Energy use of ALAMO/ALTO floats that ran out of battery

Alex Ekholm

9 November 2026

Summary

- **92 of 252 floats that stopped reporting died of battery depletion**, judged by a collapse of the pump battery voltage at the end of their record, usually over the last 14–24 % of their dives.
- **The energy model accounts for 55–100 % of the nominal pack energy in every group but two.** The RBR ALTO 11150 used 99 % of its 6.7 MJ, the Micro-ALTOs 97 % and the 15.4 V SBE ALTOs 89 %; the ALAMOs 55–73 % of their 1.1–2.5 MJ; the ALTOs on VOP11 boards 63–67 % (about 80 % with the board's diode loss). No float is clearly above nominal (highest: 9301, 101 %).
- **On long missions the controller drain is the largest use**: 66–68 % of an SBE ALTO's lifetime energy. A Bluetooth power fault on boards built before mid-2022 adds about 15 mW to the 20 mW baseline.
- **A new ALTO with the fixed board should last about 5 years (185 cycles) with an SBE CTD and 6 years (220 cycles) with an RBR CTD** on a 10-day, 2000 dbar Argo mission, against 3.6 years with the faulty board.
- **A long-lived float profiled about 200 km** (sum of profile depths): 2000 dbar ALTOs in about 120 deep profiles, ALAMOs in about 500 shallow ones. ALAMOs get about twice as far per MJ as ALTOs, which are twice their size. On long missions the controller, not the pumps, sets the reach; a new fixed-board ALTO should profile about 370 km with an SBE CTD and 440 km with an RBR CTD.
- **Anomaly:** ten ALAMOs deployed 2020-09-17/18 died after 0.45 MJ, 18 % of their packs. That points at those packs, not the model.
- **The cycles a float has left can be estimated only roughly.** With 68 % of nominal taken as usable the estimate is unbiased for normal floats and about three quarters end inside its range, but only about half within ±30 %. A falling pump voltage warned of the end a median 60 dives ahead, anomalies included.

1 Method

The floats are ALAMOs [1, 2] and the larger ALTOs, both built by MRV Systems.

Depletion. A float counts as depleted when it has not reported for over 60 days, made at least 10 dives, and on its last dive its highest oil-pump battery voltage (measured under load) was below 80 % of its median over dives 1–10. Most depleted floats show the shape of a lithium pack: flat, then a decline over the last 14–24 % of the dives (median 17 %; Figure 1). Three (10111, 11015, 9174) dropped within one or two dives. 9095 and 9115 died within three weeks at 2–7 % of their packs, more like failures than depletion.

Deployment and field resets. The deployment date is the float's first dive. Fourteen depleted floats were restarted in the field, which sends a new startup message mid-mission; for four of them (9113, 9223, 9226, 9245) the restart also reset the dive counter, and the energy model, which ordered dives by number, missed their drain before the reset (fixed 2026-11-06; 9113 gains 81 days and 0.25 MJ).

Energy model. Per dive: the oil pump from its measured voltage, current and time, with the battery's internal-resistance loss; the air pump; the CTD (SBE 41CP 0.264 J a 1 Hz scan [3] and 0.66 J a spot sample [4]; RBR argo^3 24 mJ a sample [5]); Iridium (0.95 W over the session) [6] and GPS (0.096 W over the time to fix) [7]; WIMS (0.0456 W for 590 s a dive with wave data) [8]; and on the Micro-ALTOs the MAPLe (0.3 W over each ascent). Over time: a controller drain of 20 mW, plus 15 mW for a board with the Bluetooth fault (also in storage before deployment), and self-discharge (1 % a year lithium, 3 % alkaline) [9–11].

Packs. The startup built-in test (BIT) reports the no-load battery voltage, which identifies the pack better than the metadata (Figure 2):

- **Tadiran**, 15.0–15.6 V (ALAMO from 9213, ALTO from 11040): ALTO four TLP-83121/D packs, 32 TL-6930 D cells, 6.7 MJ [12, 13]; ALAMO three TLP-82121/D packs, 24 TL-6920 C cells, 2.5 MJ [12, 14].
- **Saft** LS 26500, about 14.2 V (ALAMO 9080–9210): 24 cells, 2.4 MJ [9].
- **Alkaline Procell**, 10–13 V: 32 D cells in an ALTO (2.6 MJ), 24 C cells in an ALAMO (1.1 MJ) [11, 15].
- **Tadiran on a VOP11 board**, 12.4 V under load and 13.0–13.5 V at startup (ALTO 11020–11034, the 2017–2018 SBE ALTOs, ALAMO 9179, 9181, 9207). The VOP11 controller's power input passes through a diode and the float measures the battery after it [16]; the drop costs about 20 % of the energy as heat.

Floats whose voltage gave the wrong pack, or that would have used more than their pack holds, are overridden in the model. A few floats show a repack between startups (9166, 9178, 9216, 11017; 11072–11076 and 11343 in the float-issues list [17]).

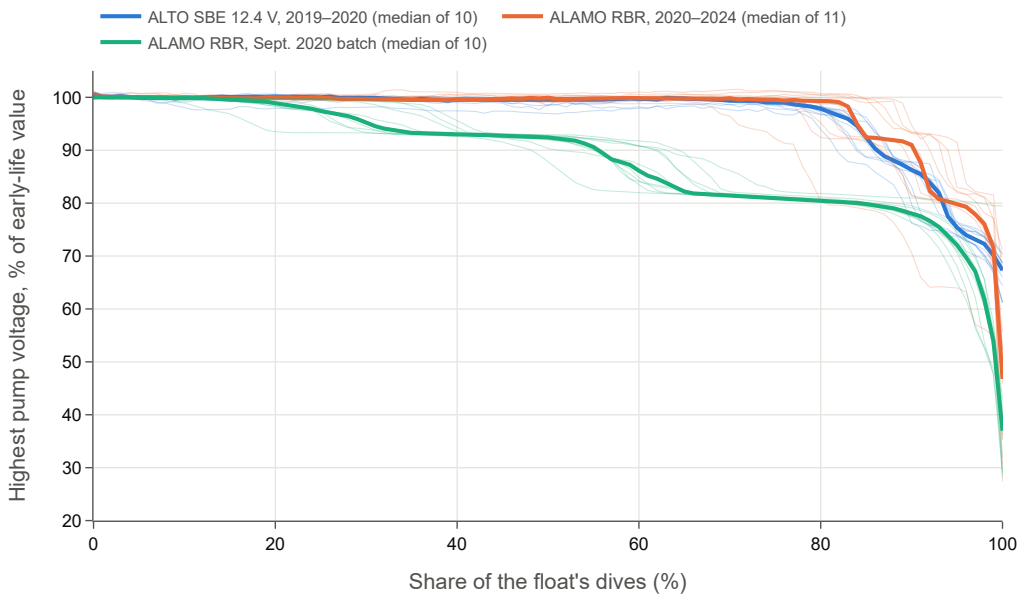


Figure 1: Highest pump voltage per dive, as a share of the early-life value, against the share of the float's dives completed. Thin lines are single floats, thick lines group medians.

