Southeast Coast Network

National Park Service
Inventory and Monitoring Division

Standard Operating Procedure 1.4.24

Inventory, Maintenance, and Testing of ARD Batteries—Version 1.0

Please cite this as:

Parrish, M. C. 2019. Inventory, maintenance, and testing of ARD batteries—Version 1.0. Southeast Coast Network Standard Operating Procedure NPS/SECN/SOP—1.4.24. Southeast Coast Network, Athens, Georgia.

Summary

This standard operating procedure (SOP) outlines battery inventory, maintenance, and testing practices that promote battery health and identify failing batteries. This applies to D-cell nickel-metal hydride (NiMH) rechargeable batteries used to power automatic recording devices (ARDs) deployed for audio sampling under the avian and vocal anuran vital signs monitoring protocols.

Revision Log

Revision Date	Author	Changes Made	Reason for Change	New Version #

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Overview

Batteries for ARD Main Power

Audio sampling under landbird (Byrne et al. 2014) and vocal anuran (Byrne et al. 2013) vital signs monitoring protocols (henceforth, “the project”) is carried out in the field using various models of automated recording devices (i.e., ARDs). Each ARD runs on four D-cell nickel-metal hydride (NiMH) rechargeable batteries. At present, the project inventory carries nearly 600 batteries, which represent both a significant financial investment (batteries cost $12 each in 2019) and a possible failure point for field sampling. If an ARD fails to record data due to a preventable battery failure, time and money are wasted and the lost data are not recoverable. Consequently, it is mission-critical to ensure that the battery inventory is properly monitored and maintained to reduce battery failures in the field.

Three battery models are currently included in project inventory (Figure 1). Imedion cells are rated for 9,500 milliampere-hour (mAh) at 1.2 V. Powerex black-top cells are rated for 10,000 mAh at 1.2 V. Powerex red-top cells are rated for 11,000 mAh at 1.2V. All NiMH batteries lose charge while sitting on the shelf due to self-discharge. Low self-discharge models, such as the Imedion and Powerex black-tops are designed to limit self-discharge, and are advertised as retaining greater than 80% of charge after 1 year of storage. Powerex red-tops are not low self-discharge batteries and may lose substantial charge if not periodically recharged, eventually reaching an over-discharged state that results in total failure of the cell. Production of Imedion and Powerex red-top batteries have been discontinued by the manufacturer. Both battery types will be replaced by the low self-discharge Powerex black-top models at the earliest time possible.

In 2019, all rechargeable batteries in the project inventory were assessed by the wildlife biologist. More than 400 batteries failed to charge or failed subsequent testing and were condemned for recycling. The majority of failed batteries were red-top Powerex models, perhaps owing to either excessive self-discharge while in storage (the project was on hiatus from mid-2017 to 2019) or simply to excessive battery age. This example reinforces the importance of regularly testing, maintaining, and cycling the battery inventory for the project.

Figure 1. Three types of D-Cell NiMH batteries are currently used with ARDs: (left) Imedion by Powerex, 9,500 mAh at 1.2 V; (center) Powerex black-top, 10,000 mAh at 1.2V; (right) Powerex red-top, 11,000 mAh at 1.2V. The Powerex red-top batteries have been discontinued by the manufacturer and are being phased out of project usage.

Battery Failure Conditions

Based on discussions with Maha Energy (manufacturer of Powerex batteries) customer service and engineers familiar with NiMH batteries, the following values were arrived at in order to characterize battery failure (Table 1). If a battery meets one of the criteria, it should be condemned and recycled. The worst case event for a battery, in terms of the project, is a battery failure in the field leading to data loss. Hence, the failure determining criteria are slightly conservative relative to non-mission-critical battery usage.

Table 1. Criteria used to classify a battery as failed. Failed cells will be condemned and recycled.

Failure condition	Indication
Over-discharge	Voltage < 0.5 V at any time
Under-voltage	Voltage < 1.1 V fresh off a recharge cycle
Excessive internal resistance	Internal resistance > 100 mΩ
Discharge capacity excessively low	Discharge capacity < [85% of rated battery capacity or 9,050 mAh, whichever is greater]
Charge capacity excessively low	Charge capacity < [85% of rated battery capacity or 9,050 mAh, whichever is greater]
Battery excessively old	Battery age > 5 years

ARD Power Requirements

During a 78-day (1,872 hour) bird/anuran sampling deployment, an ARD periodically alternates its power allocation between sleep mode and recording mode (Table 2). ARD energy consumption in milliwatts (mW) is reported in the user manuals. The battery electric charge (mAh) required to run an ARD for 1 hour is equal to 1000 times the energy consumption in watt-hours (Wh) divided by the supplied voltage (V):

1000 (Wh/V) = mAh

Note that recording times below have an additional 30 second duration added to each recording interval in order to account for the startup energy draw occurring as the ARD comes out of sleep mode.

