Safety & Usage Procedure for Lithium Polymer Batteries

Naval Postgraduate School
Version 1.4b; January 2016

Record of Review and Approval for Standing Operating Procedures

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Submitted: ____________ Date: 7JAN16
Developer

Reviewed: ____________ Date: 1/7/16
NPS Research Safety

Reviewed: ____________ Date: 8JAN16
NPS Aviation Officer

Reviewed: ____________ Date: 08Jan16
NPS OSHE

Approved: ____________ Date: 11JAN16
NPS Chief of Staff

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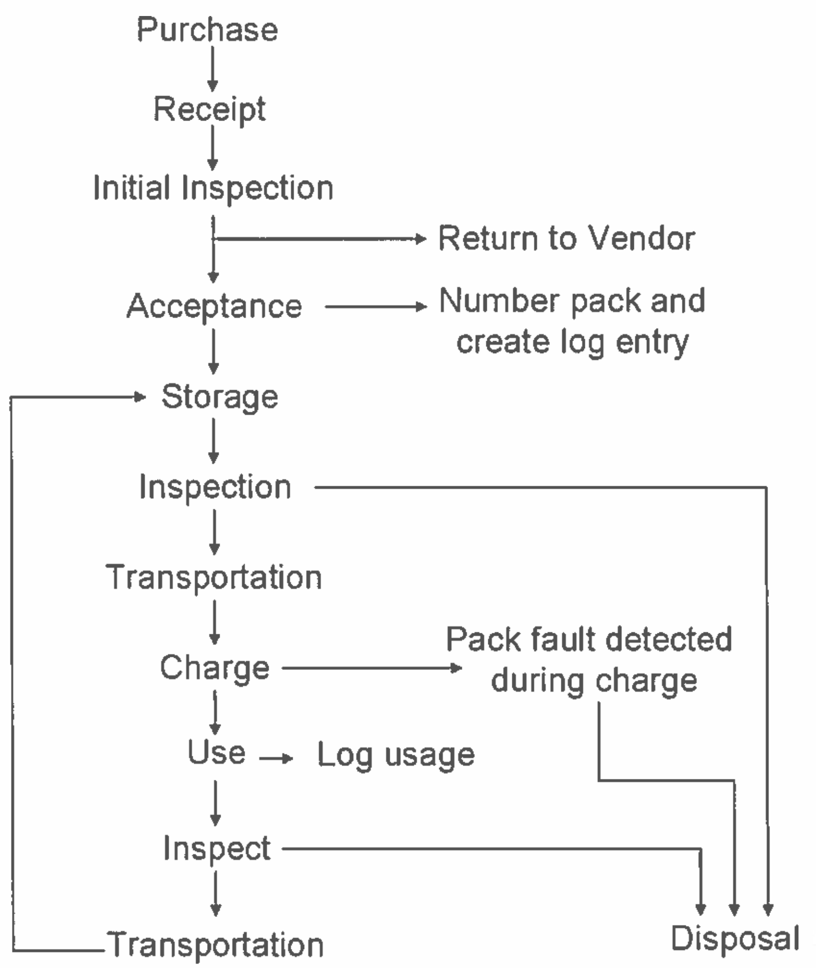

This document establishes procedures for safety and use of Lithium Polymer Battery technology in the Naval Postgraduate School (NPS), including Unmanned Aircraft Systems (UAS). All faculty, staff and students wishing to become Authorized Users of Lithium Polymer batteries shall be required to read and acknowledge this document and act in accordance with all procedures contained herein to be granted access to Lithium Polymer batteries.

1. Lithium Polymer (LiPo) Information

1.1 Scope

All Batteries must be marked HAZMAT at time of purchase, and disposed of through the Safety coordinator or HAZMAT Representative.

This SOP provides guidance for the safe handling of Lithium Polymer (LiPo) batteries at NPS, in compliance with NAVSEA S9310-AQ-SAF-010 (Tech Manual), "Navy Lithium Battery Safety Program: Responsibilities and Procedures", which has a mandate to "establish safety guidelines for the selection, design, testing, evaluation, use, packaging, storage, transportation and disposal of Lithium batteries". The Tech Manual applies to all Navy and Marine Corps activities and all Lithium battery powered devices intended for use or transportation on Navy facilities, submarines, ships, vessels and aircraft. Exceptions to these requirements include small, commercial-off-the-shelf batteries, such as laptop batteries, as defined in Appendix F.

It is recommended that project owners check and track compliance with this SOP with the NPS Lithium Polymer Safety Orientation (Appendix H).

1.2 Properties

Lithium Polymer (LiPo) batteries are comprised of Lithium-based chemistry suspended in a solid polymer matrix. The cells are assembled in stacked architecture of cathode, anode, and current collector grids and wrapped in a plastic-aluminum laminate. Most packs are not hardened beyond thin plastic heat-shrink tubing and therefore care must be taken to prevent mechanical damage or puncture.

Cell chemistry produces a nominal voltage of 3.7 Volts per cell and operating voltages between 3.2 and 4.2 V. It is <u>critical</u> that the cell voltage does not drop below the 3.2 V minimum as this can damage the cells, reducing performance or even rendering the battery useless. To accommodate this requirement, equipment should be used that is designed for use with Lithium Polymers, namely ESC's (electronic speed control) that have a low voltage cut-off setting that will reduce power to the motor when pack voltage approaches 3.2 V per cell. Even more important, the cells must not exceed a safe maximum voltage, typically 4.205 V, as this can start a runaway reaction resulting in fire. To meet this requirement, chargers designed for Lithium chemistry batteries must be used, and for packs with multiple cells in series, either active cell balancing or individual cell under/over-voltage protection circuitry must be used during charge. The exception is some devices with built-in LiPo packs with two cells in series, where cell balancing is typically not provided.