2 Lifetime energy by group

The floats are grouped by type, pack and deployment batch (Table 1; years are first-dive years). Eight depleted floats fit no group (9095, 9115, 9119, 9132, 9239, 9288, 11143, 11146) and are only in the per-float table.

Table 1: Battery groups. Startup voltage from the BIT before the first dive.

Group	Floats	Pack in the model	Startup voltage
ALTO SBE, VOP11, 2017–2018	10110–10113, 10115, 10116, 11013, 11015	Tadiran	12.8–13.4 V
ALTO SBE 12.4 V, VOP11, 2018–2021	11020–11024, 11026, 11027, 11029–11031, 11034	Tadiran	13.2–13.5 V
ALTO SBE 15.4 V, 2019–2021	11044, 11046, 11048, 11049, 11055, 11058	Tadiran	15.3–15.6 V
ALTO RBR, 2022	11150	Tadiran	15.5 V
ALTO SBE, fixed board, short-cycle, 2022	11340, 11342	Tadiran	15.6 V
Micro-ALTO, 2023	11491, 11495	Tadiran	15.6 V
ALAMO, 2015–2016	9010, 9033, 9039, 9045, 9046, 9054, 9062, 9064, 9069, 9078	Saft	13.7–14.4 V
ALAMO Saft, 2017–2018	9103, 9107, 9109, 9152	Saft	13.7–14.3 V
ALAMO alkaline, 2018–2021	9165, 9167, 9174, 9223, 9226, 9276	alkaline	10.3–12.9 V
ALAMO Tadiran, VOP11, 2018–2019	9179, 9181, 9207	Tadiran	12.6–12.8 V
ALAMO redeployed, 2019–2022	9097, 9101, 9105, 9112–9114	Saft or Tadiran	14.1–15.2 V
ALAMO RBR, 2020–2024	9245, 9280, 9282, 9283, 9290, 9300, 9301, 9322–9324, 9327	Tadiran	14.9–15.5 V
ALAMO RBR, Sept. 2020 batch	9246, 9248, 9249, 9265–9267, 9269–9271, 9273	Tadiran	14.9–15.1 V
ALAMO RBR with WIMS, 2024–2025	9292, 9296, 9302, 9309	Tadiran	15.1–15.3 V

- **The estimate closes on the pack energy.** Groups with one mission and pack agree closely (spread 4 % for the 15.4 V ALTOs), and most end at 55–100 % of nominal, as packs that lose capacity at pump currents and in the cold should. The agreement is partly built in, because the drain was estimated from these floats (Section 4).
- **Long missions spend most on the controller** (Figure 3): 66–68 % on the SBE ALTOs and 62 % on the RBR ALTO 11150, then the oil pump (12–15 %) and CTD (12–13 %).

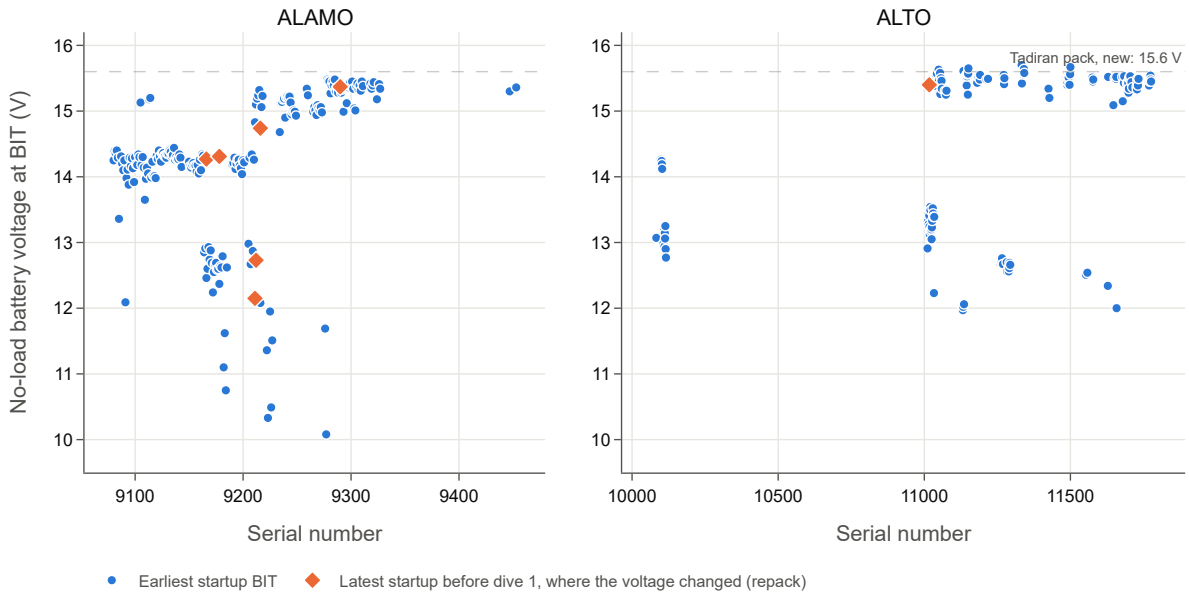


Figure 2: No-load battery voltage at the earliest startup BIT, by serial number (374 floats). Diamonds mark a later startup before dive 1 whose voltage differs by more than 0.7 V (a repack).

- **Short cycles spend most on the oil pump**: 68 % on the Micro-ALTOs (plus 6 % on the MAPLe), 57 % on the short-cycle SBE ALTOs and 42–52 % on the RBR and Saft ALAMOs, with Iridium at 7–18 %.
- **WIMS costs little**: the 27 depleted ALAMOs that ran it spent a median 1.3 % of their energy on it (at most 2.1 %).
- **Some groups end low**: alkaline ALAMOs 56 % (21–93 %), Tadiran ALAMOs on VOP11 boards 58 %, and redeployed ALAMOs 38 %, whose packs had already aged or been used.

