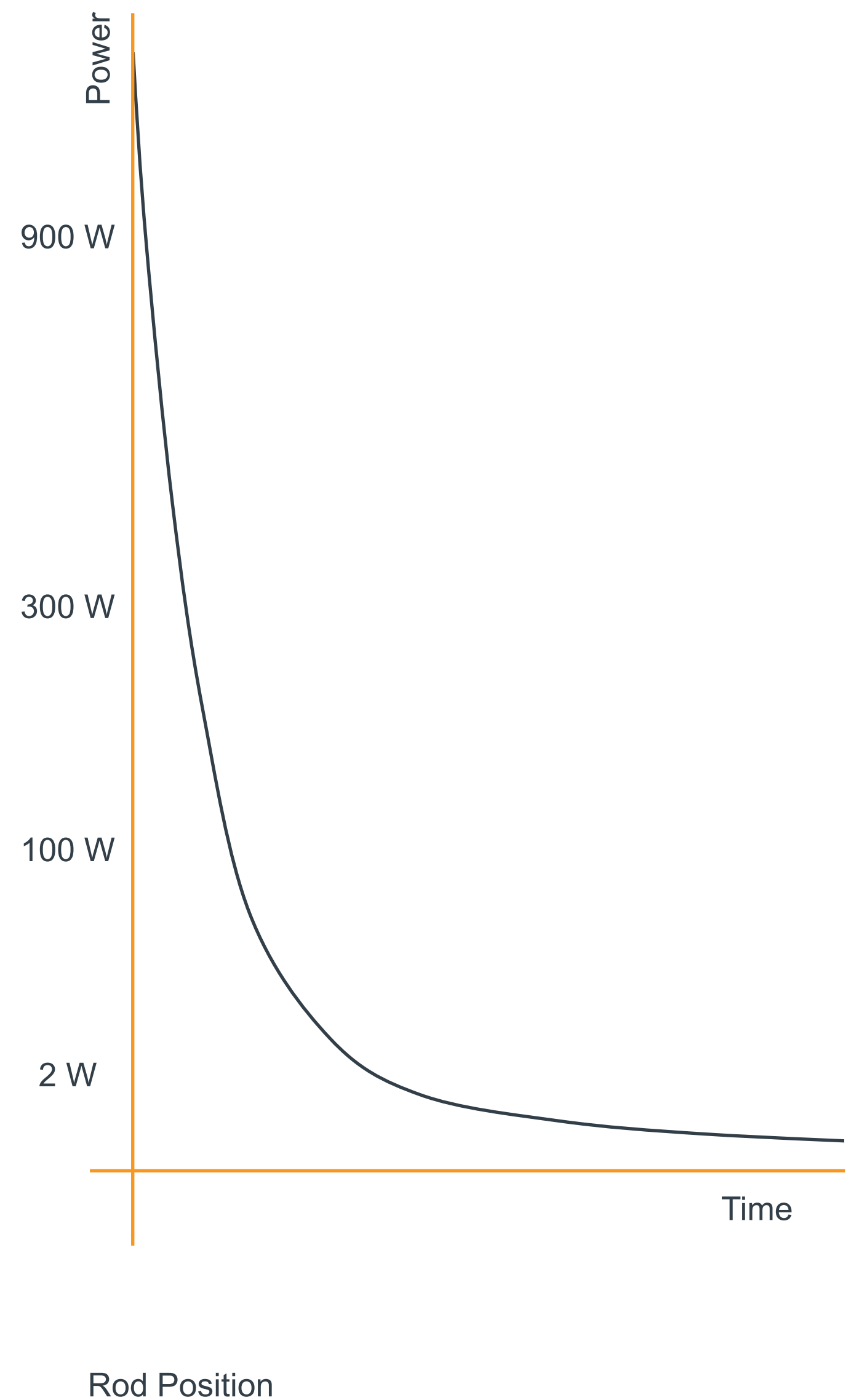
Calibration Process

After power exceeds 900 W, operators reduce power without moving the rod under calibration, then prepare for the next pull.



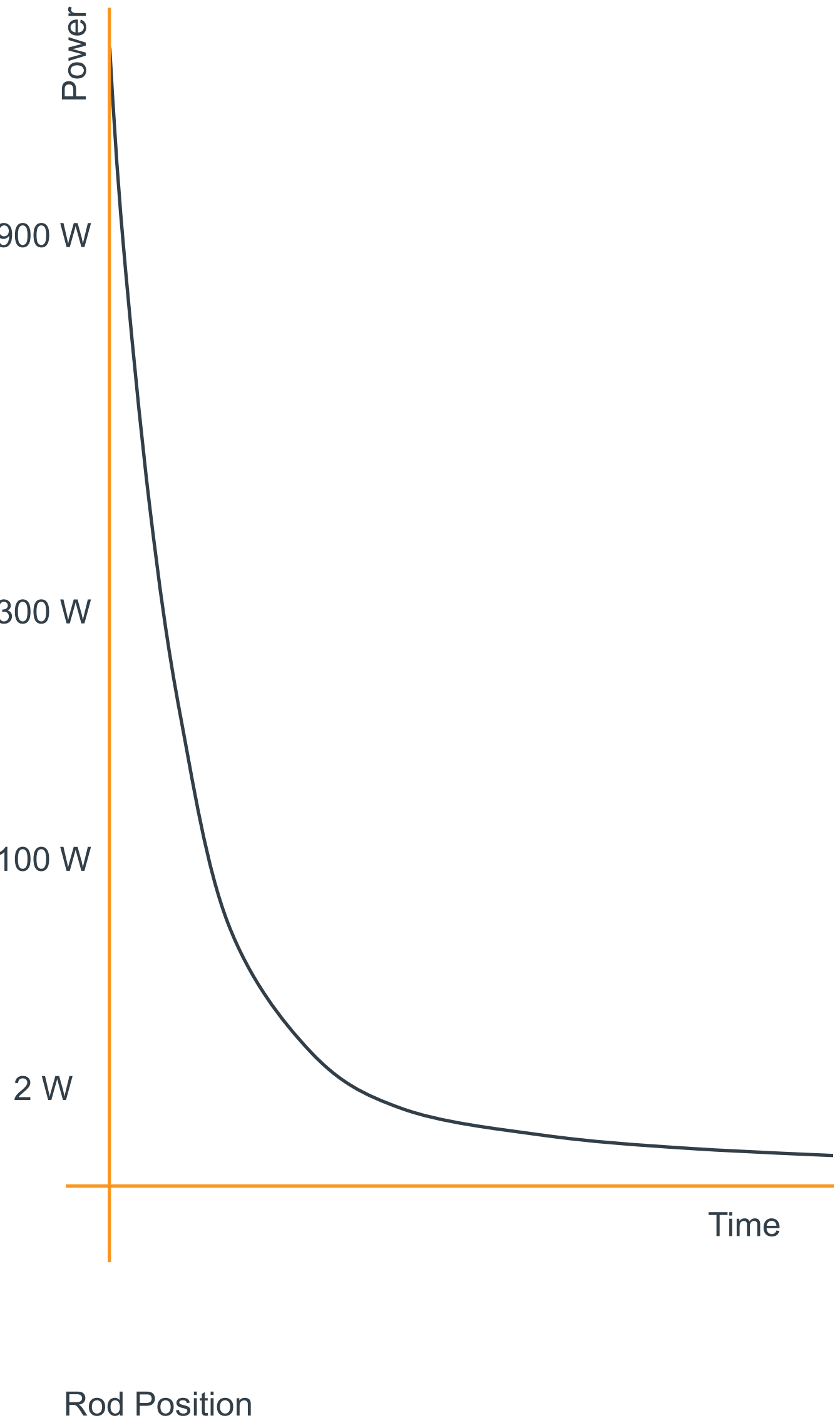
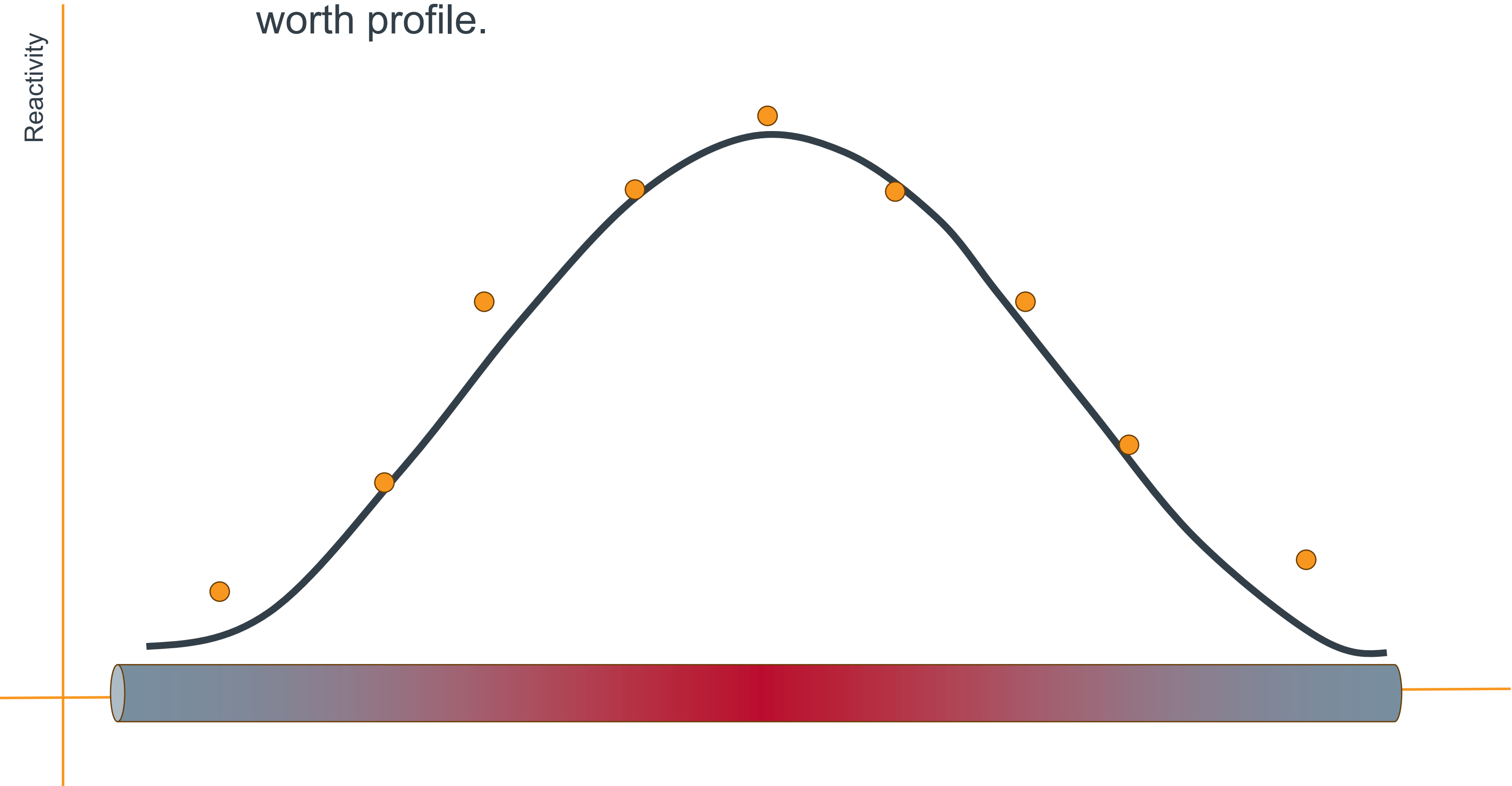
Calibration Process

The measured reactor period determines the **reactivity worth** of each rod pull.