Cell capacity is determined by cell dimensions, and cells are wired in series and parallel configurations to construct battery packs of desired voltages and capacities. LiPo discharge ratings vary widely as a function of construction and chemistry. Batteries are commercially available to RC modelers with ratings as high as 70C continuous and 140C burst, where 1C nominally equates to a one hour discharge time (e.g., for a 4 Ahr pack this would be a 4 A load). Energy densities typically run between about 120 and 190Whr/kg. Typically energy density is higher for cells with a lower C-rating, but users should avoid using low C-rated packs for high discharge rates. This may cause packs to overheat which will reduce the pack's lifespan and may cause them to produce gas internally making them swell. Severe swelling can cause mechanical stress in packs constructed of several cells and in the worst case can cause cell damage or internal shorts which can lead to a fire. For that reason, packs that show notable swelling must be disposed of.

LiPo batteries do not demonstrate cell memory (hysteresis) effects like NiCd batteries do. Internal current is extremely low in LiPo batteries so storage of them is simple, provided that the batteries are not stored at voltages near the minimum 3.2 V per cell or maximum 4.2 V per cell. Most manufacturers recommend storing batteries at 3.8 to 3.9 V per cell (50% charge), which they refer to as a "storage charge." Many modern chargers have a storage-charge/discharge function to make sure batteries are at an appropriate voltage before extended inactivity.

1.3 Safety Considerations

While having proven to be safe and reliable under proper operating conditions, Lithium Polymer batteries do present significant safety challenges if mishandled.

The batteries have the potential, because of their chemistry, to ignite through a process known as thermal runaway. This can occur if the battery has taken physical damage that ruptures internal components of a cell, enabling a catalytic reaction to occur involving the cathode and the absorbed Lithium.

Although quite rare, ignition can occur as a direct result of physical damage alone. This will usually occur within fifteen minutes of the damaging incident. If the battery does not ignite in this time span and is not charged or used after such damage has occurred, then the damaged cell or cells will simply swell as out-gassing occurs from internal reactions, and ignition will usually not occur. The exception is multi-cell packs where internal swelling can mechanically damage internal connections potentially causing an internal short. Because of this risk, packs that show signs of swelling should be disposed of immediately. Proper procedures for handling and storing LiPo batteries can effectively mitigate this risk.

Ignition can result from charging using improper equipment such as chargers not specifically designed for LiPo batteries, miss-use of chargers that are intended for Lithium chemistry packs, or from charging damaged battery packs. Strict adherence to inspection and charging procedures can very effectively mitigate this risk.

Ignition can result from shorting a LiPo battery pack. Care must be taken when soldering battery connectors onto the battery leads to ensure that the battery is NEVER shorted in the process. Proper handling and maintenance of the packs can effectively mitigate this risk.

Another risk is over-discharging the battery pack. If the pack is discharged below 3.2 V per cell, cell damage or reversal can occur. In such cases the battery should be considered unusable and disposed of. Careful monitoring of pack voltages, use of proper equipment, and strict adherence to inspection and storage procedures can very effectively mitigate this risk. <u>NOTE</u>: some modern chargers will enter a "low voltage" charge cycle if a battery below 3.2 V per cell is attached. Even though the charger may successfully revive the pack, this procedure is discouraged, as the probability of internal damage to the pack exists. The cost of a replacement pack does not warrant the risk to the asset, the battery, or potential injury to humans that may not be aware of the battery's history. A low-voltage reading MUST be recorded in the log.

1.4 Disposal Procedure

Contact your Department's Hazardous Material (HM) Representative for proper procedures for turning in used batteries. If NPS OSHE/Safety Office-approved manufacturer core return programs are available, this purchase pathway can be considered as the first option.

If a battery must be disposed of as HW drain the packs to 3.8 V per cell or lower, and place tape or other secure electrical insulation over any exposed leads before handing them off to your HM rep. If the pack is damaged to the point where discharge is impossible, notify the HM Rep. to ensure the information is disseminated prior to turn in.

Many LiPo manufacturers recommend disposal of the packs by draining them to the lowest possible voltage you can get at a discharge rate of C/10 or less, then puncturing the cells and dropping them into a saltwater mix in a non-metallic container. However, if the cells are not sufficiently drained, the act of puncturing the cells can cause ignition. Because of this, most manufacturers no longer recommend this disposal technique, and it is not authorized for NPS users.

2. Quality Control Procedures

This section will outline quality control and inspection requirements and procedures for LiPo batteries.

2.1 Acceptance Criteria

All LiPo batteries shall conform to the following criteria to be deemed acceptable for use.

2.1.1 Criteria for Designating for Disposal

Any battery pack failing to meet any of the following criteria shall be disposed of in accordance with Section 1.4:

1. The battery pack shall not show any punctures or deep scratches to individual cell casings.
2. The battery pack shall not show any sign of significant deformation to any cell resultant from crashes or mishandling.
3. The battery pack shall not show any sign of swelling in any cell, which may indicate internal damage.
4. The battery pack shall not show a total voltage equivalent to less than 3.2 V per cell, and the voltages from each cell shall not vary more than 0.1 V.
5. The battery must be balanced at the end of a charge.
6. The battery pack shall not show any bare wires or leads that create significant risk of shorting the pack. Packs demonstrating significant risk of shorting shall be assumed to have been shorted, and disposed of in accordance with Section 1.4.
7. The battery pack must be free of the smell of electrolyte, which would indicate poor sealing or leaking.
8. The battery pack must be free of any unexplained heating, which would indicate an internal short circuit.
9. The battery pack shall not show any pouch discoloration (visible as discoloration of the aluminum layer or the cell case).