3 Vertical profiling distance

The accumulated vertical profiling distance is each float's sum of the maximum pressure of every profile. The depleted floats profiled 15,900 km in all: 7,100 km by the ALTOs and 8,800 km by the ALAMOs. The 35 that lived more than a year profiled a median 205 km (middle half 193–235 km), as Jayne et al. [2] give for an ALAMO, but the spread across groups is wide (Table 3, Figure 5).

What sets the distance. Distance is the number of profiles times their depth, and the two trade against each other. The 2000 dbar SBE ALTOs made 106–136 profiles of 2 km each; the ALAMOs 450–530 profiles of 0.3–0.5 km. Both reached about 200 km. How fast they got there differs tenfold: about 75 km a year for the SBE ALTOs on 10-day cycles, 400–1,150 km a year for ALAMOs and Micro-ALTOs cycling every few hours to days.

What a km costs.

Table 2: Estimated lifetime energy by group. Per-dive terms: pumps, CTD, Iridium, GPS, WIMS and MAPLe; the full estimate adds the controller drain and self-discharge.

Group	Floats	Lifetime (d)	Pack (nominal)	Per-dive terms	Full estimate, mean (range)	Share of nominal
ALTO SBE, VOP11, 2017–2018	8	616–1,085	Tadiran, 6.7 MJ	1.27 MJ	4.22 MJ (3.10–5.06)	63 % (46–76)
ALTO SBE 12.4 V, VOP11, 2018–2021	11	690–1,074	Tadiran, 6.7 MJ	1.22 MJ	4.50 MJ (3.40–4.73)	67 % (51–71)
ALTO SBE 15.4 V, 2019–2021	6	1,273–1,385	Tadiran, 6.7 MJ	1.66 MJ	5.94 MJ (5.60–6.28)	89 % (84–94)
ALTO RBR, 2022	1	1,360	Tadiran, 6.7 MJ	2.12 MJ	6.64 MJ	99 %
ALTO SBE, fixed board, short-cycle, 2022	2	741–1,065	Tadiran, 6.7 MJ	3.26 MJ	4.99 MJ (4.16–5.82)	74 % (62–87)
Micro-ALTO, 2023	2	97–107	Tadiran, 6.7 MJ	6.26 MJ	6.51 MJ (6.48–6.55)	97 % (97–98)
ALAMO, 2015–2016	10	169–554	Saft, 2.4 MJ	0.94 MJ	1.73 MJ (1.46–2.27)	72 % (61–95)
ALAMO Saft, 2017–2018	4	51–123	Saft, 2.4 MJ	1.33 MJ	1.55 MJ (1.13–1.74)	65 % (47–73)
ALAMO alkaline, 2018–2021	6	23–237	alkaline, 1.1 MJ	0.19 MJ	0.62 MJ (0.23–1.03)	56 % (21–93)
ALAMO Tadiran, VOP11, 2018–2019	3	89–396	Tadiran, 2.5 MJ	0.56 MJ	1.47 MJ (1.42–1.54)	58 % (56–61)
ALAMO redeployed, 2019–2022	6	14–223	Saft or Tadiran, 2.4–2.5 MJ	0.72 MJ	0.94 MJ (0.49–1.78)	38 % (20–70)
ALAMO RBR, 2020–2024	11	72–445	Tadiran, 2.5 MJ	1.31 MJ	1.85 MJ (1.45–2.54)	73 % (58–101)
ALAMO RBR, Sept. 2020 batch	10	17–36	Tadiran, 2.5 MJ	0.36 MJ	0.45 MJ (0.37–0.53)	18 % (15–21)
ALAMO RBR with WIMS, 2024–2025	4	79–377	Tadiran, 2.5 MJ	0.93 MJ	1.38 MJ (0.41–1.79)	55 % (16–71)

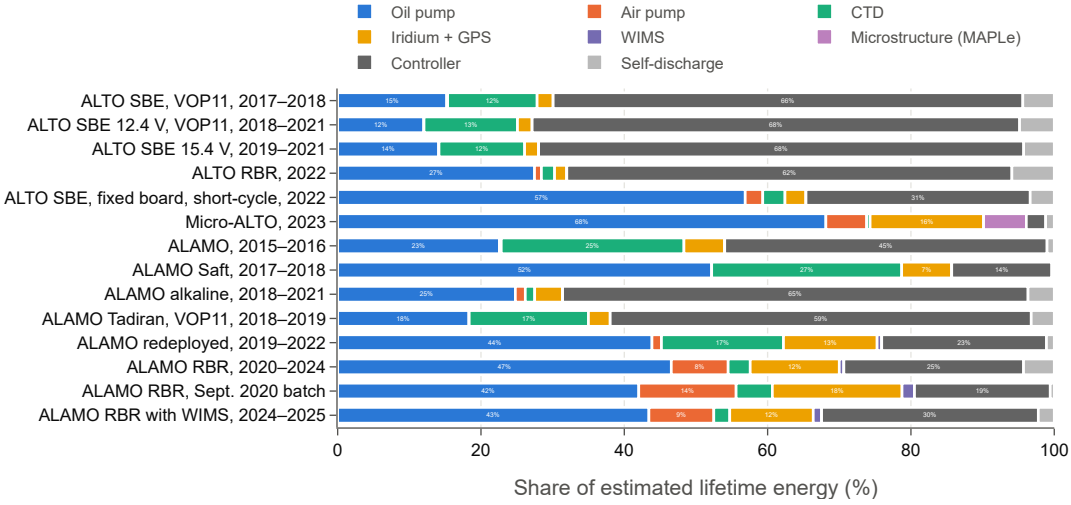


Figure 3: Share of the estimated lifetime energy by component, per group. Oil pump includes battery internal-resistance loss.

- **Deep profiles are cheaper per km for the pumps.** Each cycle costs a roughly fixed amount of pumping to rise from the park depth and to fill the air bladder at the surface, whatever the profile depth. The 2000 dbar ALTOs spend 2.5–3.7 kJ of pumping a km; the ALTOs profiling to 180–290 dbar 16–18 kJ; the ALAMOs, half the size, 1.8–5.4 kJ.
- **On long missions the controller sets the reach.** An SBE ALTO spends about 15 kJ a km on the controller, about 70 % of its 21–22 kJ a km in all; its pumps, CTD and communications cost only about 6 kJ. On fast cycles the controller costs about 1 kJ a km. The RBR ALTO 11150 profiled 511 km to 2000 dbar, twice an SBE ALTO, because without the SBE pump its CTD is cheap and it made 260 profiles in 3.7 years.
- **ALAMOs get about twice as far per MJ** (70–92 km against 30–40 km for the SBE ALTOs). An ALTO is about twice the size, so the same buoyancy change pumps about twice the oil; ALAMOs also profile shallower (250–480 dbar) and cycle faster, leaving less time for the drain. The furthest, 9280, 9324, 9322 and 9054, profiled 460–570 km to about 1,000 dbar.
- **The groups that died early profiled least**: the alkaline ALAMOs a median 7 km on



Figure 4: Estimated lifetime energy as a share of the pack's nominal energy, against lifetime.