Calibration Process

The cumulative measurements are fit to a $\sin^2$ curve to estimate the full rod-worth profile.

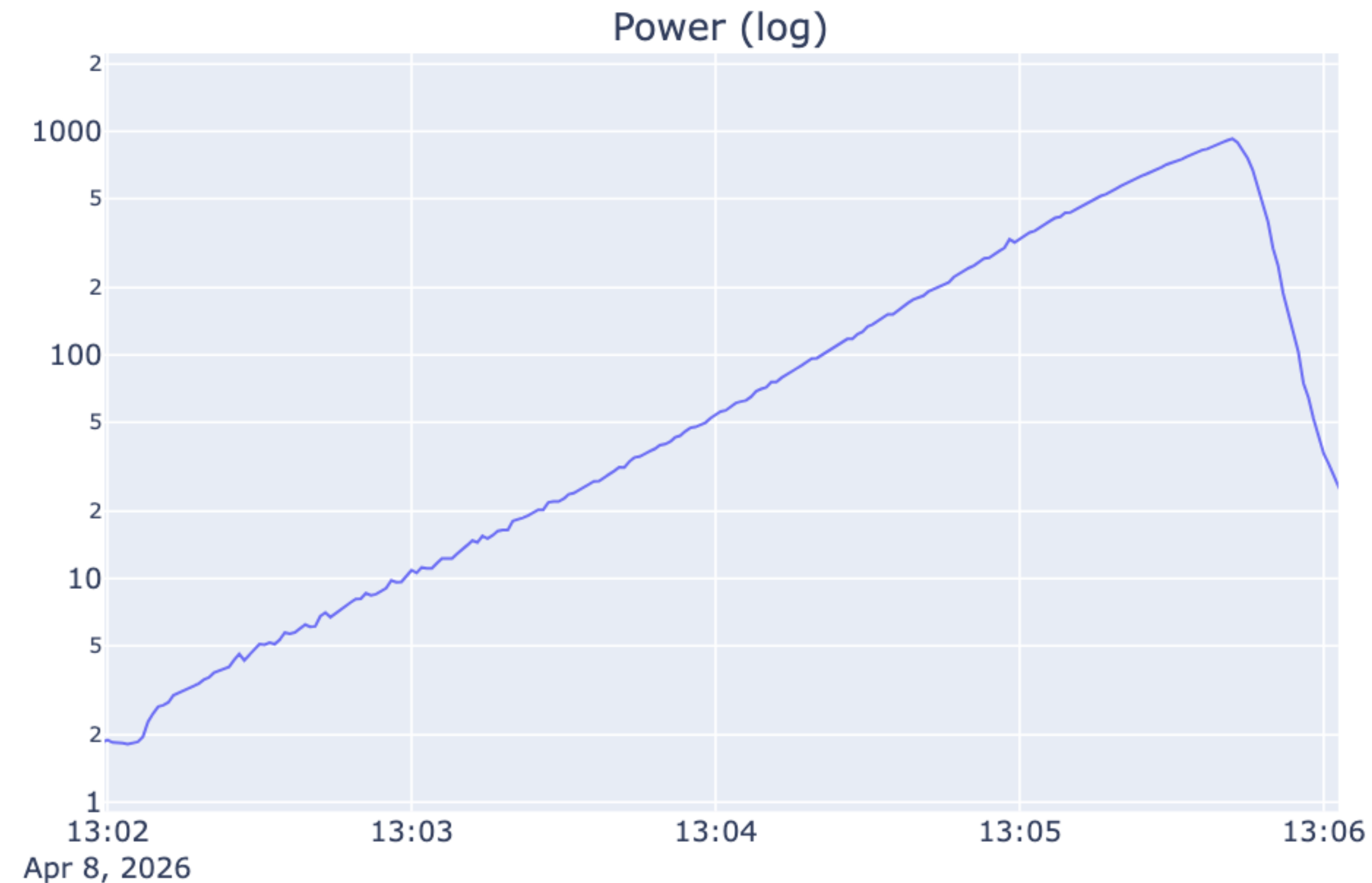


Why Automate Rod Calibration

- Traditional rod calibration requires substantial operator time.
 - A full calibration takes **one to two days** and may **involve several people**.
- Inaccuracy:
 - **Stopwatch timing** introduces human error.
 - High-power timing intervals include **temperature-feedback** bias.
 - Using the **midpoint** of each pull does not accurately represent the nonlinear rod-worth curve.

Automated Timing

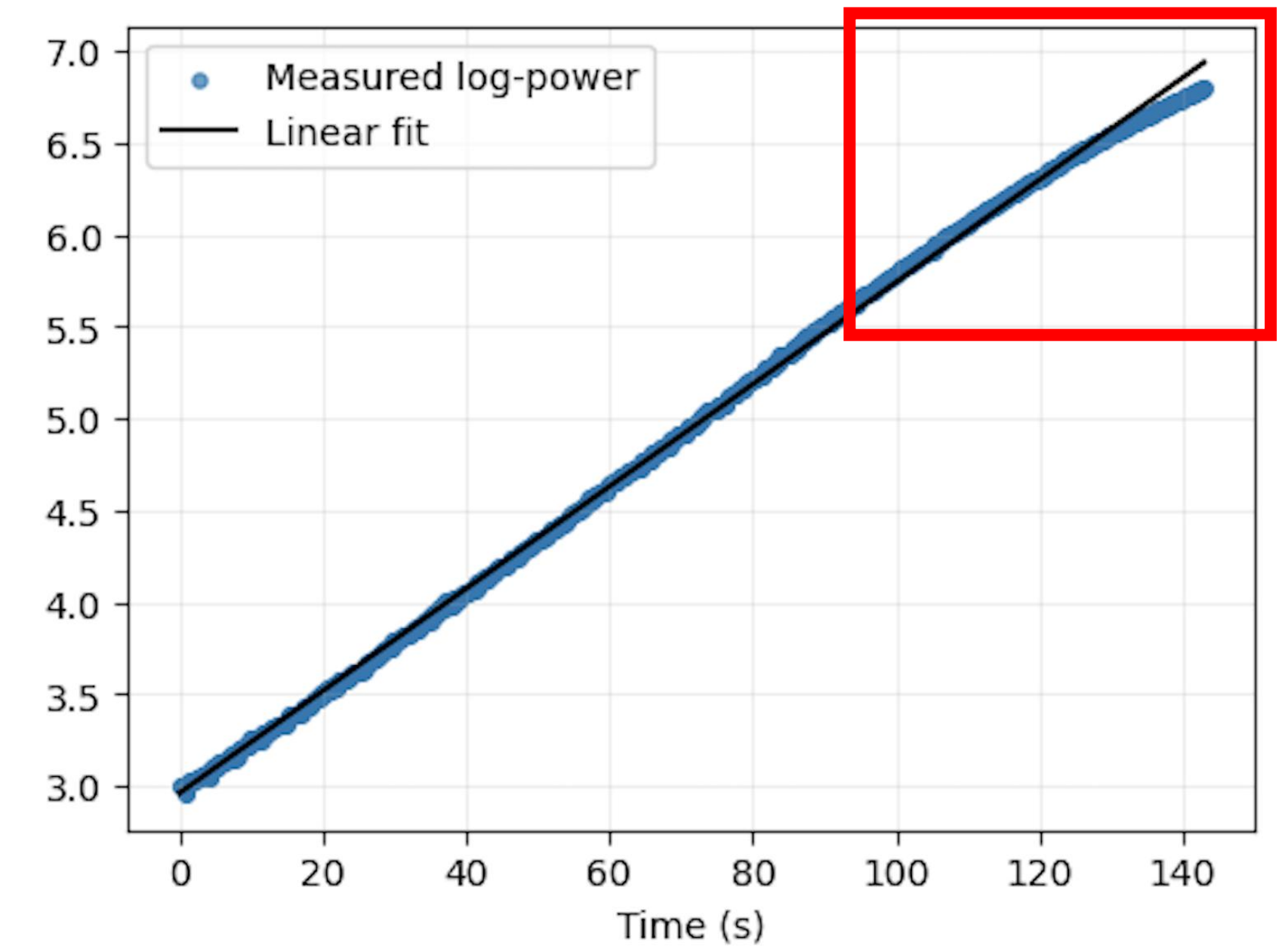
- Automated timing removes the stopwatch from the measurement process and eliminates the need for multiple timers.
- Errors of fractions of a second can accumulate and shift total rod worth by **as much as 10 cents**.