2.1.2 Repair Criteria

Battery packs showing minor damage meeting the following criteria shall be repaired prior to further use in accordance with procedures in Section 3.1.4. **Repair shall be carried out only if the battery meets all criteria in Section 2.1.1, and must be noted in the battery maintenance logs in accordance with Section 4.1.**

1. Damage that is limited to the pack heat-shrink wrapper and does not penetrate to any cell inside the pack shall be repaired in accordance with Section 3.1.4.
2. Bare leads due to insulator cracking that does not result in a significant risk of shorting the battery pack[1] shall be repaired in accordance with Section 3.1.4.
3. Damaged battery connectors that do not result in a significant risk of shorting the battery pack[1] shall be repaired in accordance with Section 3.1.4.

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[1] **PACKS DEMONSTRATING SIGNIFICANT RISK OF SHORTING SHALL BE ASSUMED TO HAVE BEEN SHORTED, AND DISPOSED OF IN ACCORDANCE WITH SECTION 1.3.**

2.2 Initial/Purchase Inspection

Lithium battery orders shall be noted as HAZMAT in the NPS purchasing system. Upon receipt of a new battery pack, the battery shall be inspected for any signs of physical damage such as punctures, broken heat shrink, bare wires, dents, scratches, and swollen or ruptured cells. All general multi-cell LiPo packs that are not sold as part of a complete system (e.g. packs in a plastic case for cameras or toys) must have a balancing lead that provides a means to monitor individual series cell voltages. Before soldering a connector to the main pack leads, individual cell voltages must be checked. They should be about 3.8 V, but **must be in the range of 3.4 V to 4.0V. Additionally, the individual cell voltages in a pack must not have an imbalance exceeding 0.1 V.**

After confirming that the battery's physical condition is acceptable, a female battery connector[2] shall be soldered to the battery leads in accordance with Section 3.1.3.1. Extreme care must be taken to never expose both leads simultaneously, as this can easily lead to inadvertent shorting. Typically a clamp or jig is used to hold the connector during soldering, and heat-shrink tubing or other protective materials shall be used to protect the soldered joint from shorting with other open leads.

If the battery does not meet any of the acceptance criteria in Sections 2.1.1 or 2.1.2, it shall be returned to the manufacturer immediately. **REPAIR IS NOT ACCEPTABLE FOR NEWLY PURCHASED PACKS.**

2.3 Post Storage

Upon removal of a battery from storage, the battery shall be inspected for any signs of physical damage such as punctures, broken heat shrink, bared wires, dents, scratches, and swollen or ruptured cells.

After confirming that the battery condition is acceptable, the battery shall be connected to a LiPo battery pack checker to ensure that each cell is in the range 3.2 V to 4.2 V and that the cell imbalance is less than 0.1 V.

If the battery does not meet any criterion in Section 2.1.1 Disposal Criteria, it shall be disposed of immediately in accordance with the disposal procedure in Section 1.4. Any minor damage meeting the criterion of Section 2.1.2 shall be repaired in accordance with Section 3.1.4, only if all criteria of Section 2.1.1 are met.

[2] **NOTE: SOLDERING OF A MALE CONNECTOR TO A BATTERY IS A SHORTING HAZARD AND SHALL SUBJECT THE BATTERY TO IMMEDIATE DISPOSAL PURSUANT TO CRITERION 5 OF SECTION 2.1.1.**

3. Maintenance & Storage

This section will outline maintenance and storage requirements and procedures for LiPo batteries.

3.1 Maintenance

LiPo batteries shall be maintained (charging, balancing, connectors and repairs) and stored in accordance with the following procedures.

3.1.1 Charging

Charging of LiPo batteries shall be carried out in accordance with the following procedures:

1. If charging at a field location, batteries shall not be charged inside of an aircraft or any other vehicle. Exceptions are: systems with built-in battery packs as shipped by the manufacturer, which must be charged using charging equipment shipped with the system, and packs that have built-in cell protection equipment to prevent cell under/over voltage and/or cell balancing during charge, often referred to as Battery Management Systems (BMS).
2. Inspect the battery to verify that it is in accordance with all requirements given in Section 2, prior to charging.
3. Charge the battery using a charger that is qualified for LiPo charging in accordance with battery manufacturer's specifications.
4. Virtually all modern multi-cell LiPo packs ship with a balancing lead that provides a voltage monitoring tap between each cell. The exception is two cell series packs that are frequently shipped with devices that have a slow drain rate. **For any standalone multi-cell LiPo packs, charging with a balancer attached, or preferably with a balancing charger, is required.**
5. Never charge batteries unattended.
6. Charge in an isolated area, away from flammable materials.
7. Let the battery cool down to ambient temperature before charging. **Do not charge hot packs.**
8. Do not charge battery packs in series.
9. When selecting the cell count or voltage for charging purposes, select the cell count and voltage as it appears on the battery label. Selecting a cell count or voltage other than the one printed on the label may result in overcharging and fire. As a safety precaution, please confirm that the information printed on the battery is correct. For example: If a battery label indicates that it is a 3 cell battery (3S), its voltage should read between 9.6 and 12.6 volts. This battery must be charged as a 3 cell battery (peak of 12.6V).
10. You must check the pack voltage after each usage, before re-charging. Do not attempt to charge any pack if the unloaded individual cell voltages are less than 3.2 V. For example: Do not charge a 2-cell pack if below 6.4V.
11. In general, a charge rate of 1C (one times the capacity of the battery) is considered to be normal. However, many modern LiPo packs, in particular, packs with high C-counts, can handle higher charge rates. In this case higher charge rates are acceptable, but shall never exceed the manufacturers rating as printed on the label. Higher charge rates may degrade the battery's lifespan, and should be avoided when possible. If no rating is shown on the battery label, a maximum charge rate of 1C shall be used.