Table 3: Accumulated vertical profiling distance by group (medians). Pumps and controller: energy a km of profile, in kJ.

Group	Floats	Profile depth	Profiles	Distance (range)	Per year	Pumps	Controller	Full estimate a km	Per MJ of pack
ALTO SBE, VOP11, 2017–2018	8	2,000 dbar	114	198 km (119–240)	75 km	2.5	14.6	21 kJ	30 km
ALTO SBE 12.4 V, VOP11, 2018–2021	11	2,000 dbar	106	205 km (197–213)	73 km	2.6	15.1	22 kJ	31 km
ALTO SBE 15.4 V, 2019–2021	6	2,000 dbar	136	264 km (159–282)	74 km	3.1	14.9	22 kJ	39 km
ALTO RBR, 2022	1	2,000 dbar	260	511 km	137 km	3.7	8.1	13 kJ	76 km
ALTO SBE, fixed board, short-cycle, 2022	2	180 dbar	991	220 km (148–292)	97 km	15.8	8.4	27 kJ	33 km
Micro-ALTO, 2023	2	290 dbar	908	265 km (229–302)	946 km	18.4	0.7	25 kJ	40 km
ALAMO, 2015–2016	10	480 dbar	463	221 km (172–462)	401 km	1.8	2.8	8 kJ	92 km
ALAMO Saft, 2017–2018	4	310 dbar	524	168 km (11–181)	1,155 km	5.4	1.0	10 kJ	70 km
ALAMO alkaline, 2018–2021	6	70 dbar	82	7 km (1–62)	25 km	24.6	69.4	106 kJ	6 km
ALAMO Tadiran, VOP11, 2018–2019	3	480 dbar	99	50 km (47–139)	49 km	4.2	22.6	28 kJ	20 km
ALAMO redeployed, 2019–2022	6	280 dbar	188	64 km (4–171)	678 km	6.0	1.0	11 kJ	26 km
ALAMO RBR, 2020–2024	11	310 dbar	529	202 km (57–566)	564 km	4.4	1.1	11 kJ	80 km
ALAMO RBR, Sept. 2020 batch	10	250 dbar	322	82 km (61–100)	1,145 km	2.9	1.0	5 kJ	33 km
ALAMO RBR with WIMS, 2024–2025	4	270 dbar	452	125 km (46–234)	212 km	4.8	3.0	10 kJ	50 km

short, shallow profiles, the September 2020 batch 82 km.

- **Distance alone predicts energy poorly** (28 % of the variance across ALAMOs, 57 % across ALTOs): park depth, drift sampling and the number of surfacings matter as much.

Expected distance of a new ALTO. At 2 km a profile, the lifetimes of Section 8 give about 370 km (270–440 km) for a new SBE ALTO and 440 km (310–550 km) for an RBR ALTO with the fixed board. With the faulty board an SBE ALTO would make 132 profiles, 264 km, the same as the median of the faulty 15.4 V ALTOs (264 km).

4 Controller drain

The Bluetooth fault. MRV found at the end of 2021 [18] that the VOP11 and early VOP12 boards left the Bluetooth module powered, whatever its setting. In January 2023 MRV reported

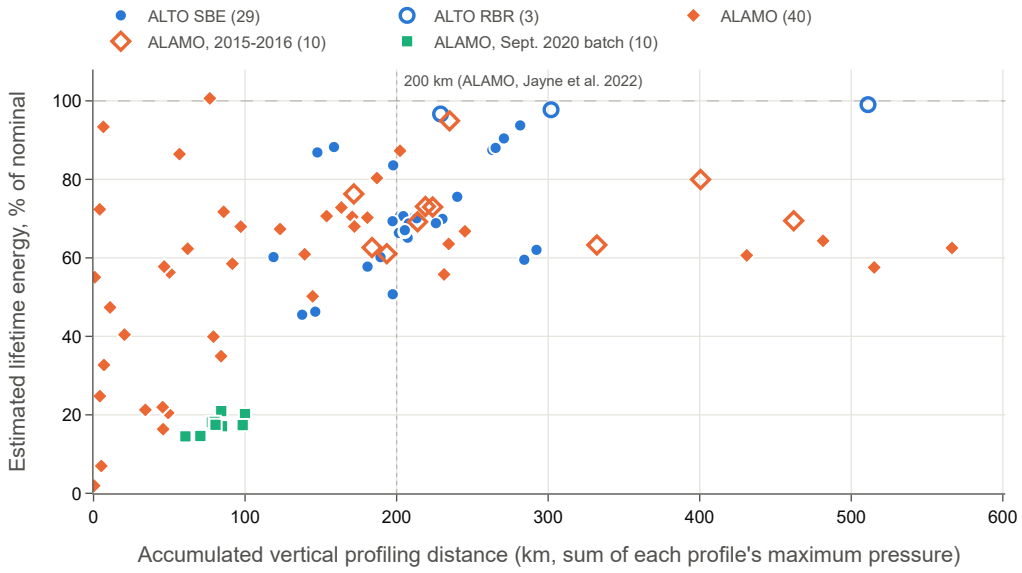


Figure 5: Accumulated vertical profiling distance against the estimated lifetime energy as a share of nominal, for the 92 depleted floats. The dotted line marks the 200 km Jayne et al. [2] give for an ALAMO.

that affected ALTOs draw about 2 mA in sleep with periodic 15 mA spikes, about 30 mW at 15 V, and the fault drains the pack in storage too: 9300 and 9301 shipped together in August 2021, and 9301, deployed 14 months later, made 304 profiles against 9300's 688. Floats shipped from August 2022 have the fixed board; several were sent back for new boards and batteries in 2022–2023. The model takes a board as faulty when the float's first message is before July 2022 and its first dive before 2024, unless it was refitted.

Estimate. A depleted float has used its pack's usable energy U, so the drain is (U − per-dive terms − self-discharge) / lifetime. The Micro-ALTOs 11491 and 11495 lived about 100 days, too short for the drain to matter, and drew 6.4 MJ (95 % of nominal) with the MAPLe at 0.3 W, or 5.9 MJ (88 %) without it. Taking that as U for the long-lived ALTOs:

Table 4: Controller drain implied by $U = 6.4$ MJ, long-lived ALTOs (over 600 days). VOP11 floats corrected for a 20 % diode loss.