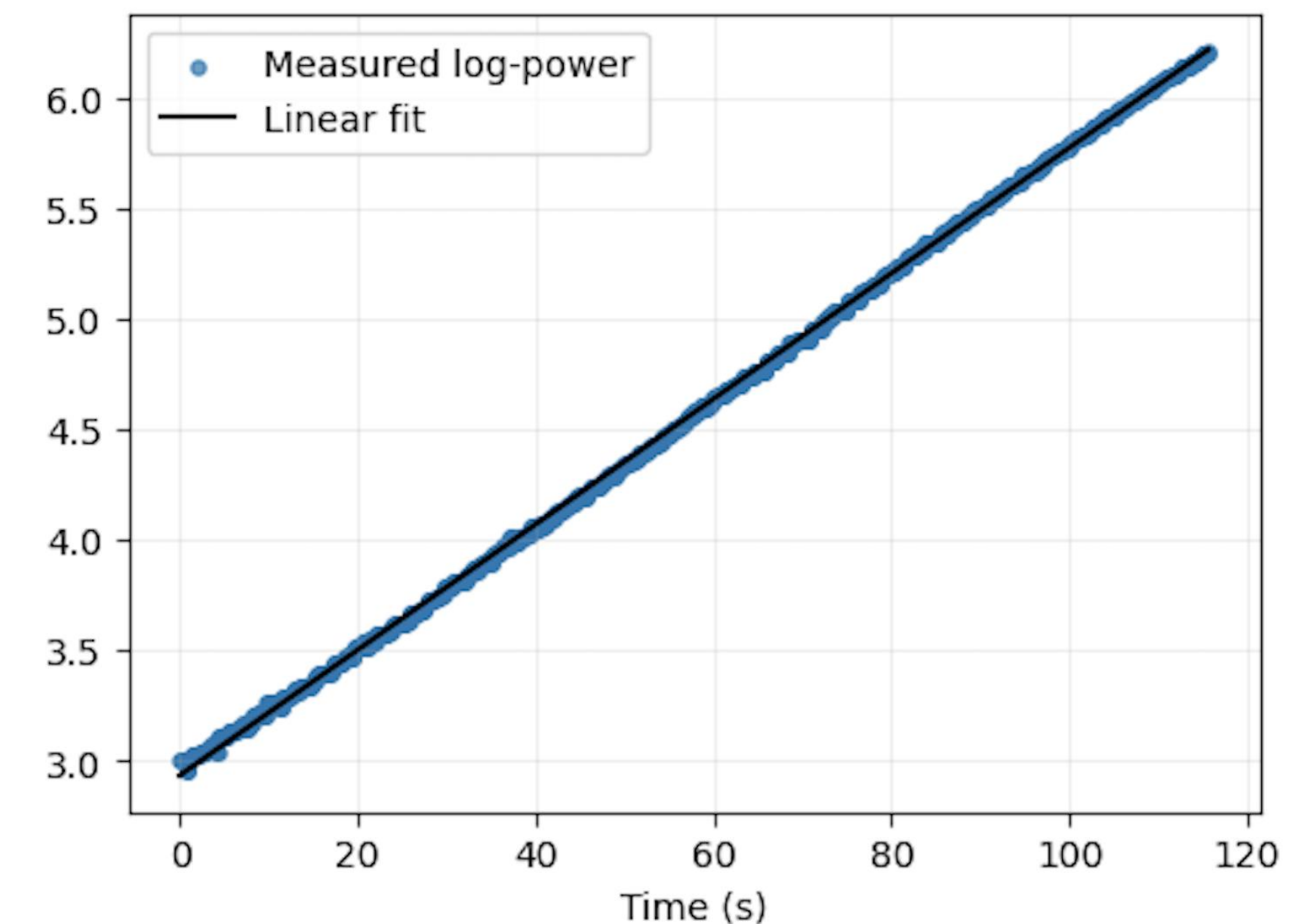
TEMPERATURE FEEDBACK

- The current Mathcad workflow calculates reactor period from the 90 to 900 W interval.
- Temperature feedback begins near 500 W and biases a period calculated across the full interval.
- Continuous digital data lets us use a lower-power interval and improve accuracy.

900 W

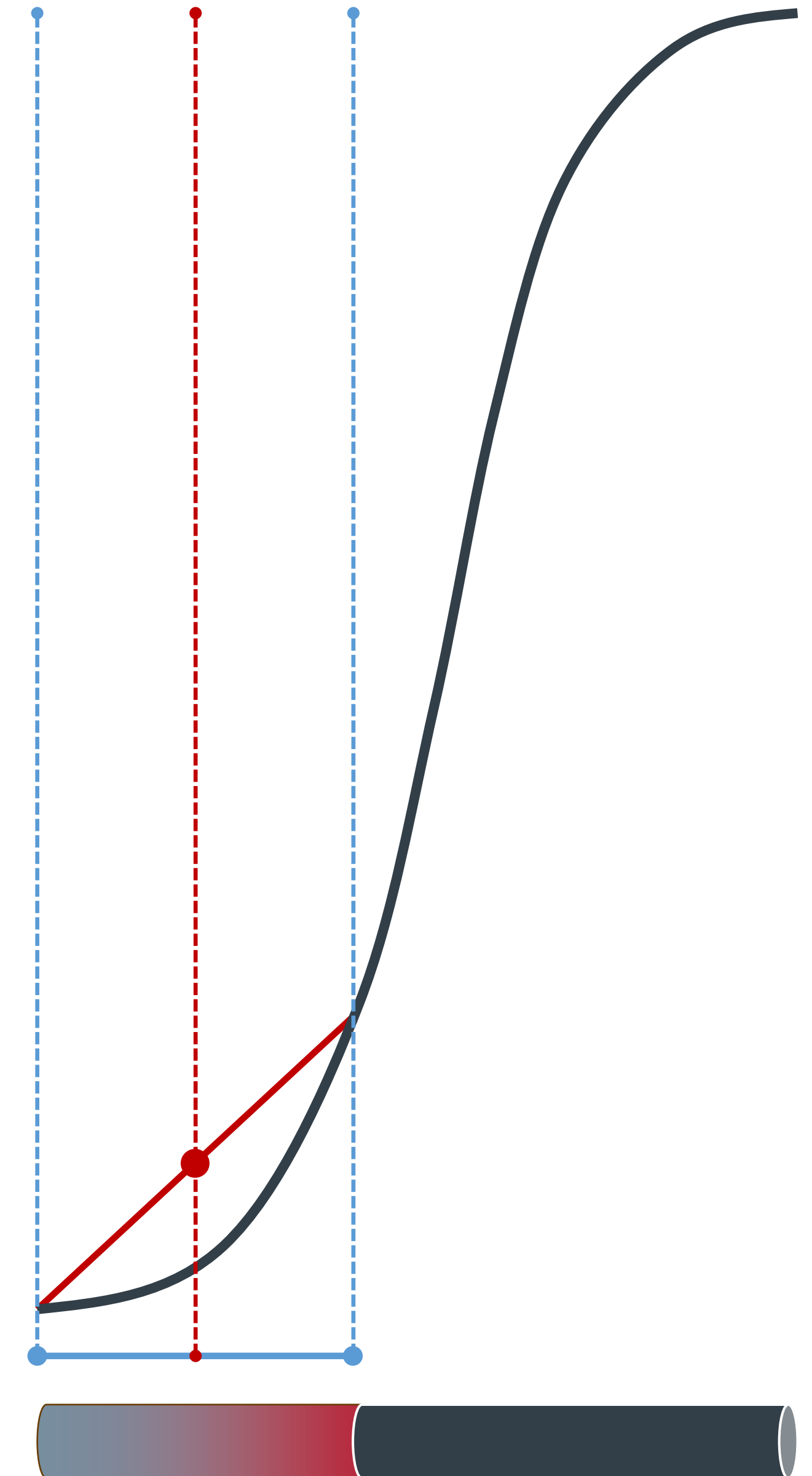


500 W



Integral Method

- The current method assigns each pull's measured worth to the midpoint of that rod interval.
- That linear approximation does not match the nonlinear $\sin^2$ worth curve.
- Integrating an estimated curve over each pull better represents the measured reactivity.



DIGITAL LOGBOOK



Physical Logbook Limitations

- Operators use handwritten logs to document startup checks, experiments, and reactor operations.
- Paper records can be difficult to read, easy to misfile, and cumbersome to search, archive, or summarize.

Time	Comments
0810	Commence Rx S/U checks, Rodrigo V. signed in as SKD
0908	S/U checks complete, BPI sample sweep 1
090915	Commence Rx S/U to SOW
0919	Rx PWR at SOW
0926	Raising Rx PWR to 100kw 100w, Rx PWR at 100w
0927	Raising Rx PWR to 300w
0928	Rx PWR at 300w
0932	Raising Rx PWR to 1kw
0933	Rx PWR at 1kw
0935	Rx PWR Raising Rx PWR to 3kw
0936	Rx PWR at 3kw
0938	Raising Rx PWR to 10kw
0939	Rx PWR at 10kw
0947	Rx PWR at 10kw, LMZ SAT
0953	Commence Rx S/D
0953	All rods down
1046	Sample w/ att + fast startup in BPI
1047	Commence Rx S/U to 10kw
1051	Rx PWR at 10kw
1102	DON LOGGED ONTO CONSOLE RELIEVING ROD
1117	Rx PWR @ 10 kw, LMI SAT
1147	Rx PWR at 10kw, LMZ SAT
1217	Rx PWR at 10kw, LMZ SAT
1234	Commence Rx S/D
1240	All rods down
1434	BPI sample box pecks removed, lead shield added
1439	Commence Rx S/U to 50 10kw
1443	Reactor Power at 10kw
1512	Reactor Power at 10kw, LMZ SAT
1612	Commence Rx S/D, All rods down
1731	Commence Rx S/U + 0 50 w
1737	Reactor at 50 w
1745	Preparing for a 3 pulse, 194,599,598,600
1758	Pulse complete Post pulse checks passed
1759	Commence Rx S/D checks
1809	S/D checks complete