3.1.2 Balancing

LiPo batteries shall be balanced using a cell balancer or balancing charger in accordance with manufacturer's specifications during charging, each time the battery is charged. The exception are packs that include internal cell-balancing and/or under/over voltage protections. If battery cells remain unbalanced after a charge cycle, balancing shall be continued off the charger in accordance with manufacturer's specifications and the battery shall be charged to completion when balancing is finished. If a battery cannot be balanced, it shall be disposed of in accordance with Section 2.3.

3.1.3 Connectors

Battery connectors shall be added to newly purchased packs or changed on existing inventory only with the permission of the battery owner. When adding or changing connectors, the following procedures shall be followed:

3.1.3.1 Adding New Connectors

CAUTION: Heat from solder iron or heat gun can damage the battery.

1. Remove the factory installed heat shrink from the positive (red) lead only. **NOTE: The negative lead must remain in heat shrink until the positive has been soldered and heat shrunk to its final condition to avoid a shorting hazard.**
2. Strip as little of the lead as possible and tin the exposed wire with a coating of solder. Use enough solder to hold all strands of the wire in a cohesive bunch. This is usually aided by wicking solder into the open end of larger gage wires, followed by wetting the exterior. No dry strands should be visible prior to attempting to join the wire to the connector, as this may result in a "cold" connection.
3. Slide a piece of heat shrink onto the lead and as far as possible from the solder joint to prevent premature shrinking. Be sure to use a sufficiently large piece of heat shrink to cover all exposed metal.
4. Tin the plate of the connector to which the lead will be attached.
5. Solder the lead to the intended connector, ensuring that a solid soldering connection has been made to prevent de-soldering and ensure good electrical contact.
6. Using a heat gun, shrink the heat shrink securely around the solder joint, ensuring that no exposed metal remains.
7. Repeat the procedure for the negative lead.

3.1.3.2 Changing Existing Connectors

1. Remove the heat shrink from the positive (red) solder joint only. **NOTE: The negative lead shall remain in heat shrink until the positive has been soldered and heat shrunk to its final condition to avoid a shorting hazard.**
2. De-solder the joint.
3. Re-tin the exposed wire with a thin coating of solder if necessary. Use enough solder to hold all strands of the wire in a cohesive bunch.
4. Slide a piece of heat shrink onto the lead and as far as possible from the solder joint to prevent premature shrinking. Be sure to use a sufficiently large piece of heat shrink to cover all exposed metal.
5. Tin the plate of the new connector to which the lead will be attached.
6. Solder the lead to the new connector, ensuring that a solid soldering connection has been made to prevent de-soldering and ensure good electrical contact.
7. Using a heat gun, shrink the heat shrink securely around the solder joint, ensuring that no exposed metal remains.
8. Repeat the procedure for the remaining lead.

NOTE: Due to the difficulty of the above procedures and the risk of catastrophic failure if done improperly, either through poor quality solder joints on the typically heavy gage wiring or through accidental shorting of the battery poles, no one shall carryout this procedure until having been mentored through the process with a person already experienced.

3.1.4 Repairs

Repairs may only be made to battery packs demonstrating minor damage that meets the criterion outlined in Section 2.1.2, and all repairs must be logged in accordance with Section 4.1.

Damage that is limited to the pack heat-shrink wrapper and does not penetrate to any cell inside the pack may be covered with electrical tape after inspection of the underlying cell.

Bared leads due to insulator cracking that does not result in a significant risk of shorting the battery pack* may be repaired by de-soldering the lead from the connector and placing a piece of heat shrink over the damaged region and then re-soldering the lead back onto the connector and re-heat shrinking the joint.

NOTE: If both leads need repair, only one lead should be de-soldered at a time. The remaining lead should remain soldered until the first has been completely repaired and re-soldered to avoid a shorting hazard.

Damaged battery connectors that do not result in a significant risk of shorting the battery pack** may be replaced with another connector in accordance with the procedure in Section 3.1.3.2.

***PACKS DEMONSTRATING SIGNIFICANT RISK OF SHORTING SHALL BE ASSUMED TO HAVE BEEN SHORTED, AND DISPOSED OF IN ACCORDANCE WITH SECTION 1.4.**

****NOTE: SOLDERING OF A MALE CONNECTOR TO A BATTERY IS A SHORTING HAZARD AND SHALL SUBJECT THE BATTERY TO IMMEDIATE DISPOSAL PURSUANT TO CRITERION 5 OF SECTION 2.1.1.**

3.2 Storage

LiPo Batteries shall be stored in accordance with the following requirements:

1. Batteries should be stored at room temperature between 40 and 70 degrees Fahrenheit. <u>Lithium batteries are not to be stored in a refrigerator</u>.
2. Batteries shall be stored separate from Hazardous Materials storage.
3. Batteries shall be stored at distance from combustible materials as much as possible considering space considerations.
4. Batteries shall be stored in a metal cabinet away from combustible materials, on ceramic tiles. The storage cabinet shall be identified with "Lithium Battery Storage Only".
5. As an alternative for small numbers of LiPo batteries, they may be stored in specifically designed LiPo bags from <u>LiPoGuard</u>, LiPoSafe, LiPoSack, or Dynomite. No more than 5 batteries per bag, no more than 100 Watthours per bag. These bags shall each be placed on ceramic tiles.