Group	Floats	Lifetime	Drain, median (range)
ALTO SBE, VOP11, 2017–2018	8	616–1,085 d	46 mW (36–67)
ALTO SBE 12.4 V, VOP11, 2018–2021	11	690–1,074 d	41 mW (39–64)
ALTO SBE 15.4 V, 2019–2021	6	1,273–1,385 d	39 mW (36–41)
ALTO RBR, 2022	1	1,360 d	33 mW
11340, fixed board	1	741 d	54 mW
11342, fixed board	1	1,065 d	26 mW

The faulty boards give 39–46 mW (35–42 mW with $U = 5.9$ MJ); 11342, the one long-lived ALTO with a fixed board, 26 mW (21 mW); so the fault adds 13–14 mW whatever U. 11340, also fixed, died at 62 % of nominal on a shallow short-cycle mission, more like a failure. The ALAMOs live

1–15 months, so the drain is a small part of their use and cannot be pinned down from them. The model uses 20 mW plus 15 mW for the fault, set against $U = 5.9$ MJ, the low end of the estimate; it keeps every depleted float within its nominal pack energy. Over a year 35 mW is about 1.1 MJ, a sixth of an ALTO's packs; self-discharge (under 1 % a year for the lithium cells, about 2 mW for an ALTO) does not explain it.

5 Anomalies

The September 2020 ALAMO batch. Ten RBR floats deployed on 2020-09-17/18 (firmware 0x08000101) died after 0.37–0.53 MJ. Their voltage was already down to about 13.8 V halfway through and fell over 69 % of the dives instead of the usual 17 % (Figure 1). 9245, deployed a month earlier with the same firmware, used 1.69 MJ, and the WIMS the batch ran costs only about 2 %. The cause is in the packs (a smaller pack, a weak cell lot or passivation); build records would settle it.

Micro-ALTOs. 11491–11496 are RBR ALTOs with a Rockland Scientific MAPLe turbulence system (shear and FP07 probes), powered from the float's pack while it logs during the ascent; four were deployed in the NORSE campaign on 2023-11-09, on cycles of about 2.5 hours (Table 5). No document gives the MAPLe's power. 11491 and 11495 ran out after a modeled 6.1 MJ without it, so with packs of 6.7–7.2 MJ it drew at most 0.5–0.8 W while logging; the model takes 0.3 W, 0.35–0.43 MJ per float. Their pump records (0.27 A at 14.9 V for about 1,200 s a dive) are measured, not modeled.

Table 5: The Micro-ALTOs. Modeled energy includes the MAPLe at 0.3 W.

Float	Dives	Reporting	Profiled	Per dive	Total
11491	850	2023-11-09 to 2024-02-14	229 km	7.6 kJ (pump 5.2, MAPLe 0.4)	6.48 MJ (97 %)
11495	966	2023-11-09 to 2024-02-24	302 km	6.8 kJ (pump 4.6, MAPLe 0.4)	6.55 MJ (98 %)
11492	332	2023-11-09 to 2023-12-14	101 km	6.5 kJ	2.15 MJ
11494	136	2023-11-09 to 2023-11-24	41 km	6.9 kJ	0.94 MJ

6 Accuracy

The spread within a group bounds the random error: 2.5–4 % for groups with one mission and pack, 15–30 % for mixed missions. The main systematic uncertainty is the controller drain: ±30 % moves an SBE ALTO's total by about 20 %, an ALAMO's by under 8 %. Regulator losses for the modem and GPS are not counted and may add a few percent.

7 Predicting the cycles left

The float pages estimate after every dive how many cycles a float has left on its current mission: (usable energy − energy used so far) / energy of a cycle, with the cycle's energy the median of the last 10 dives and a range from the usable share of the pack and ±30 % on the controller drain. To see how well that works, the estimate was recomputed after every dive of the 92 depleted floats and compared with the dives each actually made afterwards (Table 7).

Table 6: Accuracy of the energy terms.

Term	Share	Basis	Check	Likely error
Oil pump	12–68 %	Measured voltage × current × time	Groups with one mission agree to a few %	A few %
Internal resistance, other loads	–	Not counted (oil pump only, 0–3 %)	–	Under 1–2 %
Air pump	0–14 %	Current × run time × pump voltage	None	About 10 %
CTD, SBE 41CP	12–27 %	22 mA at 12 V; 2.5 s pump time a spot sample	[3, 4]	5–10 % (20 % spot)
CTD, RBR argo^3	up to 5 %	24 mJ a sample	[5]	About 10 %
Iridium	2–18 %	0.95 W over the session	Up to 1.0 W [6]	About 20 %
GPS, WIMS	under 2 %	Datasheet and manual powers	[7, 8]	Small
MAPLe	6 % (Micro-ALTOs)	0.3 W over each ascent	At most 0.5–0.8 W	About ±50 %
Controller	3–68 %	20 mW, 35 mW with the fault	Depleted floats; 2 mA with the fault [18]	About ±30 %
Self-discharge	0–5 %	1 % a year lithium, 3 % alkaline	[9–11]	Small

Table 7: Remaining-cycles estimate against the cycles the depleted floats actually had left: median of predicted / actual, and the share of floats whose actual count fell inside the estimate's range. "Normal" leaves out the September 2020 batch, the redeployed ALAMOs and the ungrouped floats (68 floats).

Point in the float's life	Usable 65/80/95 %, all 92	Usable 50/68/95 %, all 92	Usable 50/68/95 %, normal
25 %	1.47, 47 %	1.21, 57 %	1.05, 71 %
50 %	1.57, 50 %	1.19, 65 %	1.02, 78 %
75 %	1.92, 48 %	1.23, 64 %	1.01, 79 %
90 %	3.31, 47 %	1.56, 68 %	0.93, 85 %

- **The first calibration over-predicted.** Taking 80 % of nominal as usable (range 65–95 %), the estimate gave 1.5–3.3 times the cycles the floats had left, more the closer they came to the end, because they died at a median of about 67 %. The float pages now take 68 % (range 50–95 %), which removes the bias for normal floats and puts about three quarters of them inside the range.
- **The count is uncertain even so.** Only 41–56 % of the normal floats' estimates fall within ±30 % of the actual count through mid-life, because floats die anywhere between about 50 and 99 % of nominal; late in life the estimate is mostly the gap between that share and what has been used. The range, not the central number, is the honest answer.
- **Anomalies cannot be predicted from energy.** The September 2020 batch, the redeployed packs and some alkaline packs died at 18–40 % of nominal, and the estimate over-predicts them several times over.
- **A falling pump voltage is the better warning.** Flagging a float when the dive's highest pump voltage stays below 95 % of its median over dives 1–10 for 3 dives caught 90 of the 92 depleted floats, a median 60 dives (16 % of their dives) before the end, the anomalies included. Using the flag to shorten the count did not make it more accurate for normal floats (it under-predicted late in life), so the float pages keep the energy estimate and mark the flag on the plot. Of the 28 floats reporting in November 2026, 3 were flagged.