Digital Logbook

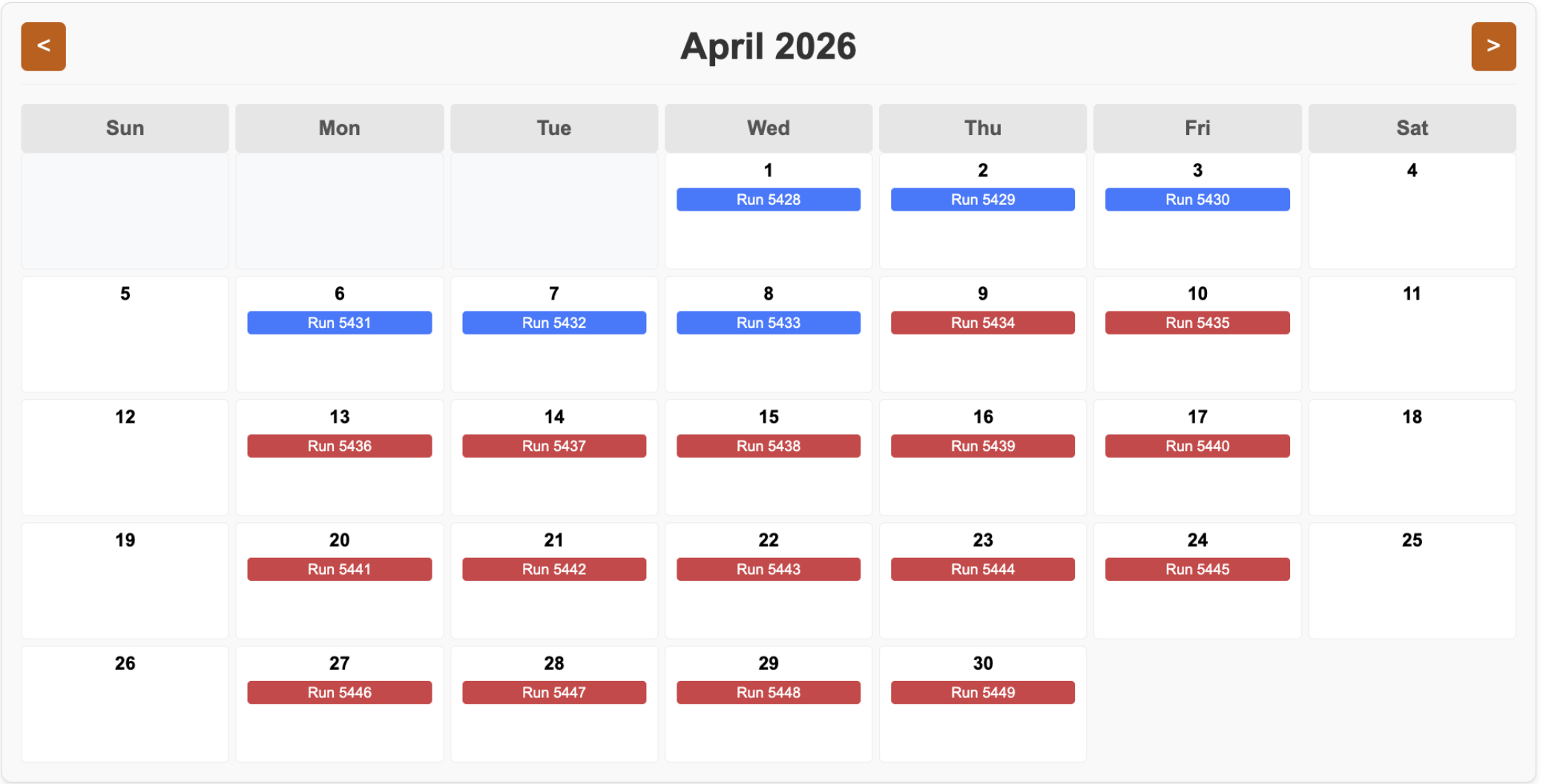
The digital logbook creates **legible, searchable records** and provides a foundation for automated reports without adding physical storage in the NETL facility.

Run Number: 5440

Time	Comments
08:10	Commence reactor startup checks, Rodrigo V signed in as SRO
09:08	startup checks complete, BP1 sample swapped
09:15	Commence reactor startup to 50W
09:19	Reactor power at 50W
09:26	Raising reactor power to 100W, Reactor power at 100W
09:27	Raising reactor power to 300W
09:28	Reactor power at 300W
09:32	Raising reactor power to 1kW
09:33	Reactor power at 1kW
09:35	Raising reactor power to 3kW
09:36	Reactor power at 3kW
09:38	Raising reactor power to 10kW
09:39	Reactor power at 10 kW
09:47	Reactor power at 10kW, LMI SAT
09:53	all rods down
09:53	commence reactor shutdown
10:46	sample with after dosimetry in BPI
10:47	Commence reactor startup to 10kW
10:51	Reactor power at 10 kW
11:02	Don logged onto console relieving Rod
11:17	Reactor power at 10 kW, LMI SAT
11:47	Reactor power at 10 kW, LMI SAT
12:17	Reactor power at 10 kW, LMI SAT
12:39	All rods down
12:39	Commence reactor shutdown
14:39	BP1 Sample tox pecks removed, Ized shield added
14:43	Reactor power at 10kW
15:12	Reactor power at 10kW, LMI SAT
16:12	Commence reactor shutdown, all rods down
17:31	Commence reactor startup to 50W
17:37	Reactor at 50W
17:45	preparing for a \$3 pulse. 194,644,578,600
17:58	Pulse complete post pulse checks passed
17:59	Commence reactor shutdown checks
18:09	Shutdown checks complete

DIGITAL LOGBOOK

- Interactive calendar with status-based color coding
- PDF export for required paper records
- Shortcuts for common operating entries



Time	Comments	
09:08		
09:15		
09:19		
09:26		
09:27		
09:28		
09:32		
09:33		
09:35	Raising reactor power to 3kW	
09:36	Reactor power at 3kW	
09:38	Raising reactor power to 10kW	
09:39	Reactor power at 10 kW	
09:47	Reactor power at 10kW, LMI SAT	
09:53	commence reactor shutdown	

Use the following shortcuts to enter common log entries:

Replacing Shortcuts
(Replaces all text in the cell)

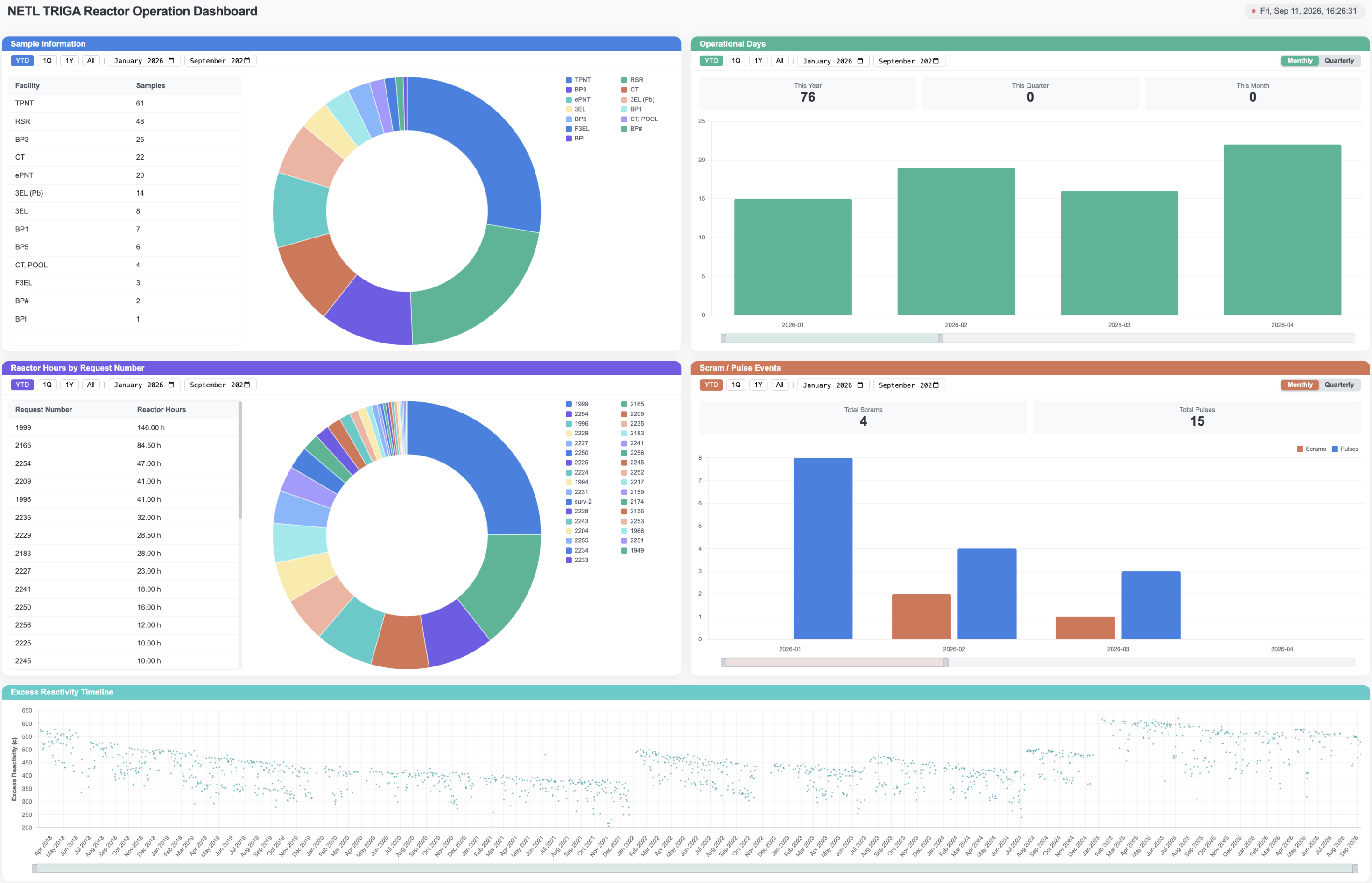
- Ctrl + 1: Commence reactor startup checks
- Ctrl + 2: Reactor startup checks complete
- Ctrl + 3: Commence reactor startup
- Ctrl + 4: Increasing reactor power
- Ctrl + 5: Reactor power at
- Ctrl + 6: Decreasing reactor power
- Ctrl + 7: Commence reactor shutdown
- Ctrl + 8: All rods down
- Ctrl + 9: Commence reactor shutdown checks
- Ctrl + 0: Reactor shutdown checks complete

Appending Shortcuts
(Adds text to the end of the cell)

- Alt + 1: LMI, SAT
- Alt + 2: All conditions normal
- Alt + 3: All rods down
- Alt + 4: Safety Channel 1&2 passed
- Alt + 5: p < 5¢
- Alt + 6: Ar CAM offline
- Alt + 7: Reactor shutdown
- Alt + 8: Key out, Light off
- Alt + r: p
- Alt + c: ¢

Dashboard

The digital logbook converts routine entries into searchable data and dashboards for operational analysis.