6. A minimum of 4 inches vertical clearance between the top of a stored battery and the bottom of the next shelf shall be maintained.
7. Battery packs shall be charged to at least 3.5 V per cell prior to short term storage (two weeks or less) after any usage, where a full charge is not conducted immediately.
8. Battery packs shall be charged to between 3.8 and 3.9 V per cell in accordance with manufacturer's specification, and any necessary repairs authorized by Section 2.1.2 shall be completed, prior to long term storage (more than two weeks). Batteries with voltages already in excess of 3.9 V per cell should be discharged prior to storage.
9. Battery packs in long term storage should be **inspected every three months** and checked to ensure that pack voltage is still within the 3.8-3.9 V range, and do not show signs of swelling. Packs falling below this range shall be recharged to this range prior to re-storage, and packs that show signs of swelling must be disposed of as detailed in Section 1.4.

4. Inventory Control & History

All new batteries will be designated with a unique identifier (lab-specific) and dated with the time of original purchase. The "battery owner" shall keep a log of the pack's history which will, at a minimum, track the date of each cycle with additional entries for each "event" the pack has experienced. Logged events will include crashes, repairs, and charge anomalies (e.g. difficulty balancing, large cell imbalance at start of charge). Owners may wish to track additional data such as start/end voltage of a particular use, time used, mAhr replaced when charged and individual cell internal resistance (reported by some LiPo chargers). Tracking of such data may help users determine if the particular battery is suitable for the application, and will help identify when a pack is aging and will need to be replaced. A sample battery pack log sheet is presented in Appendix E.

It is recommended that each project owner keep a log of the inventory of LiPo batteries under their ownership. A sample inventory sheet is presented in Appendix D.

5. Transportation Procedures

Transportation of LiPo batteries shall be conducted in accordance with the following requirements:

1. Batteries shall be transported in sealed, hard cases to prevent physical damage or exposure to moisture.
2. Batteries shall not be charged while being transported.
3. More than one battery may be transported in a given case.
4. Do not expose battery packs to direct sunlight (heat) for extended periods.
5. When transporting or temporarily storing in a vehicle, temperatures should be greater than 20 degrees F but no more than 150 degrees F.
6. Storing LiPo batteries at temperatures greater than 170 degrees F for extended periods of time (more than 2 hours) may cause damage to battery and possible fire.
7. Ensure batteries are protected from damage and possible short circuits during transport; do not place non-battery items, such as tools, in the battery container.
8. Damaged or suspect batteries shall be transported in isolation in a ceramic vessel or specially designed fire retardant container for protection, and only after a 45 minute minimum observation period to ensure that ignition is unlikely. A flower pot or LiPo bag is recommended to isolate and protect suspect or damaged batteries.

6. Emergency Procedures

This section will outline emergency procedures for LiPo use. MSDS/SDS sheets for specific batteries shall be maintained at the storage and usage locations, readily visible and accessible for emergency response personnel.

6.1 Fire Control

An ABC fire extinguisher shall be kept on hand wherever LiPo batteries are being charged, stored, or utilized. For field operations the fire extinguisher shall be kept near the batteries during charging, and on the flight line during flights.

As an alternate, water has been approved by NSWC Crane's battery safety technical review team for NOSSA, as being shown to be effective for extinguishing and cooling Lithium battery fires. MSDS warnings against water are directed to bulk or significant quantities of Lithium, but it is not expected that you will get a Lithium/water reaction on these types of batteries.

In the event of a LiPo battery ignition the following procedures shall be followed:

6.1.1 Battery Ignition While Charging

The primary risk associated with Lithium Polymer technology is battery ignition while charging. This can result from improper charging, or charging a physically damaged battery pack. In the event of a battery ignition during charging, the following procedure shall be followed:

1. The battery shall be allowed to burn to completion.
2. If there is any danger to surrounding structures or property, contact emergency services immediately.
3. The burn shall be monitored and the fire extinguisher used to ensure that surrounding materials do not catch fire.
4. The fire extinguisher shall not be discharged at the battery charger unless necessary to prevent the spread of fire.
5. After the ignition has subsided, continue to monitor the battery for at least fifteen minutes.
6. After fifteen minutes disconnect the charger, and carefully move the battery to a safe location.
7. Leave the battery in a safe location for at least 24 hours prior to disposing of battery remains.

6.1.2 Storage

LiPo batteries have not demonstrated significant tendency to ignite while in storage provided that a damaged pack is not stored until it has been given sufficient time to ensure stability (45 minute observation period). None the less, to be prepared for the possibility of a battery igniting in storage, the following procedure shall be followed:

1. The battery shall be allowed to burn to completion within the cabinet.
2. If there is any danger to surrounding structures or property, contact emergency services immediately.
3. The burn shall be monitored and the fire extinguisher used to ensure that surrounding materials do not catch fire.
4. After the ignition has subsided, continue to monitor the battery for at least 45 minutes.
5. After 45 minutes carefully move the battery to a safe location and store in a ceramic vessel (flower pot) or specially designed fire protective bag.
6. Leave the battery in a safe location for at least 24 hours prior to disposing of battery remains.

Appendix A
Unmanned Aircraft Systems (UAS) Specialized Procedures

Charging
If charging at a field or flying location, batteries shall not be charged inside of an aircraft or any other vehicle. Exceptions are: systems with built-in battery packs as shipped by the manufacturer, which must be charged using charging equipment shipped with the system, and packs that have built-in cell protection equipment to prevent cell under/over voltage and/or cell balancing during charge, often referred to as Battery Management Systems (BMS).

You must check the pack voltage after each flight before re-charging. Do not attempt to charge any pack if the unloaded individual cell voltages are less than 3.2 V. For example: Do not charge a 2-cell pack if below 6.4V.

Post Flight
Upon retrieval of a battery after a flight, the battery shall be inspected for any signs of physical damage such as punctures, broken heat shrink, bared wires, dents, scratches, and swollen or ruptured cells.

After confirming that the battery's physical condition is acceptable, the battery shall be connected to a LiPo battery pack checker to ensure that each cell is in the range 3.2 V to 4.2 V and that the cell imbalance is less than 0.1 V.