8 Expected lifetime of a new ALTO on an Argo mission

Table 8: Expected lifetime of a new ALTO (four TLP-83121/D packs, fixed controller board) on a 10-day cycle, parking at 1000 dbar and profiling from 2000 dbar.

	ALTO SBE	ALTO RBR
Oil and air pump, per cycle	6.5 kJ	6.5 kJ
CTD, per cycle	5.7 kJ	0.5 kJ
Iridium and GPS, per cycle	0.8 kJ	0.8 kJ
Controller, 20 mW over 9.9 days	17.1 kJ	17.1 kJ
Self-discharge, 1 % a year of 6.7 MJ	1.8 kJ	1.8 kJ
Total per cycle	**31.9 kJ**	**26.7 kJ**
Expected lifetime (5.9 MJ usable)	**185 cycles, 5.0 years**	**220 cycles, 6.0 years**
Range	135–220 cycles, 3.7–6.0 years	155–275 cycles, 4.3–7.4 years

The per-dive loads are the medians of the five 2000 dbar SBE ALTOs 11044–11055 (13.0 kJ a dive); the RBR column replaces the SBE 41CP's 0.264 J a scan with RBR's 24 mJ a sample. The range covers the drain ±30 % and a usable energy of 75–88 % of nominal; with $U = 6.4$ MJ and the matching 26 mW the result is nearly the same (172 and 200 cycles). With a faulty board's 35 mW an SBE ALTO makes 132 cycles (3.6 years), as the faulty 15.4 V ALTOs did (131–144). The controller is still over half of each cycle's energy, so a shorter cycle gives more profiles.

References

[1] S. R. Jayne and N. M. Bogue, "Air-deployable profiling floats," *Oceanography*, vol. 30, no. 2, pp. 29–31, Jun. 2017, doi: 10.5670/oceanog.2017.214.

[2] S. R. Jayne, W. B. Owens, P. E. Robbins, A. K. Ekholm, N. M. Bogue, and E. R. Sanabia, "The Air-Launched Autonomous Micro Observer," *J. Atmos. Ocean. Technol.*, vol. 39, no. 4, pp. 491–502, Apr. 2022, doi: 10.1175/JTECH-D-21-0046.1.

[3] Sea-Bird Scientific, "SBE 41/41CP CTD module," datasheet and hardware reference, Bellevue, WA, USA.

[4] K. I. Martini, D. J. Murphy, R. W. Schmitt, and N. G. Larson, "Corrections for pumped SBE 41CP CTDs determined from stratified tank experiments," *J. Atmos. Ocean. Technol.*, vol. 36, no. 4, pp. 733–744, Apr. 2019, doi: 10.1175/JTECH-D-18-0050.1.

[5] RBR Ltd., "RBR*argo*^{3}," product datasheet, Ottawa, ON, Canada.

[6] Iridium Communications Inc., *Iridium 9602 SBD Transceiver Product Developers Guide*, rev. 5.

[7] u-blox AG, "NEO-M8 u-blox M8 concurrent GNSS modules," datasheet UBX-13003366, Thalwil, Switzerland.

[8] *WIMS User Manual*, rev. 3.22.

[9] Saft, "LS 26500 primary lithium-thionyl chloride cell," datasheet.

[10] Tadiran Batteries, "HLC-1550A hybrid layer capacitor," datasheet.

[11] Duracell, "Procell PC1300 (D) and PC1400 (C) alkaline cells," datasheets.

[12] Tadiran Batteries, TLP-83121/D and TLP-82121/D battery packs: pack drawing (rev. C, 2016), UN 38.3 test summaries 15Q-990 and 15Q-996, and transport certificate, WHOI lab records.

[13] Argo, "Report from the 2nd Float and CTD Technical Workshop," Univ. of Washington, Seattle, WA, USA, Sep. 2017. [Online]. Available: `https://argo.ucsd.edu/wp-content/uploads/sites/361/2022/05/Report_floattechnicalworshop_2017.pdf`

[14] MRV Systems, private communication (email), Apr. 23, 2024.

[15] MRV Systems, private communication (email), Sep. 2020.

[16] MRV Systems, private communication (emails), Jul. and Nov. 2018.

[17] WHOI, "Float issues list," internal spreadsheets, Apr. 2023 and Jan. 2024.

[18] WHOI and MRV Systems, private communication (emails), Jan.–May 2023.

9 Per-float data

The 92 depleted floats. Deployed is the first dive; V start is the median highest pump voltage on dives 1–10, V end the highest on the last dive; Pack is the chemistry the model uses; MJ is the full estimate.