Table 2. ARD operating mode time allocation during a standard 78 day deployment.

Activity	Calculation of Time Allocated	Minimum time allocated (hours)
Recording Anurans	(20 days × 13 hours per day × 6 minutes of sampling) / 60 minutes	26
Recording Birds	(38 days × 12.5 minutes of sampling) / 60 minutes	8 (rounded)
Sleep	(78 days × 24 hours per day) - 26 hours anuran recording - 8 hours avian recording	1,838

Based on SM4 maximum power draw calculations (Table 3), the minimum power requirement (i.e., discharge capacity) for this deployment schedule is: 5,243 mAh (recording) + 2,757 mAh (sleeping) = **8,000 mAh total.** This estimate of the power requirement assumes the sampling period begins at the same time as deployment and does not account for battery inefficiency due to cold weather.

Table 3. ARD power draw based on operation mode, assuming 1.2V power input.

ARD Model	Operation Mode	Estimated Power Consumption (mW)	Calculated Power Draw at 1.2V (mAh)
SM4	Sleep	1.8	1.5
	Recording	135–185	112.5–154.2
SM3	Sleep	0.5	0.4
	Recording	250–500	208.3–416.7
SM2+	Sleep	< 1	< 1
	Recording	60–200	50–166.7
SM2	Sleep	< 1	< 1
	Recording	55–120	45.8–100
SM1	Sleep	< 1	< 1
	Recording	130–160	108.3–133.3

Power Requirements for Pre-survey Sleep Intervals

In some circumstances, it may be desirable to place the ARD in the field a few weeks (or more) before the survey period is scheduled to initiate. For example, a location may be easier to access earlier in the year before rain makes the area too wet. Pre-survey sleep intervals have relatively low power demands compared to recording mode, but nevertheless, the power needs for several weeks of sleep mode are non-trivial.

A 14-day sleep period before survey initiation (i.e., deploying the ARDs two weeks before the 78 day sampling cycle begins) requires an additional 504 mAh (**8,504 mAh total**). A 28-day wait period adds an additional 1,008 mAh (**9,008 mAh total**). A 56-day wait period adds an additional 2,016 mAh (**10,016 mAh total**), while an 84-day wait period adds 3,024 mAh (**11,024 mAh total**).

Consider a deployment cycle including a four-week pre-survey sleep interval, requiring that four batteries provide 9,008 mAh at a cumulative 4.8 V. Four 10,000 mAh D-cell NiMH batteries in series will provide 10,000 mAh at 4.8V, *nominally*, although actual power output may be lower due to battery aging and ambient temperature (colder temperatures reduce power output and cause batteries to drain more quickly). Older batteries may not provide sufficient mAh to sustain the ARD through the full deployment period. Information from battery testing, specifically discharge capacity measures, should clearly be incorporated into planning deployment timing.

If a longer pre-survey sleep interval is desired than can be accommodated by available rechargeable NiMH cells, another option would be to use alkaline single-use cells, which provide greater power (up to 16,500 mAh). SM4 ARDs also allow for external power sources to be applied. However, this is outside the scope of this SOP.

Clock Batteries for ARDs

In addition to the D-cell batteries used as the main power supply, each ARD requires a secondary power source to power its onboard clock. SM4, SM3, and SM1 models use one 3.0 V lithium CR2032 coin cell battery. The SM2+ and SM2 models use two AA alkaline battery cells.

CR2032 coin cells are expected to provide a three-year life cycle in an ARD. AA alkaline batteries are expected to provide a two- to three-year life cycle. However, both CR2032 and AA batteries should be removed at the completion of each field deployment before the ARD is stored, and new batteries should be replaced before deployment.