If the battery does not meet any criterion in Section 2.1.1, it shall be disposed of immediately in accordance with the disposal procedure in Section 1.4. Any minor damage meeting the criterion of Section 2.1.2 shall be repaired in accordance with Section 3.1.4 only if all disposal criteria of Section 2.1.1 are met.

Emergency Procedures
An ABC fire extinguisher shall be kept on hand wherever LiPo batteries are being charged, stored, or utilized. For field operations the fire extinguisher shall be kept near the batteries during charging, and on the flight line during flights.

Aircraft Crash (battery ignition)
Although rare, LiPo batteries can ignite as a direct and immediate result of physical damage alone. In the event of a battery ignition subsequent to an aircraft crash, the following procedure shall be followed:

1. If smoldering, the battery shall be allowed to burn to completion within the aircraft.
2. If there is any danger to surrounding structures or property, contact emergency services immediately.
3. If burning, monitor and use the fire extinguisher if surrounding materials are at risk.
4. After crash or ignition has subsided, continue to monitor the battery for at least 45 minutes.
5. Extract the battery from the aircraft using a shovel or protective gloves.

6. Place remains in a ceramic vessel (flower pot) or LiPo bag for transport to disposal.

Leave the battery remains in a safe location for at least 24 hours prior to disposing of battery remains

Aircraft Crash (no ignition)
The great majority of aircraft crashes involving LiPo batteries will not result in battery ignition. In the event of an aircraft crash involving LiPo batteries that does not result in immediate ignition, the following procedure shall be followed:

1. The Pilot/operator shall immediately cut power to the motors.
2. The aircraft shall be left in place and monitored for a 45 minute period after the crash to ensure that ignition is not going to occur.
3. After 45 minutes, the aircraft can be recovered and the battery removed.
4. The battery shall then be inspected in accordance with Section 2.5.
5. The exception is crash sites which are in the midst of highly combustible materials. In this case, approach the crash site with caution, with an extinguisher, and upon inspection, determine if the aircraft can be moved without posing additional hazards. If so, move the wreckage to a safe site for the cooling-off period. Consider using protective gloves.

Post Crash
If an airplane containing LiPo batteries is involved in a crash, motor power shall be turned off immediately. The aircraft shall be left in place and monitored for a 45 minute period after the crash to ensure that ignition is not going to occur. The exception is if the crashed aircraft is located in the vicinity of highly combustible materials. In this case the owners should approach the crash site with caution, with an approved fire extinguisher, and attempt to relocate the wreckage to a safer location. Use of a LiPo bag or ceramic container for the batteries is encouraged.

After 45 minutes, the aircraft can be disassembled and the battery removed. Upon retrieval of a battery after a crash, the battery shall be inspected for any signs of physical damage such as punctures, broken heat shrink, bared wires, dents, scratches, and swollen or ruptured cells.

After confirming that the battery condition is acceptable, the battery shall be connected to an open circuit voltmeter and the pack voltage shall be confirmed to be a minimum of 3.2 V per cell.

If the battery does not meet any criterion in Section 2.1.1, it shall be disposed of immediately in accordance with the disposal procedure in Section 1.4. Any minor damage meeting the criterion of Section 2.1.2 shall be repaired in accordance with Section 3.1.4 only if all disposal criteria of Section 2.1.1 are met.

Appendix B
Multi-Pack Wiring/Usage Requirements

Many systems require LiPo packs to be used in parallel or serial configurations in order to achieve the needed voltage and capacity requirements. Individual packs that include serial and/or parallel connections are not considered in this section, but they are discussed in previous sections.

Parallel Connections
Typically multiple packs are connected in parallel when increased endurance is required, increasing the system Amp-Hour capacity at the same voltage as a single pack. This poses a significant risk if an operator inadvertently plugs one fully charged battery in parallel with a second battery at a significantly lower charge state. Without safeguards in the circuitry, the full pack and the low pack will immediately attempt to balance, with the low pack getting charged at a very high rate, controlled only by line resistance in the wiring. There is a significant chance of ignition occurring in the low pack.

In the radio control community, this is typically mediated through operator training. However, in campus labs with potentially untrained students working with these systems, some form of electrical safeguard is required to prevent or limit back current into the packs. The simplest scheme is through the use of a diodes or a Schottky rectifier. Use of an inline diode will prevent current to flow from the system back into the battery. In a system with parallel packs, each behind a diode, in use the system will draw power from the pack with the highest voltage until the packs are balanced, and then power will be drawn equally from the two.

Note, some precautions may need to be taken to protect other electronics if diodes are used in this way. For example, many electronic speed controls (ESCs) have a brake capability built in to stop a propeller from spinning at zero throttle. Many of these brake systems work through regenerative braking (as on the Toyota Prius), where the freewheeling motor acts as a generator, and feeds power back into the battery. Since the propeller typically doesn't have much inertia, the total energy spike is quite small. However, with the diode in place, this small surge cannot reach the battery, and other circuitry in the line may be subjected to a very brief power surge with voltages roughly twice the nominal battery voltage. Systems should be capable of handling these surges, use a fly-back diode to isolate the surge, or disable the brake.

Series Connections
Typically series connections are used when a higher voltage is required, but for mechanical or other reasons, smaller packs were used. The voltage is increased to the sum of all the packs in series, and the capacity is equal to the weakest pack in the system.

In principal, series connections are less dangerous, as the possibility of high-rate pack-balancing is removed. However, some care must be taken to insure that the energy is removed from the packs uniformly. For example, as packs age, their internal resistance increases, and they are less willing to release power. If a new pack is mated with an old pack in series, the new pack will end up draining more quickly than the old pack. The net result can be that the new pack is drawn well below the 3.2v/cell safe limit while the old pack remains at a safe voltage level. Monitoring the total system voltage will not catch this, as the full system voltage may be above 3.2v/cell.