Float	CTD	Deployed	Last	Days	Dives	V start	V end	Pack	MJ	% nom.	Group
9010		2016-06-09	2017-03-13	277	376	13.74	8.06	Saft	1.83	76	ALAMO, 2015–2016
9033		2015-06-30	2017-01-04	554	893	13.77	2.85	Saft	2.27	95	ALAMO, 2015–2016
9039		2015-08-02	2016-06-01	304	648	13.73	10.46	Saft	1.52	63	ALAMO, 2015–2016
9045		2015-07-26	2016-03-04	222	474	13.77	9.55	Saft	1.75	73	ALAMO, 2015–2016
9046		2015-07-25	2016-05-02	282	421	13.68	9.32	Saft	1.92	80	ALAMO, 2015–2016
9054		2015-10-02	2016-04-20	201	336	13.76	10.23	Saft	1.66	69	ALAMO, 2015–2016
9062		2016-09-02	2017-02-24	175	405	13.25	8.54	Saft	1.50	63	ALAMO, 2015–2016
9064		2016-10-06	2017-03-24	169	454	13.71	10.82	Saft	1.46	61	ALAMO, 2015–2016
9069		2016-08-31	2017-03-17	198	477	13.84	10.38	Saft	1.75	73	ALAMO, 2015–2016
9078		2016-08-31	2017-03-12	193	479	13.74	9.02	Saft	1.66	69	ALAMO, 2015–2016
9095		2016-08-19	2016-09-05	17	92	11.86	2.66	Saft	0.17	7	
9097	SBE	2022-09-18	2022-10-12	24	195	12.87	2.71	Saft	0.49	20	ALAMO redeployed, 2019–2022
9101	SBE	2022-09-20	2022-10-04	14	190	12.34	9.83	Saft	0.53	22	ALAMO redeployed, 2019–2022
9103		2017-03-04	2017-04-24	51	512	13.55	10.54	Saft	1.74	73	ALAMO Saft, 2017–2018
9105	SBE	2020-10-04	2020-12-02	59	834	14.53	4.44	Tadiran	1.78	70	ALAMO redeployed, 2019–2022
9107		2017-03-04	2017-04-26	53	536	13.66	10.47	Saft	1.63	68	ALAMO Saft, 2017–2018
9109		2017-03-05	2017-05-02	58	573	13.57	10.56	Saft	1.68	70	ALAMO Saft, 2017–2018
9112	SBE	2022-11-04	2023-03-22	138	510	12.86	2.45	Saft	0.59	25	ALAMO redeployed, 2019–2022
9113	SBE	2019-10-27	2020-06-06	223	238	14.91	6.64	Tadiran	1.01	40	ALAMO redeployed, 2019–2022
9114	SBE	2022-11-04	2023-01-30	87	515	14.54	5.35	Tadiran	1.27	50	ALAMO redeployed, 2019–2022
9115		2016-06-07	2016-06-14	7	21	10.67	2.51	Saft	0.05	2	
9119	RBR	2017-09-12	2017-12-08	87	600	13.55	9.80	Saft	0.97	40	
9132	RBR	2018-09-11	2018-11-03	53	759	13.71	10.75	Saft	1.34	56	
9152	SBE	2018-06-17	2018-10-18	123	336	13.20	9.80	Saft	1.13	47	ALAMO Saft, 2017–2018
9165	SBE	2018-10-19	2019-04-29	192	67	11.46	5.34	alkaline	0.80	72	ALAMO alkaline, 2018–2021
9167	SBE	2018-10-19	2019-06-13	237	73	11.31	6.58	alkaline	1.03	93	ALAMO alkaline, 2018–2021
9174	SBE	2018-11-26	2019-05-10	165	15	11.52	6.55	alkaline	0.61	55	ALAMO alkaline, 2018–2021
9179	SBE	2019-09-24	2020-10-01	373	100	11.43	8.47	Tadiran	1.42	56	ALAMO Tadiran, VOP11, 2018–2019
9181	SBE	2019-09-10	2020-10-10	396	101	11.39	8.27	Tadiran	1.46	58	ALAMO Tadiran, VOP11, 2018–2019
9207	SBE	2018-11-22	2019-02-19	89	322	11.87	6.57	Tadiran	1.54	61	ALAMO Tadiran, VOP11, 2018–2019
9223	RBR	2021-08-18	2021-12-12	116	214	11.22	4.51	alkaline	0.69	62	ALAMO alkaline, 2018–2021
9226	RBR	2021-09-27	2021-10-20	23	98	10.14	4.76	alkaline	0.23	21	ALAMO alkaline, 2018–2021
9239	RBR	2020-07-29	2021-03-27	241	363	15.00	7.40	Tadiran	1.48	59	
9245	RBR	2020-08-14	2020-10-25	72	1184	14.97	5.40	Tadiran	1.69	67	ALAMO RBR, 2020–2024
9246	RBR	2020-09-18	2020-10-14	26	328	14.92	4.32	Tadiran	0.53	21	ALAMO RBR, Sept. 2020 batch
9248	RBR	2020-09-18	2020-10-05	17	233	14.88	11.83	Tadiran	0.37	15	ALAMO RBR, Sept. 2020 batch
9249	RBR	2020-09-18	2020-10-11	23	303	14.83	4.17	Tadiran	0.46	18	ALAMO RBR, Sept. 2020 batch
9265	RBR	2020-09-18	2020-10-13	25	280	14.89	5.76	Tadiran	0.37	15	ALAMO RBR, Sept. 2020 batch
9266	RBR	2020-09-18	2020-10-11	23	314	14.97	5.28	Tadiran	0.46	18	ALAMO RBR, Sept. 2020 batch
9267	RBR	2020-09-18	2020-10-22	34	338	14.95	4.79	Tadiran	0.43	17	ALAMO RBR, Sept. 2020 batch
9269	RBR	2020-09-18	2020-10-24	36	395	15.01	4.42	Tadiran	0.51	20	ALAMO RBR, Sept. 2020 batch
9270	RBR	2020-09-18	2020-10-14	26	317	14.95	6.42	Tadiran	0.44	17	ALAMO RBR, Sept. 2020 batch
9271	RBR	2020-09-18	2020-10-24	36	398	14.93	6.16	Tadiran	0.51	20	ALAMO RBR, Sept. 2020 batch
9273	RBR	2020-09-18	2020-10-19	31	391	14.91	6.04	Tadiran	0.44	17	ALAMO RBR, Sept. 2020 batch
9276	RBR	2020-09-26	2020-11-29	64	155	10.95	5.80	alkaline	0.36	33	ALAMO alkaline, 2018–2021
9280	RBR	2024-03-15	2024-12-19	279	590	15.03	4.12	Tadiran	1.58	63	ALAMO RBR, 2020–2024
9282	RBR	2021-08-27	2021-11-21	86	969	14.84	6.94	Tadiran	1.81	72	ALAMO RBR, 2020–2024
9283	RBR	2021-08-27	2022-02-01	158	806	14.96	7.80	Tadiran	2.18	86	ALAMO RBR, 2020–2024
9288	RBR	2021-08-27	2021-12-08	103	279	14.80	9.00	Tadiran	0.88	35	
9290	RBR	2021-08-27	2022-02-28	185	639	14.96	10.02	Tadiran	1.70	67	ALAMO RBR, 2020–2024
9292	RBR	2024-09-26	2025-09-03	342	1168	14.82	9.06	Tadiran	1.79	71	ALAMO RBR with WIMS, 2024–2025
9296	RBR	2024-09-26	2025-10-08	377	751	14.63	8.45	Tadiran	1.61	64	ALAMO RBR with WIMS, 2024–2025
9300	RBR	2021-08-05	2022-10-24	445	688	15.05	5.33	Tadiran	2.21	87	ALAMO RBR, 2020–2024
9301	RBR	2022-09-27	2023-04-01	186	304	14.94	10.62	Tadiran	2.54	101	ALAMO RBR, 2020–2024
9302	RBR	2025-08-30	2026-02-14	168	299	14.35	8.89	Tadiran	1.72	68	ALAMO RBR with WIMS, 2024–2025
9309	RBR	2025-08-19	2025-11-06	79	184	14.80	8.23	Tadiran	0.41	16	ALAMO RBR with WIMS, 2024–2025
9322	RBR	2022-11-17	2023-04-30	164	506	15.03	7.87	Tadiran	1.63	64	ALAMO RBR, 2020–2024
9323	RBR	2022-11-05	2023-04-20	166	525	14.99	8.35	Tadiran	1.53	61	ALAMO RBR, 2020–2024