Procedures

Acquisition and Inventory Tracking

To provide power to 125 ARD units, a minimum of 500 batteries are required. A 15% failure margin allows for removal of batteries that may be condemned after testing. Thus, the project goal is to maintain at least 575 batteries in inventory. Because NiMH battery reliability suffers after five years, a five-year rolling replacement cycle will be implemented starting in 2020. Each year, 116 new batteries will be purchased and the oldest 116 batteries (greater than five years old) will be retired from service. (In 2019, more batteries may need to be purchased to replace failed batteries discovered during initial testing.)

Each new battery will be assigned a unique number that is written with a sharpie pen on the positive terminal end of the battery, above the terminal button (Figure 2). The Battery ID represents the means of tracking each battery in the database as it is maintained, tested, and deployed.

Figure 2. Batteries in inventory are uniquely numbered on the positive terminal, above the terminal button. The 74 batteries on this tray represent a purchase cost of $1,000 (in 2019) and weigh 10.75 kilograms (23.7 pounds).

A Microsoft Access database has been developed in order to manage the battery inventory (Table 4). The database is currently located at:

\\INPSECNS01\SECNshare\NEW DIRECTORY STRUCTURE\Monitoring\Landbirds\Operations\Equipment\ Batteries\Batteries.accdb

Table 4. Overview of battery inventory database fields. FK = foreign key.

Table	Field	Comments
ActiveStatus	ID	Primary key.
	BatteryID (FK)	Unique battery identifier.
	ActiveStatus	Indicates if battery is available for deployment.
	Notes	User notes.
ChargingEvents	ID	Primary key.
	BatteryID (FK)	Unique battery identifier.
	ChargeDate	Date the battery underwent a charge.
	Notes	User notes.
Deployment	ID	Primary key.
	BatteryID (FK)	Unique battery identifier.
	Deployment	Year the battery was deployed.
	ARD	ARD unit number battery was deployed within.
	ParkID	NPS 4-letter park code.
	Notes	User notes.
Inventory	ID	Primary key.
	BatteryID (FK)	Unique battery identifier.
	BatteryType (FK)	Make and model of battery.
	PurchDate	Date battery was purchased.
	Notes	User notes.
Specs	ID	Primary key.
	BatteryType (FK)	Make and model of battery.
	V_Spec	Specified voltage of battery type.
	mAH_Spec	Specified maH rating of battery type.
	CellSize	Battery cell size.
	SelfDischarge	Is battery a low self-discharge model (notes).
TestResults	ID	Primary key.
	BatteryID (FK)	Unique battery identifier.
	TestDate	Date battery was tested.
	Voltage_V	Tested voltage.
	IntResistance_mOhm	Tested internal resistance.
	ChargeCapacity_mAh	Tested charge capacity.
	DischargeCapacity_mAh	Tested discharge capacity.
	RoomTemp_C	Room temperature during testing.
	Notes	User notes.

Standard Recharging Cycle

Recharging is carried out on the Maha MH-C808M charger. The MH-C808M is an eight-bank charger and can charge D-cells at 2.0 Ampere (A) on fast mode (time required: 1 to 5 hours). Operating the charger is trivial, however the display screen may be the first indicator of a failing or failed cell.

Insert a battery to be recharged and consult the display. A battery icon should appear on the display in the appropriate bay location. Usually it will be blinking, indicating charging has begun. If no battery icon appears, the charger is not recognizing the battery, which usually indicates a battery has failed. Such batteries should be removed for further testing. Once charging is complete, the display will read 'DONE' for that bay and the battery may be removed. A simple data sheet (MP-01) is provided for noting the battery ID and charge date (Appendix A), but extensive data collection is unnecessary for this task.

Considerations:

- Each charger draws 1.2 A. Consider this when plugging multiple chargers into a power strip. Avoid tripping the room circuit.
- The open design of the charger is susceptible to allowing conductive items (e.g., paperclips) to fall into the charger. Basic care should be taken to disallow any foreign items from falling into the charger.

More detailed operation information on the MH-C808M is available in the operation manual (Maha Power Corp. 2006).

Battery Testing Overview

Testing will be performed with the XTAR Dragon VP4+ tester/charger. Each VP4+ can accommodate four D-cell batteries at a time. Voltage and internal resistance testing is a trivial procedure and takes perhaps 30 seconds per cell. However, capacity testing, while operationally simple, requires a much longer period of time. During capacity testing, the cell is completely charged, then nearly completely discharged, and then recharged again, a process taking 36 to 48 hours due to the large storage capacity of these batteries.