To mediate this, packs that are to be used in series should be of identical size and manufacture, and should remain as a matched pair throughout their useful life. The unique identifier on the packs should reflect that it is part of a series group.

Appendix C
Safe Storage Examples

Depending on the volume of lithium packs that a lab has, the level of protection may vary, but at a minimum, all LiPo packs that are not built into a system (cell-phones, laptops, cameras, etc), must be stored in a metal cabinet away from other combustible materials. Due to the extreme heat generated by LiPo packs during ignition, materials that are not normally considered to be combustible will readily catch on fire and burn. For example, plastics, cured epoxies and paints, rubber tires all will easily ignite and burn when exposed to a LiPo undergoing ignition.

If more than a few small packs exist in a lab, additional precautions should be taken. Batteries should not be stacked or packed tightly together. They should not rest on a metal surface, as this can lead a single pack ignition to trigger additional packs to ignite as the heated metal shelf burns through the heat-shrink encapsulation of nearby packs. This can be mitigated by placing packs on ceramic tiles.

While a flammables container is ideal, other metal cabinets are acceptable as long as no combustible material is stacked on top of or next to the cabinet. The cabinet must be marked with external warning to prevent infractions of this rule.

Appendix D
Example Inventory Sheet

Dept.	Incept Date	ID	Battery type	Size	Storage location	Primary use	Balancing charger ?	Point of contact	Green box/approved
MAE	Mar-14	4S-3900-25C-04	lipo	57Whr	BLD 234 Rm 025	Small aircraft model	yes	Dr. Kevin Jones	yes/no

Appendix E
Example Battery Log

ID	Date	Event	details
4S-3900-25C-04	2/14/2014	Incept	Inspection on arrival - no problems
4S-3900-25C-04	3/17/2014	Installed connector	none
4S-3900-25C-04	3/19/2014	Charged	Arrived at storage charge, and was balanced

Appendix F
Exceptions

Excerpts from NAVSEA S9310-AQ-SAF-010 SECOND REVISION

CHAPTER 3
EXCEPTIONS TO TESTING, REVIEW, AND/OR APPROVAL REQUIREMENTS

3-1. TESTING. The NOSSA Technical Agents may determine that sufficient safety test data are available from other sources for any lithium battery under review. Analyses or comparisons with similar cells/batteries in similar applications may be sufficient to eliminate the need for testing.

3-2. CERTAIN SMALL BATTERIES. The NOSSA Technical Agents may rev iew and independently recommend for Program Manager approval small lithium batteries that meet the following criteria. A request letter in accordance with paragraph 2-2 must be submitted to the Technical Agent. A sample request letter is provided in appendix D.
a. Primary or secondary battery;
b. One battery with no more than two identical cells;
c. Maximum rated capacity of 3.0 Ampere-hours (Ah) per cell.

3-3. COIN CELLS. Non-rechargeable lithium coin cells meeting the following criteria are approved for all uses and do not require individual testing and review by NOSSA. However, they do require an initial procurement report from the purchaser in accordance with appendix E.
a. Unmodified, commercial-off-the-shelf (COTS) item;
b. Used in single-cell configuration;
c. Maximum nominal output of 3 Volts;
d. Maximum rated capacity of 1 Ah.

3-4. CERTAIN LITHIUM ION BATTERIES. The use of COTS electronics and equipment powered by lithium ion rechargeable (secondary) batteries meeting the following criteria is approved for all uses and does not require individual testing and review by NOSSA. However, the batteries do require an initial procurement report in accordance with appendix E.
a. Unmodified, COTS battery;
b. Underwriter's Laboratories (UL) listed;
c. Used in the device as recommended by the manufacturer. Modifications to the devices may only be made in accordance with the manufacturer's recommendations; e.g., addition of memory;
d. Recharged only by devices expressly designed for recharge of the specific battery in use;
e. No more than four cells in series (less than or equal to 18-Volt output);
f. Rated for no more than 100 Watt-hours, as listed in the manufacturer's specification or calculated by multiplying the capacity in Ah by the maximum working (nominal performance) voltage.
3-4.1. ALTERATION OF COTS SECONDARY BATTERIES. There shall be no attempt to open, modify, reform, or repair batteries in this approved category.

3-4.2. FAILED COTS SECONDARY BATTERIES. Failed batteries in this approved category shall be returned to the manufacturer or properly disposed of in accordance with chapter 9.

3-5. PRIMARY (NON-RECHARGEABLE) LITHIUM BATTERIES. Primary lithium batteries used in primary lithium battery-powered equipment meeting the criteria below are exempted from testing requirements. A request letter in accordance with paragraph 2-2 must be submitted. Sample request letters are provided in appendix D.

3-5.1. PRIMARY BATTERIES IN EQUIPMENT DESIGNED FOR COMMERCIAL USE. UL-approved equipment designed for commercial use and procured from commercial sources that use a single primary battery meeting the following criteria.

a. No more than two identical cells in the single battery;
b. Maximum rated capacity of 3.0 Ah per cell;
c. Equipment is unmodified, to include replacing the battery with one of a different chemistry or size;
d. A single 9-volt PP3 size, snap connector battery is included in this category.

3-5.2. PRIMARY CELLS IN EQUIPMENT DESIGNED FOR A SPECIFIC NAVY USE. This exception applies to normal repair and maintenance of the equipment, including procurement and storage of replacement batteries.

a. No more than two identical cells;
b. Maximum rated capacity of 3.0 Ah per cell;
c. No other source of electrical power to the unit exists; or
d. The battery is protected from other sources of electrical power by appropriate combinations of blocking diodes and resistors.