Float	CTD	Deployed	Last	Days	Dives	V start	V end	Pack	MJ	% nom.	Group
9324	RBR	2024-03-20	2024-11-25	250	529	14.94	6.85	Tadiran	1.45	58	ALAMO RBR, 2020–2024
9327	RBR	2023-09-10	2024-01-09	121	567	14.84	4.54	Tadiran	2.03	80	ALAMO RBR, 2020–2024
10110	SBE	2018-05-17	2021-03-25	1043	134	12.52	8.61	Tadiran	4.68	70	ALTO SBE, VOP11, 2017–2018
10111	SBE	2017-09-11	2019-09-02	721	82	11.36	8.42	Tadiran	3.10	46	ALTO SBE, VOP11, 2017–2018
10112	SBE	2017-09-11	2020-02-22	894	98	12.07	7.42	Tadiran	3.87	58	ALTO SBE, VOP11, 2017–2018
10113	SBE	2017-10-24	2020-04-17	906	103	12.07	8.30	Tadiran	4.03	60	ALTO SBE, VOP11, 2017–2018
10115	SBE	2017-10-23	2020-09-02	1045	126	11.23	7.78	Tadiran	4.61	69	ALTO SBE, VOP11, 2017–2018
10116	SBE	2017-10-24	2020-08-03	1014	115	11.16	7.64	Tadiran	4.36	65	ALTO SBE, VOP11, 2017–2018
11013	SBE	2018-05-31	2021-05-20	1085	141	12.87	8.54	Tadiran	5.06	76	ALTO SBE, VOP11, 2017–2018
11015	SBE	2018-09-06	2020-05-14	616	469	11.73	7.11	Tadiran	4.03	60	ALTO SBE, VOP11, 2017–2018
11020	SBE	2019-03-08	2021-12-30	1028	106	12.43	8.73	Tadiran	4.57	68	ALTO SBE 12.4 V, VOP11, 2018–2021
11021	SBE	2019-04-16	2022-03-15	1064	110	12.41	7.99	Tadiran	4.71	70	ALTO SBE 12.4 V, VOP11, 2018–2021
11022	SBE	2019-03-12	2021-12-10	1004	103	12.32	8.68	Tadiran	4.45	66	ALTO SBE 12.4 V, VOP11, 2018–2021
11023	SBE	2019-03-20	2022-01-06	1023	105	12.28	8.43	Tadiran	4.46	67	ALTO SBE 12.4 V, VOP11, 2018–2021
11024	SBE	2020-02-23	2023-01-18	1060	109	12.40	7.58	Tadiran	4.73	71	ALTO SBE 12.4 V, VOP11, 2018–2021
11026		2020-04-01	2023-03-11	1074	111	12.39	7.58	Tadiran	4.73	71	ALTO SBE 12.4 V, VOP11, 2018–2021
11027	SBE	2020-02-24	2022-12-07	1017	106	12.41	8.52	Tadiran	4.61	69	ALTO SBE 12.4 V, VOP11, 2018–2021
11029	SBE	2019-04-15	2022-03-03	1053	108	12.32	8.13	Tadiran	4.70	70	ALTO SBE 12.4 V, VOP11, 2018–2021
11030	SBE	2018-11-20	2021-09-26	1041	106	12.38	8.51	Tadiran	4.49	67	ALTO SBE 12.4 V, VOP11, 2018–2021
11031	SBE	2021-12-27	2023-11-17	690	101	12.30	8.81	Tadiran	3.40	51	ALTO SBE 12.4 V, VOP11, 2018–2021
11034	SBE	2020-02-25	2023-01-28	1068	111	12.39	7.60	Tadiran	4.65	69	ALTO SBE 12.4 V, VOP11, 2018–2021
11044	SBE	2021-12-17	2025-07-13	1304	133	15.28	10.51	Tadiran	5.86	87	ALTO SBE 15.4 V, 2019–2021
11046	SBE	2019-08-26	2023-06-11	1385	142	15.46	8.65	Tadiran	6.28	94	ALTO SBE 15.4 V, 2019–2021
11048	SBE	2019-08-29	2023-02-22	1273	131	15.43	10.54	Tadiran	5.91	88	ALTO SBE 15.4 V, 2019–2021
11049	SBE	2019-12-28	2023-07-25	1305	134	15.41	11.14	Tadiran	5.90	88	ALTO SBE 15.4 V, 2019–2021
11055	SBE	2020-02-28	2023-10-13	1323	137	15.29	8.53	Tadiran	6.06	90	ALTO SBE 15.4 V, 2019–2021
11058	SBE	2019-11-18	2023-08-25	1376	144	15.35	8.32	Tadiran	5.60	84	ALTO SBE 15.4 V, 2019–2021
11143	SBE	2021-08-11	2024-02-17	920	155	15.36	12.00	Tadiran	3.99	60	
11146	SBE	2021-08-20	2022-10-17	423	1310	15.11	4.32	Tadiran	3.05	46	
11150	RBR	2022-04-08	2025-12-28	1360	262	15.29	7.85	Tadiran	6.64	99	ALTO RBR, 2022
11340	SBE	2022-08-25	2024-09-04	741	879	15.21	9.45	Tadiran	4.16	62	ALTO SBE, fixed board, short-cycle, 2022
11342	SBE	2022-08-30	2025-07-30	1065	1381	15.25	4.31	Tadiran	5.82	87	ALTO SBE, fixed board, short-cycle, 2022
11491	RBR	2023-11-09	2024-02-14	97	850	14.75	9.05	Tadiran	6.48	97	Micro-ALTO, 2023
11495	RBR	2023-11-09	2024-02-24	107	966	14.77	7.98	Tadiran	6.55	98	Micro-ALTO, 2023