Thus, a group of ten or more VP4+ testers will be provided so that larger batches of batteries may be tested concurrently. With ten testers and approximately 575 batteries to test, a complete round of testing will take approximately one month. It is therefore important to remember to set up each new batch of batteries in the testers on schedule, so as not to get behind.

Data will be entered in database table *TestResults.* Measure voltage and resistance first, then start capacity testing. After capacity testing is completed (typically 2 days), record the results. To simplify data recording and entry, first record test results on data sheet MP-02 (Appendix A), and later enter them into the database.

Note on VP4+ Display

Figure 3. XTAR Dragon VP4+ battery charger display screen. Display button (center) and channel indicators (left and right) are indicated by yellow boxes.

Pressing the DISPLAY button (Figure 3, highlighted) switches between pairs of channels (only two channels are displayed at any one time). However, this function is non-intuitive. The screen will indicate that it is displaying *either* channels 1 and 4 (the two *outside* channels) or channels 2 and 3 (the two *inside* channels; Fig. 3). Pressing DISPLAY switches between those pairs. **Do not confuse which channels you are actually looking at!**

Testing Voltage and Internal Resistance

Voltage and internal resistance are the first characteristics of each cell to be tested (Figure 4). Use data sheet MP-02 (Appendix A) to record Battery ID number, voltage, and internal resistance.

Figure 4. A business card holder makes an excellent battery testing cradle in which to support the battery as the test leads are applied for voltage and internal resistance testing.

Perform this test procedure on freshly charged batteries (ideally within a week or two of charging on the Maha MH-C808M charger) and carry out the procedure at room temperature (about 21° C or 70° F).

Conduct voltage and resistance testing with the battery **outside** of the VP4+ housing (i.e. the battery is not inserted into the VP4+ for those tests.)

Turn on XTAR Dragon VP4+ tester and plug in USB test leads. Short the leads by touching them together, which activates testing mode.

1. For the technician's convenience, place the battery in a testing cradle (Figure 4) for measurements. Touch the test leads to battery terminals (Red to positive, black to negative).

2. Record Voltage (V) and internal resistance (mΩ, i.e., “milliohms”). Reported V and mΩ may fluctuate during measurement, so allow the tester to cycle through voltage and resistance three to five times, recording the lowest voltage and internal resistance that are displayed.

3. Note any problems with the batteries (e.g., damage to battery wrapper or a cell that is rejected by the tester) or testing procedure in the margin of the data sheet.

4. Once all batteries are tested, press middle button twice to turn off testing mode and return to charge mode.

5. Generally, once voltage and resistance are tested, the next step will be to perform capacity testing (next section).

Testing Charge and Discharge Capacity

Charge and discharge capacity are the next two characteristics of each cell to test (Figure 5). Continue using data sheet MP-02 from voltage/resistance testing (Appendix A), to record the capacity testing data for each battery cell.

Figure 5. A group of 40 D-cell batteries are mounted in ten XTAR Dragon VP4+ chargers to undergo capacity testing. A pair of test leads is placed in a testing cradle to the lower right.

Perform this test procedure on freshly charged batteries (ideally within a week or two of charging on the Maha MH-C808M charger) and carry out the test at room temperature (21° C or 70° F).

Note: Batteries must be in the VP4+ charger units during capacity testing.

Note: this procedure fully charges the cell, discharges it, and then recharges it. The procedure takes approximately 36 to 48 hours to complete!

1. Following voltage/resistance testing, place batteries into VP4+ charger. Long-press right button to turn on TEST mode. The word 'TEST' should appear in the lower right of the display and the status light on each channel will usually turn red.

2. The channel lights will eventually turn blue (during discharge) and red again (recharge). **When the testing is completed, all four LED indicators will turn green.**

3. Before removing the cells, review the completed charge and discharge measurements. Press DISPLAY to cycle through the channels as needed.

   Note: the tester does record the previous 30 tests which can be scanned through by pressing RECORD/TEST to cycle through them. Normally, after capacity testing is done, the most recent results will be displayed. If you accidentally press RECORD/TEST, you might change the display to an earlier set of results. If that happens, simply scan through the saved results until you find the most recent.