NETL TRIGA Reactor Operation Dashboard

Sample Information

YTD

1Q

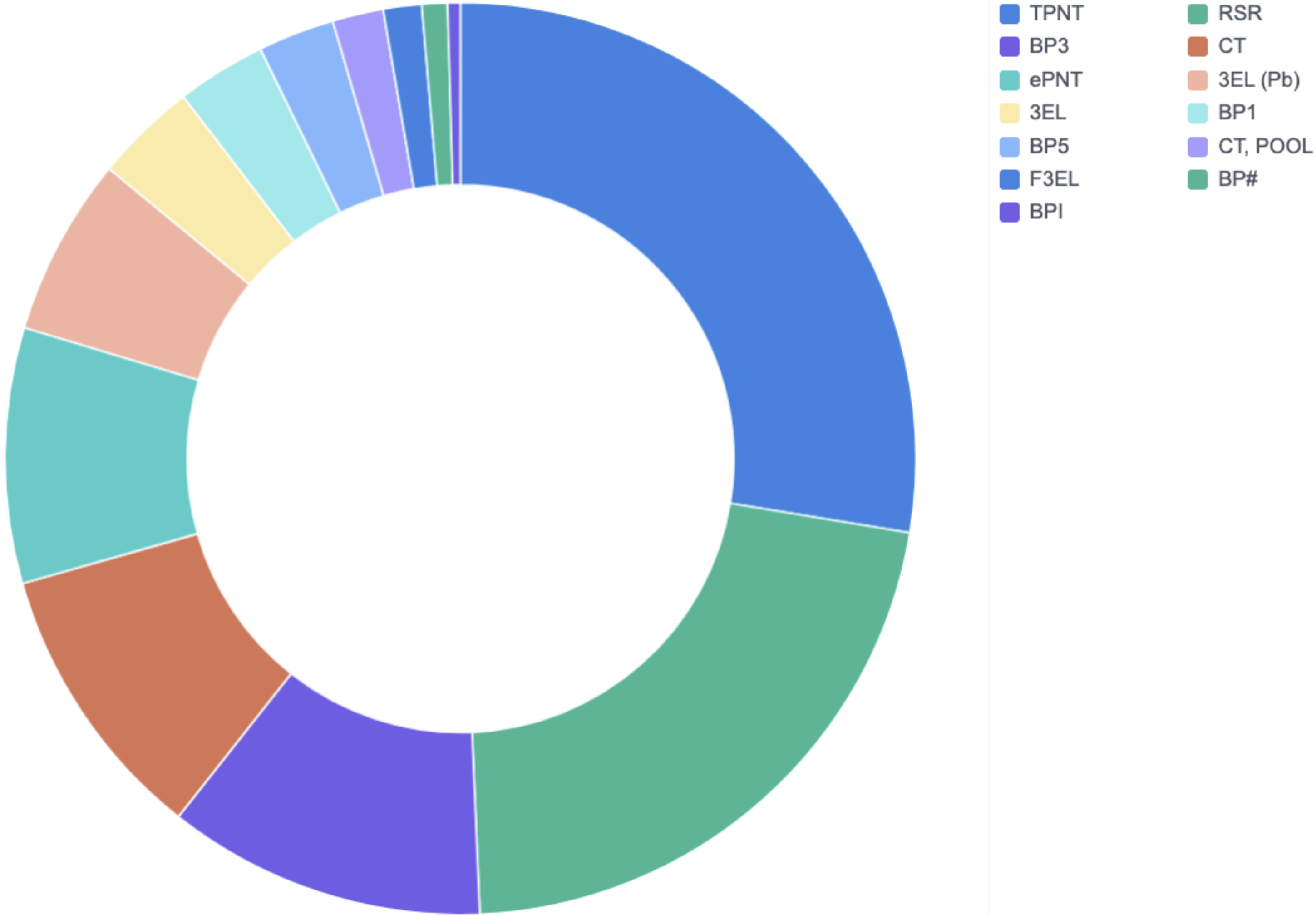
1Y

All

January 2026

September 202

Facility	Samples
TPNT	61
RSR	48
BP3	25
CT	22
ePNT	20
3EL (Pb)	14
3EL	8
BP1	7
BP5	6
CT, POOL	4
F3EL	3
BP#	2
BPI	1



Reactor Hours by Request Number

YTD

1Q

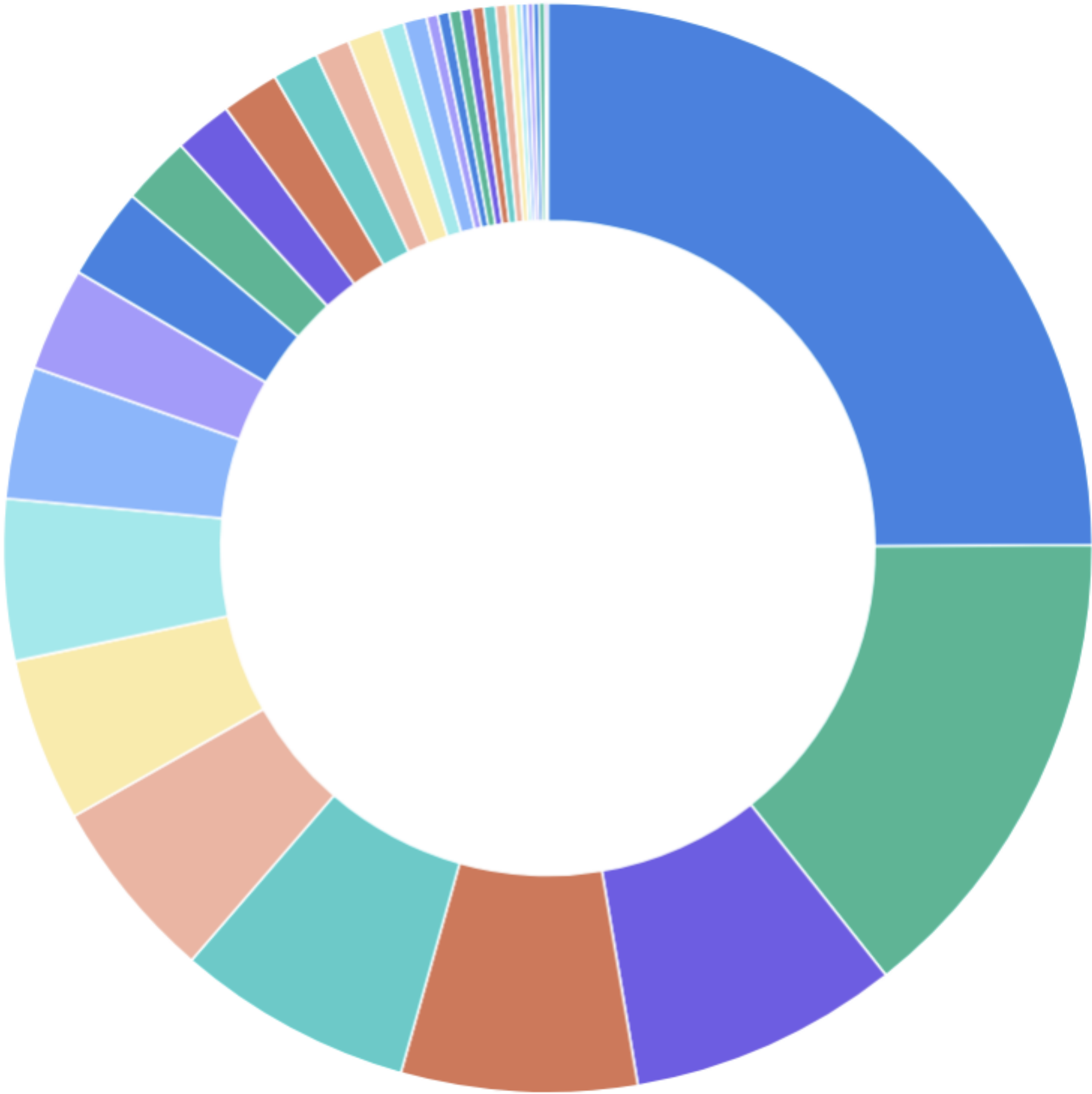
1Y

All

January 2026

September 202

Request Number	Reactor Hours
1999	146.00 h
2165	84.50 h
2254	47.00 h
2209	41.00 h
1996	41.00 h
2235	32.00 h
2229	28.50 h
2183	28.00 h
2227	23.00 h
2241	18.00 h
2250	16.00 h
2256	12.00 h
2225	10.00 h
2245	10.00 h



- 1999

2254

1996

2229

2227

2250

2225

2224

1994

2231

surv-2

2228

2243

2204

2255

2234

2233
- 2165

2209

2235

2183

2241

2256

2245

2252

2217

2159

2174

2156

2253

1966

2251

1949

Operational Days

YTD1Q1YAll

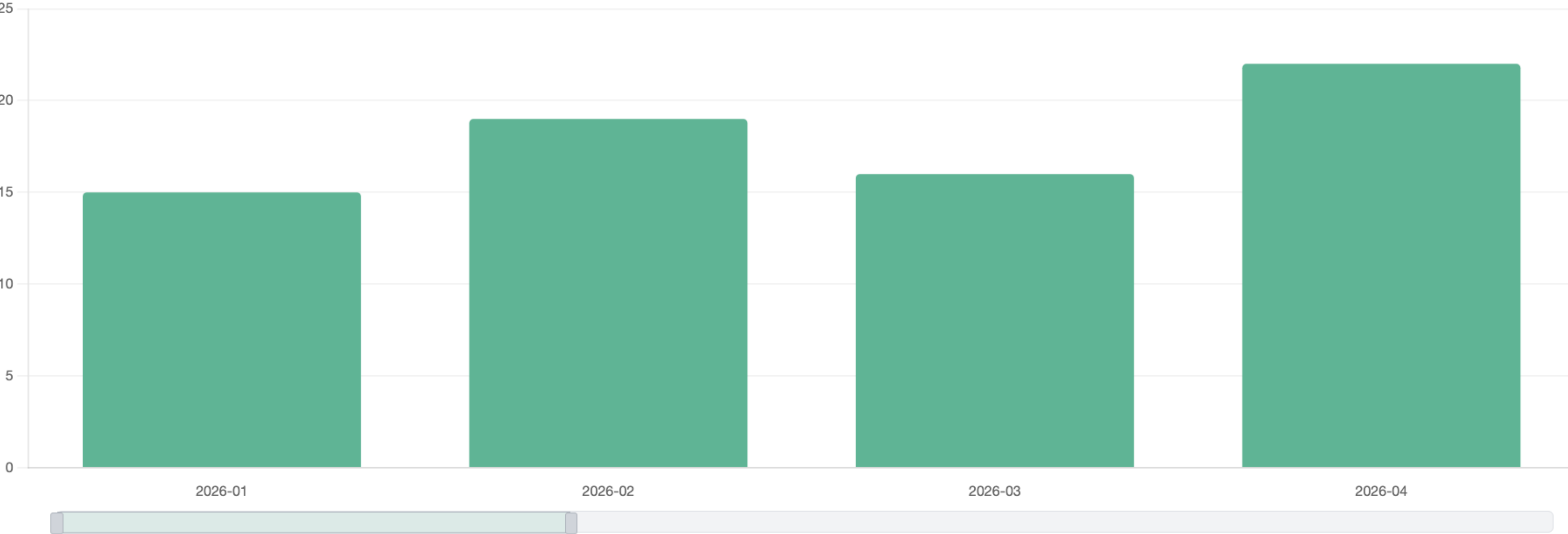
January 2026September 2026

MonthlyQuarterly

This Year76

This Quarter0

This Month0



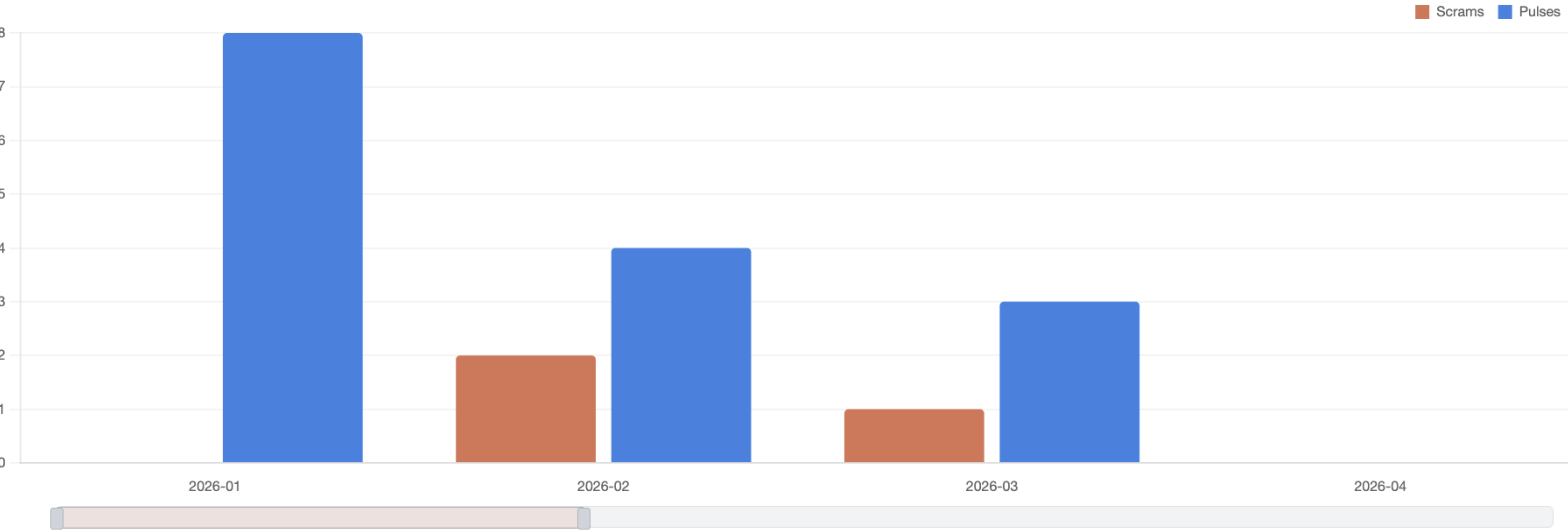
Scram / Pulse Events

YTD 1Q 1Y All | January 2026 September 2026

Monthly Quarterly

Total Scrams
4

Total Pulses
15



QUARTERLY REPORTS

- The digital logbook can automate much of the quarterly reporting workflow.
- Commercial alternatives considered cost up to \$10,000, plus thousands in annual fees.
- The in-house system integrates directly with the digital twin and avoids additional licensing fees.

CAMERA SYSTEM

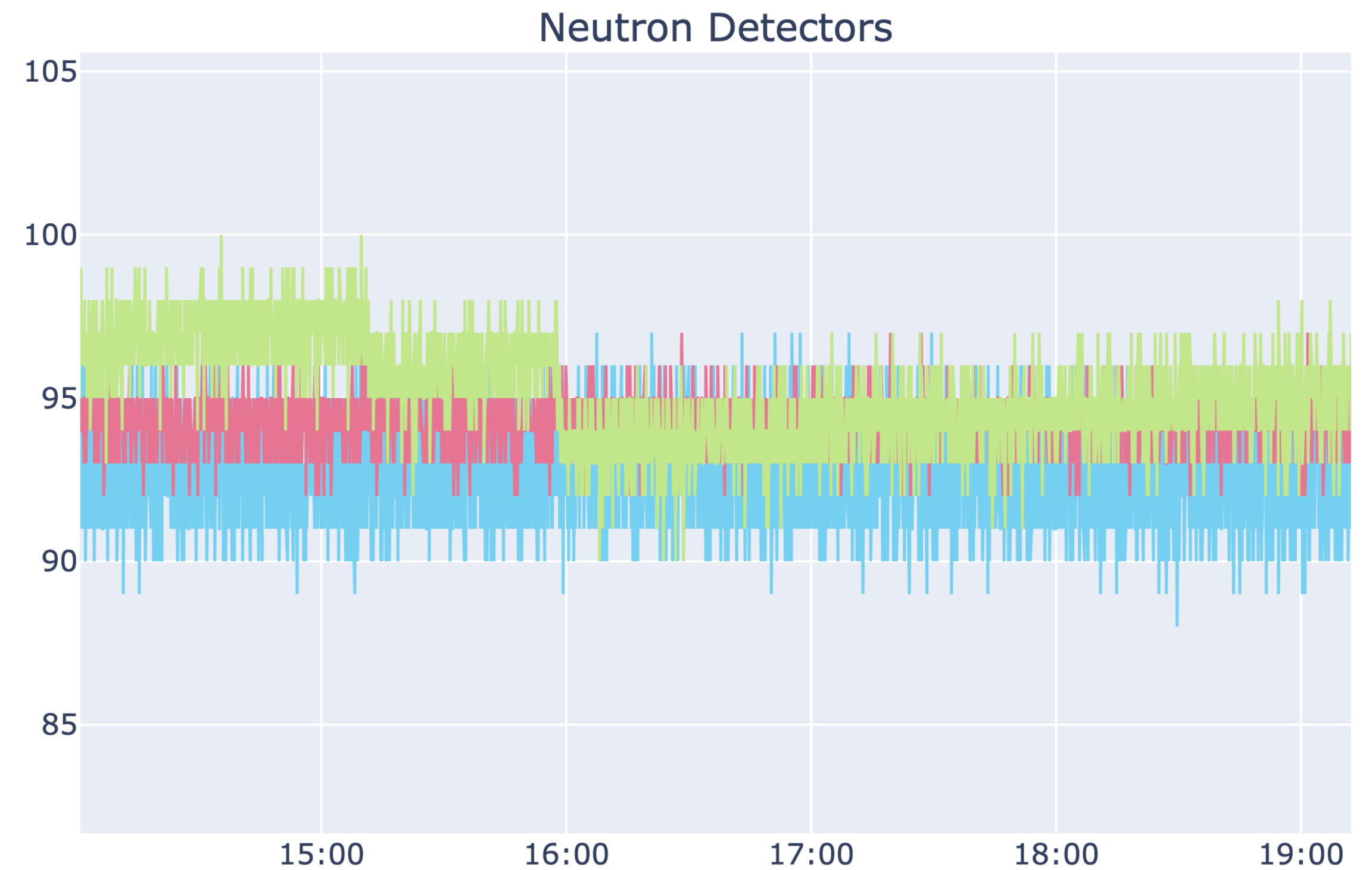
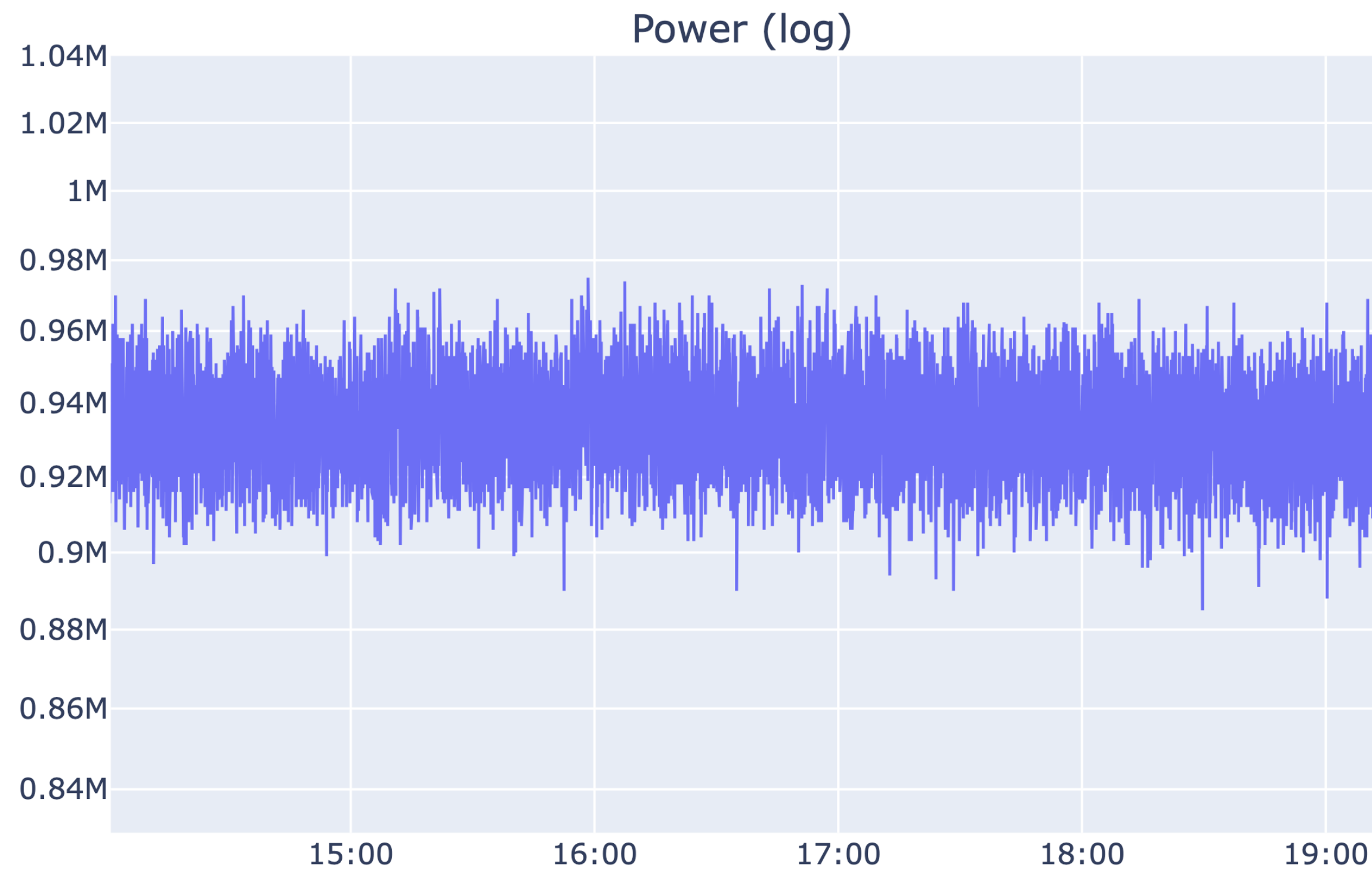
Video Feed

- The server and digital-twin framework can support a **live video feed from inside the reactor pool.**
- A GoPro provides this proof of concept. Following ROC approval, a dive camera will provide a permanent submerged feed.