4. Make note of any problems with batteries or the testing process in the margin of data sheet. For example, a battery may be rejected by the testing unit almost immediately after the test cycle begins. A NiMH cell with an internal fault may even be interpreted by the tester as a lithium cell and a warning beep will be issued. Remove any such cells from the tester and note the error on the side of the data sheet.

5. Once data are recorded, remove batteries to a tray and enter the data sheet into the database as instructed by the wildlife biologist. The database's Battery Dashboard report will identify batteries that are in a failure state. Those batteries will be reclassified as 'RETIRED' and removed from service.

Testing Clock Batteries (AA and CR2032)

Replace lithium coin cell batteries (CR2032; 3V) in ARDs once per year. Coin cells may be stored in inventory (dry conditions at room temperature) for up to five years. Test new coin cell batteries for proper voltage using the XTAR Dragon VP4+ before installation into ARDs. The voltage testing procedure is identical to the one for testing voltage of NiMH batteries. If battery voltage is less than 2.7 V (i.e., less than 90% of nominal voltage) immediately discard the cell. Coin cell testing need not be documented.

AA-cell batteries (1.5 V) will be replaced in ARDs once per year. Alkaline batteries may be stored in inventory (dry conditions at room temperature) for up to five years. Test new AA batteries for proper voltage using the XTAR Dragon VP4+ before installation into ARDs. The voltage testing procedure

is identical to the one for testing voltage of NiMH batteries. If battery voltage is less than 1.45 V, immediately discard the cell. Alkaline battery cell testing need not be documented.

Battery Recyling and Disposal

NiMH and lithium batteries that are past their usable lifespan should be recycled or disposed of according to NPS guidelines. Both types of battery are typically considered a non-hazardous waste. NiMH, lithium, and alkaline batteries are currently accepted for recycling at the Center for Hard to Recycle Materials (CHaRM; https://www.athensclarkecounty.com/CHaRM), located in Athens, Georgia. At the present time, government entities are not charged to recycle at CHaRM. Contact CHaRM before dropping off batteries for recycling to check on their current policies.

Preferred Brands

The batteries listed in Table 5 represent current preferred brands and models of batteries as of 2019. Preferred brands and models are subject to future change.

Table 5. Preferred brands of batteries as of 2019.

Cell type and chemistry	Preferred brand and rating	Notes
D-cell, NiMH rechargeable	Powerex Precharged 10,000 mAh, 1.2 V	Only low self-discharge NiMH batteries should be utilized. Made in China. Operational life: 5 years.
D-cell Alkali-manganese[1]	Varta Long Life Power 16,500 mAh, 1.5 V	Single use. Made in Germany. Storage life: 5 years.
CR 2032, Lithium (LiMNO2)	Duracell Duralock DL 225mAh, 3V	Single use. Made in Japan. Storage life: 5 years.
AA cell Alkaline	Duracell Quantum 1.5 V	Single use. Made in USA. Storage life: 5 years.

[1] Varta alkaline cells have not yet been tested for project use; however, based on specifications, they appear to show promise for use in deployments with unusually long pre-sampling sleep periods.

Literature Cited

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Appendix A: Example Battery Data Sheets

The following figures are examples of battery testing data sheets that can be used in conjunction with this SOP. Data sheets may be obtained on the network drive:

\\INPSECNS01\SECNshare\NEW DIRECTORY STRUCTURE\Monitoring\Landbirds\Protocol-SOPs\Forms

Charging Date: _____ Technician: _____ **NiMH Battery Charging Log**

Battery ID	Battery ID	Battery ID	Battery ID

Updated: May 2019 Bird/Anuran Monitoring Project Datasheet MP-01

Figure A-1. Example of data sheet MP-01 (*NiMH Battery Charging Log*) used for recording charging events for nickel-metal hydride (NiMH) batteries.

Test Start Date: _____ Technician: _____ **NiMH Battery Testing Datasheet**

Battery ID	Voltage (V)	Internal Resistance (mΩ)	Charge Capacity (mAh)	Discharge Capacity (mAh)	Notes

Battery ID	Voltage (V)	Internal Resistance (mΩ)	Charge Capacity (mAh)	Discharge Capacity (mAh)	Notes

Updated: May 2019 Bird/Anuran Monitoring Project Datasheet MP-02

Figure A-2. Example of data sheet MP-02 (*NiMH Battery Testing Data Sheet*) used for recording voltage, resistance, and charge / discharge capacity on nickel-metal hydride (NiMH) batteries.