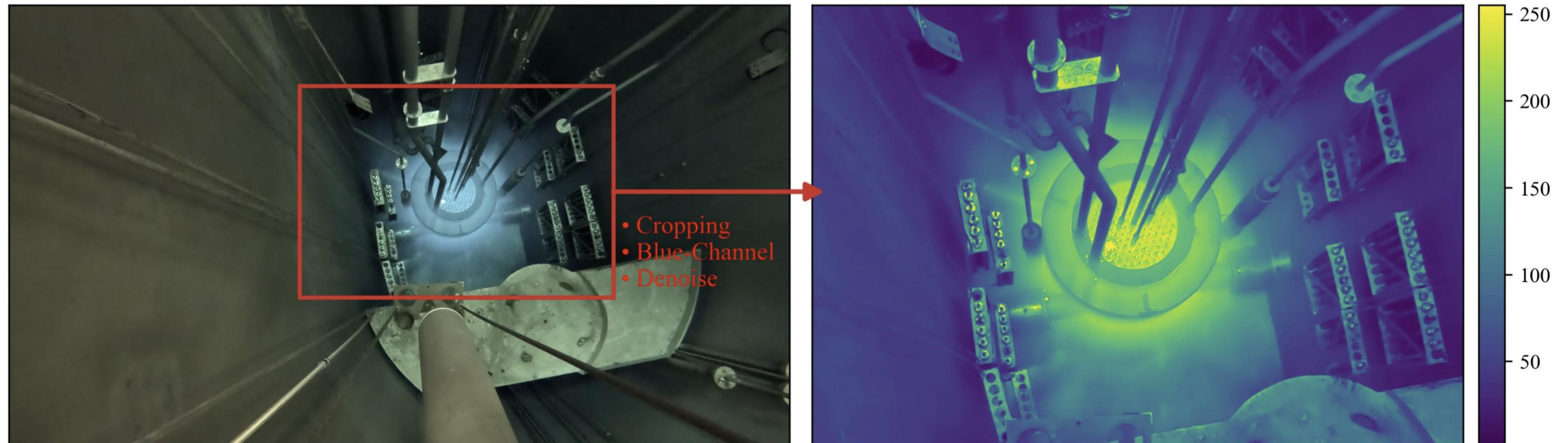
Power Estimation

- Noise in the existing power estimate constrains operation near the target peak power.
- Neutron detectors are also sensitive to flux tilt.



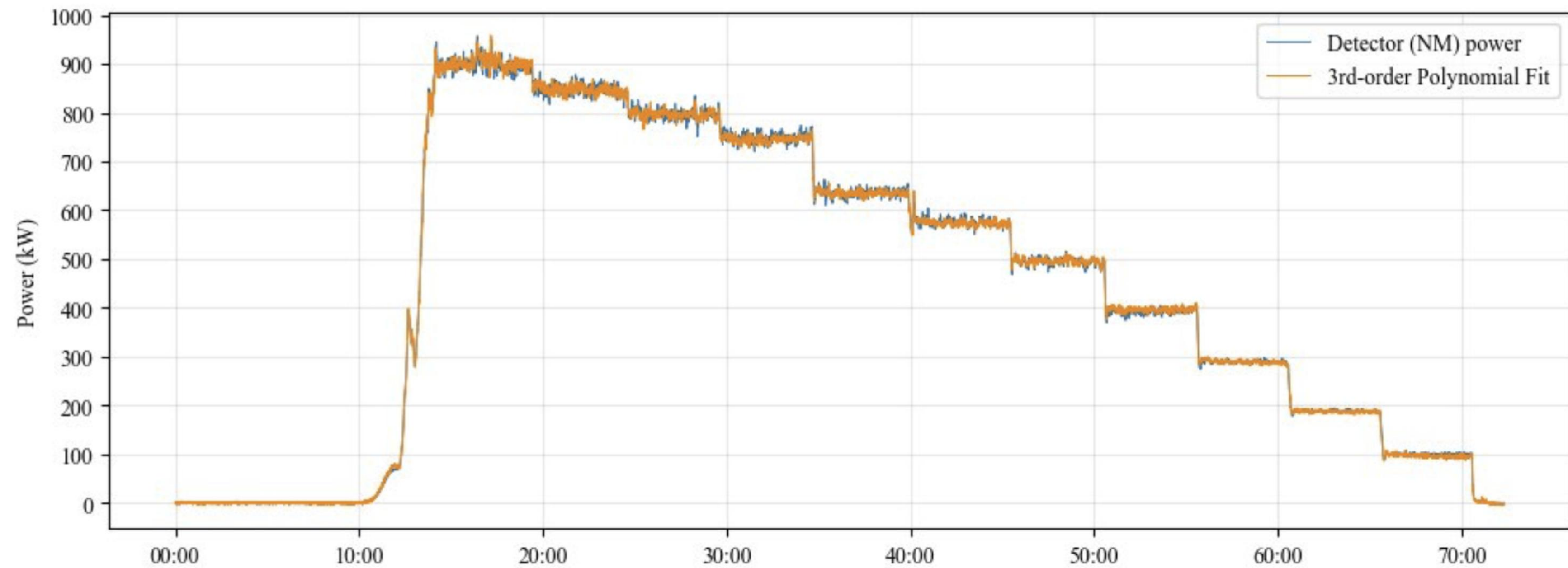
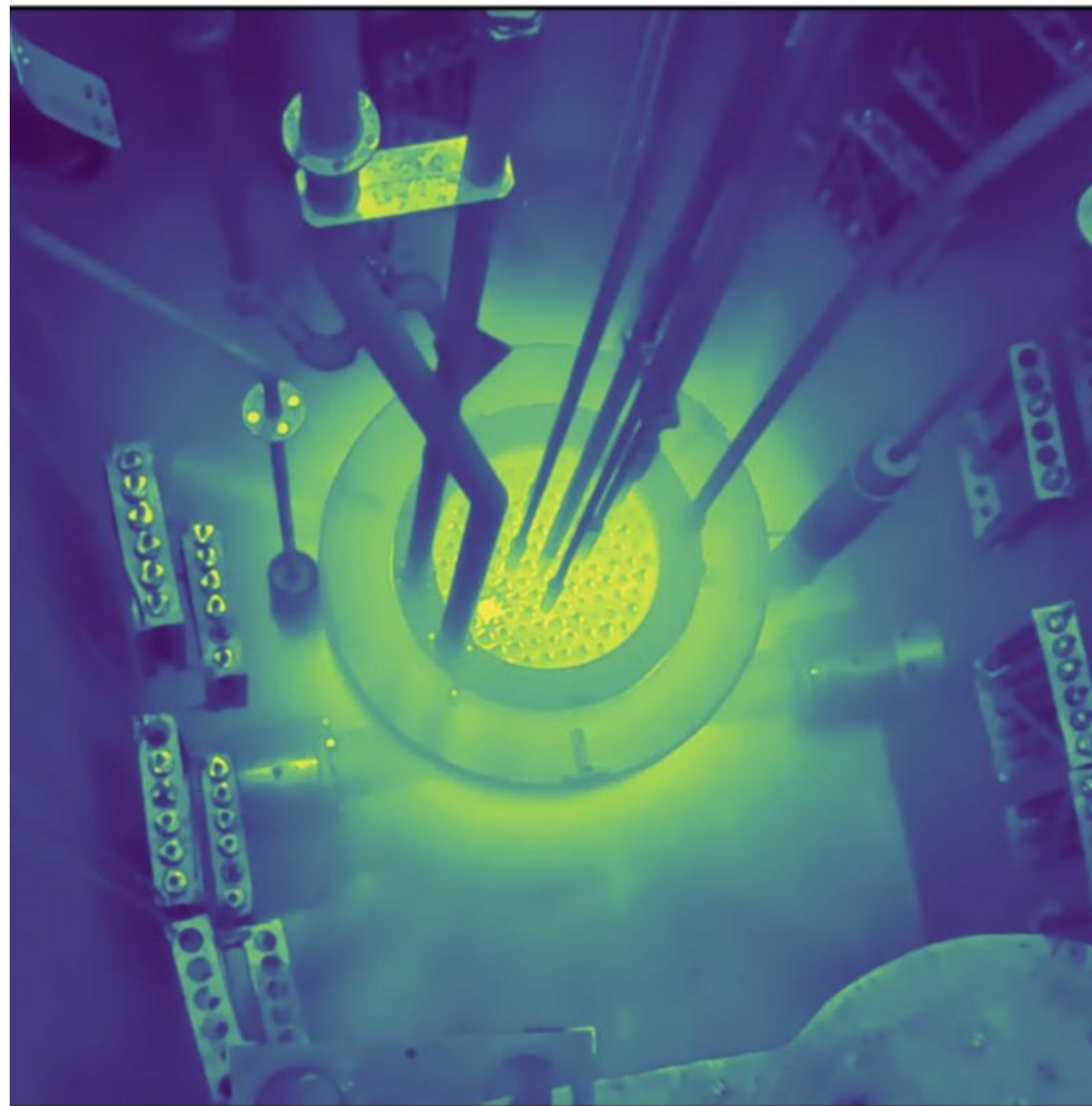
Cherenkov Power Estimation

- Cherenkov light intensity provides an **independent estimate of reactor power**.
- After isolating the blue-light signal, we correlate image intensity with measured power.



Cherenkov Power Estimation

- Cherenkov imaging provides a viable complement to the existing power monitor.
- Initial testing reduced measurement noise by approximately **10 to 30 percent**.



Facility Insertion

- Samples inserted into core facilities alter the neutron-flux distribution.
- Reliable digital-twin models require accurate records of what was inserted, where, and when.
- **Computer vision** could identify insertions and assign them to the correct facility.
- This capability can connect directly with the **experiment manager**.

EXPERIMENT MANAGER

Managing Experiments and Irradiations

- NETL currently uses an Outlook calendar to request and approve reactor time.
- The calendar handles scheduling but provides **limited operational context** for operators and experimenters.



Experiment Manager

The experiment manager combines scheduling, experiment records, and live reactor data in one operational view.

LIVE

IRRADIATION ACTIVE

OPEN IRRADIATION IN PROGRESS →

[View Calendar](#)

[Detector counting](#)

[My Ops Requests](#)

[Search Runs](#)

[Settings](#)

MY EXPERIMENTS

7 experiments

Search by ops #, run #, title, facility, status...

OPS #	RUN #	TITLE	FACILITY / POWER	STATUS	UPDATED
2026-07	5437	Yb/Lu activation – follow-up	RSR · 100 kW	Scheduled	Jul 11
2026-07	5401	Yb/Lu activation	RSR · 100 kW	Active	Jul 10
2026-02	5421	Na-24 production trial	tPnT · 450 kW	Complete	Jul 9
2026-06	5414	Au foil NAA calibration	CT · 450 kW	Complete	Jul 8
2026-04	5408	Lu-177 production trial	3El-Cd · 100 kW	Complete	Jun 22
2026-03	5403	Yb-174 enrichment sample set	RSR · 50 kW	Complete	May 30
2025-18	5288	Thermal flux map – RSR	RSR · 100 kW	Complete	Dec 14

[View Calendar](#)[Detector counting](#)[My Ops Requests](#)[Search Runs](#)[Settings](#)

MY EXPERIMENTS

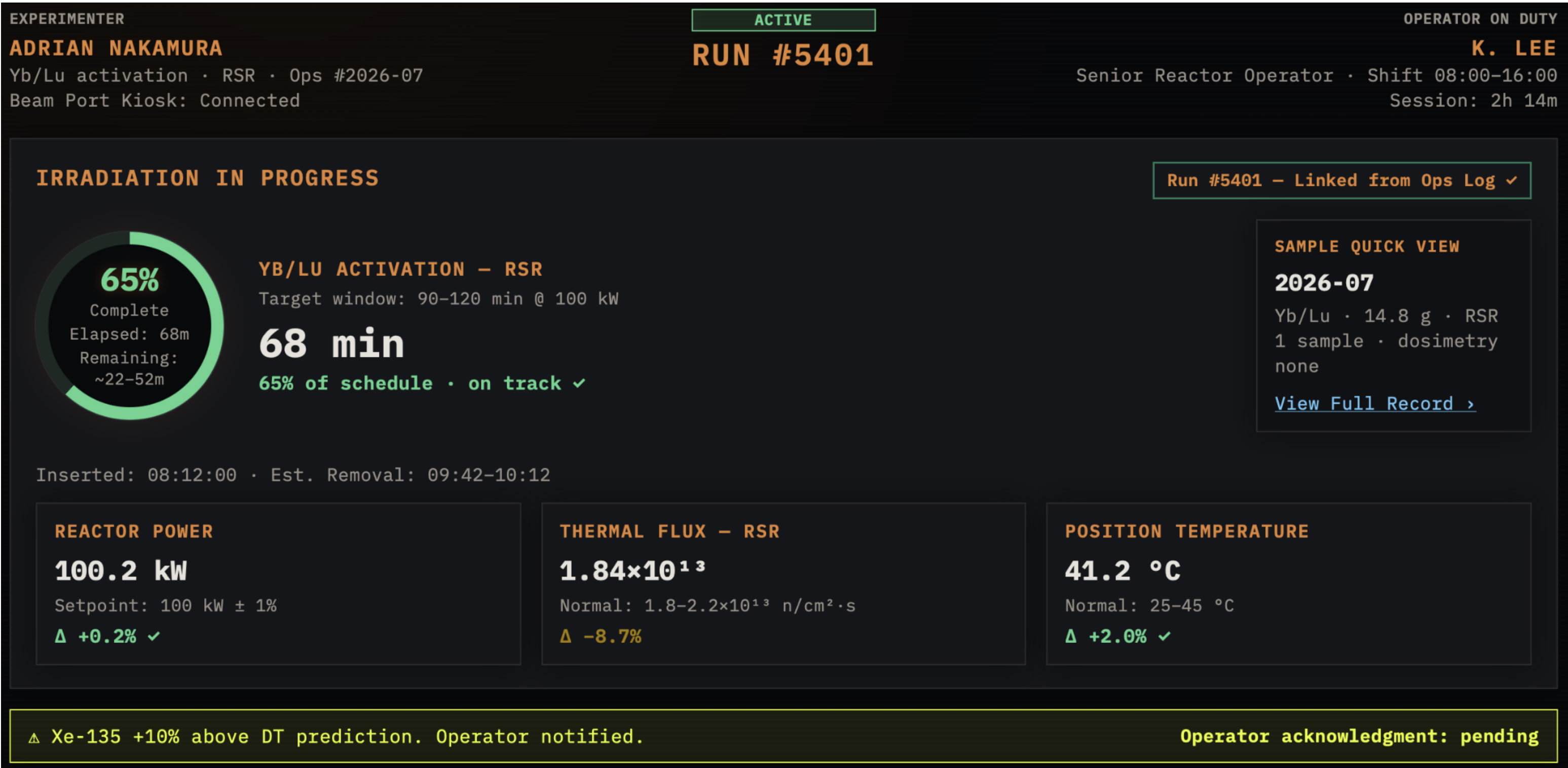
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2025-18	5288	Thermal flux map – RSR	RSR · 100 kW	Complete	Dec 14

Live Irradiation Overview

- The experiment manager connects scheduling, planning, and reactor-use records in one workflow.
- Operators and experimenters can monitor the active sample's progress in real time.



IRRADIATION IN PROGRESS

Run #5401 – Linked from Ops Log ✓

65%

Complete

Elapsed: 68m

Remaining: ~22-52m

YB/LU ACTIVATION – RSR

Target window: 90-120 min @ 100 kW

68 min

65% of schedule · on track ✓

SAMPLE QUICK VIEW

2026-07

Yb/Lu · 14.8 g · RSR

1 sample · dosimetry

none

[View Full Record >](#)

Inserted: 08:12:00 · Est. Removal: 09:42-10:12

REACTOR POWER

100.2 kW

Setpoint: 100 kW ± 1%

Δ +0.2% ✓

THERMAL FLUX – RSR

1.84×10¹³

Normal: 1.8-2.2×10¹³ n/cm²·s

Δ -8.7%

POSITION TEMPERATURE

41.2 °C

Normal: 25-45 °C

Δ +2.0% ✓

⚠ Xe-135 +10% above DT prediction. Operator notified.

Operator acknowledgment: pending

IRRADIATION IN PROGRESS



YB/LU ACTIVATION — RSR

Target window: 90–120 min @ 100 kW

68 min

65% of schedule · on track ✓

Run #5401 — Linked from Ops Log ✓

SAMPLE QUICK VIEW

2026-07

Yb/Lu · 14.8 g · RSR

1 sample · dosimetry none

[View Full Record >](#)

Inserted: 08:12:00 · Est. Removal: 09:42–10:12

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Normal: 1.8–2.2×10¹³ n/cm²·s

Δ -8.7%

POSITION TEMPERATURE

41.2 °C

Normal: 25–45 °C

Δ +2.0% ✓

Experiment Manager

Reactor data, camera tags, and digital-twin flux calculations could provide a more reliable estimate of each sample’s irradiation progress.

That visibility is especially valuable for time-sensitive **medical-isotope production**.

ISOTOPE ORDER INTAKE

M. Okafor · Production

Customer orders arrive against a catalogue. Activity is specified *at delivery*, not at end of irradiation – the decay between the two is what the schedule has to solve for.

ORDER ORD-2291

Customer	Cerlum Labs · radiopharmacy
Product	Lu-177 n.c.a.
Activity at delivery	3.70 GBq
Delivery window	2026-09-14, 06:00–09:00
Route	Courier, 4 h transit
Recurrence	Weekly, standing

Delivery activity is the contracted quantity. End-of-irradiation activity is derived, not entered.

DERIVED IRRADIATION TARGET

Target isotope	Lu-177 (T½ 6.647 d)
Precursor	Lu-176 enriched disk, 22 mg
Decay allowance	2.52 d cooling + 4 h transit
Required at EOI	4.90 GBq
Facility	CT · central thimble
Est. irradiation	5.5 h @ 950 kW

EOI

delivery

OPEN ORDER BOOK

ORDER	CUSTOMER	PRODUCT	AT DELIVERY	NEEDED BY	STATE
ORD-2291	Cerlum Labs	Lu-177 n.c.a.	3.70 GBq	09-14 06:00	SCHEDULING
ORD-2288	Regional Nuclear Med	I-131 capsule	1.11 GBq	09-12 08:00	SCHEDULED
ORD-2284	Cerlum Labs	Lu-177 n.c.a.	3.70 GBq	09-07 06:00	DELIVERED ✓
ORD-2279	St. Brendan Isotopes	Sm-153	0.74 GBq	09-05 10:00	CLOSED

Schedule ORD-2291

Decline

Customer orders arrive against a catalogue. Activity is specified *at delivery*, not at end of irradiation – the decay between the two is what the schedule has to solve for.

ORDER ORD-2291

Customer

Cerlum Labs · radiopharmacy

Product

Lu-177 n.c.a.

Activity at delivery

3.70 GBq

Delivery window

2026-09-14, 06:00–09:00

Route

Courier, 4 h transit

Recurrence

Weekly, standing

Delivery activity is the contracted quantity. End-of-irradiation activity is derived, not entered.

DERIVED IRRADIATION TARGET

Target isotope

Lu-177 (T½ 6.647 d)

Precursor

Lu-176 enriched disk, 22 mg

Decay allowance

2.52 d cooling + 4 h transit

Required at EOI

4.90 GBq

Facility

CT · central thimble

Est. irradiation

5.5 h @ 950 kW

EOI

delivery

OPEN ORDER BOOK					
ORDER	CUSTOMER	PRODUCT	AT DELIVERY	NEEDED BY	STATE
ORD-2291	Cerlum Labs	Lu-177 n.c.a.	3.70 GBq	09-14 06:00	SCHEDULING
ORD-2288	Regional Nuclear Med	I-131 capsule	1.11 GBq	09-12 08:00	SCHEDULED
ORD-2284	Cerlum Labs	Lu-177 n.c.a.	3.70 GBq	09-07 06:00	DELIVERED ✓
ORD-2279	St. Brendan Isotopes	Sm-153	0.74 GBq	09-05 10:00	CLOSED

Schedule ORD-2291

Decline

Current Status and Measured Outcomes

Application	Purpose	Status	Next Milestone
Automatic Calibration	Optimize control rod calibration for speed and accuracy	Implemented	Produce uncertainty quantification
Digital Logbook	Digitize operation logbook for easier access, storage, usability	In progress	Add requested features from reactor operators
Camera System	Provide live feed of reactor pool for power estimation, facility data, etc.	In progress	Approve permanent installation
Experiment Manager	Standalone app for all experimental facility usage	Beta testing	Parallel running test with current system

Conclusion

- Automated rod calibration **reduces manual effort** and avoids known sources of measurement error.
- Digital logbooks make operating records **searchable and simplify reporting**.
- In-pool imaging adds an independent data source for **power estimation and facility tracking**.
- The experiment manager connects planning with **live reactor and sample information**.



QUESTIONS