Appendix G
LiPo Battery Usage in Marine Research

(Note: most coin, phone, and laptop batteries are excepted from control in Chapter 3 of **NAVSEA S9310-AQ-SAF-010 Second Revision**)

As part of the pre-cruise planning at least 30 days prior to cruise, personnel from NPS who are properly trained in the use of the project LiPo batteries that require management in accordance with NAVSEA S9310-AQ-SAF-010 Second Revision shall declare the LiPo batteries to be embarked. The Chief Scientist will coordinate a brief to include the Marine techs, Crew and Science Party to cover the elements of the following checklist.

Attendance or receipt of brief:

- Chief Scientist
- Marine techs
- Crew
- Science Party

Description of LiPo batteries to be embarked
Appropriate MSDS
Applicable portions of the Ship's existing LiPo battery SOPs
Applicable portions of NPS LiPo battery SOP
Plan for normal use, operations, protection from salt spray and fog
Plan for charging

- Who will attend to charging
- Standoff - for those NOT attending to charging

Plan for normal storage (ship storage, or project supplied storage)
Plan for normal disposal
Actions required for

- Corrosion accelerated by salt spray/fog
- Pouch discoloration (discoloration of the aluminum layer or the cell case)
- Battery lost overboard
- Punctures
- Significant deformation, swelling of any one cell
- Total voltage less than 3.2V per cell
- An imbalance after a charge
- Bare wires that create risk of shorting
- Electrolyte smell
- Unexplained heating
- Battery lost overboard

Emergency Procedures

- Battery ignition on ship (ship fire response equipment and procedure, or project supplied fire response equipment and procedure)
- Battery ignition if project is deployed away from ship

Supporting Materials from the References: The Guidance for use of Lithium Batteries in Marine Research is derived from the University National Oceanographic Laboratory System (UNOLS) and the NPS Safety & Usage Procedures for Lithium Polymer (LiPo) Batteries

Pre-cruise planning and hazardous material process will capture procedures on how to handle lithium batteries. When lithium batteries are used, it is imperative that the marine techs, crew and science party are trained and aware of the proper usage, storage, disposal, and how to respond to emergencies. (UNOLS RVOC-Safety Committee Memo "Lithium Battery Safety Information" 10 May 2012)

CRUISE PLANNING: The Chief Scientist will be responsible for providing the following to the ship operator at least 30-days prior to the cruise departure date unless a shorter time is specifically allowed by the ship (UNOLS Research Vessel Safety Standards, March 2009 p49):

- A list of all hazardous materials by chemical name, common name, UN identification number, type and classification of hazard, quantity (size of containers and number of each size container), user name and contact information
- MSDS sheets for all materials listed above
- A list of the spill response materials and the amount to be brought aboard to address spills or accidents RVSS Edition 9 – 03/12/2009 50 Chapter Nine
- The plans for offloading all materials brought aboard at the end of the scheduled cruise.

LITHIUM BATTERIES: Lithium batteries require special fire extinguishing capabilities depending on the type of material used in the manufacturing process. The Chief Scientist is required to notify the ship operator of the use and/or recovery of instruments using lithium batteries and to supply appropriate fire extinguishing equipment and a stowage locker if one is not available from the ship operator. (UNOLS Research Vessel Safety Standards, March 2009 p50)

From the NPS SOP, the potential emergencies are thermal runaway that leads to ignition or swelling. (Section 1.2 Safety Considerations)

Additionally, NPS SOP highlights the indicators that could indicate a battery is at higher than normal risk in Section 2.1.1 Quality Control Procedures, Criteria for Disposal.

Additional Guidance: Consider S9086-S3-STM-010, "Navy Ships Technical Manual Chapter 555 V1 Surface Ship Fire Fighting" guidance copied below:
555-8.14.3.2 Cook-off of a large Multi-cell Lithium Battery.

1) Cook-off of a single cell in a multi-cell lithium battery results in a few seconds of electrolyte venting, which commonly ignites as a fireball and can begin a violent cascading cook-off of the remaining cells over a period of seconds to minutes, each cell venting its own fireball of electrolyte. A lithium battery cook-off involving more than a few hundred watt-hours (W•h) can produce significant thick, toxic smoke which will fill a compartment in seconds. Breathing equipment and a NFTI will be needed immediately by responding personnel to function in the space.
2) Dry chemical and carbon dioxide extinguishers are generally ineffective and are not recommended. Portable AFFF fire extinguishers may provide some limited cooling, but should not be used if hose reels or hose lines are available, as a significant volume of extinguishing media is usually needed to

combat a lithium battery fire and portable AFFF fire extinguishers will only provide limited amounts of media. Commercial Class D fire extinguishers, which are listed on some lithium battery Material Safety Data Sheets (MSDS), are ineffective and are not recommended.

3) Limited testing demonstrates that application of a narrow-angle fog of water or AFFF is the preferred method to cool the battery, suppress fireballs as they occur, and reduce likelihood cook-off of remaining cells. Water or AFFF is also used to cool exposed hazardous materials or equipment, such as ammunition and explosives (A & E), other batteries and pressurized hydraulic piping and prevent fire spread to nearby combustible material. Maintain an adequate distance for personnel safety from exposure to fireballs and from projected fragments. Utilize personnel wearing SCBAs and FFEs as soon as they are available.
4) Continue to cool the battery for several minutes after the last cell cook-off. Follow-on cell cook-off may occur without warning while the battery is hot. Do not approach until there is confidence that all reactions have stopped.
5) Initiate active desmoking of the affected compartment as soon as practicable during the casualty to remove heat, smoke and toxic gases. Active desmoking can be initiated simultaneously with other actions.

Appendix H
Safety Orientation

To be completed before laboratory work begins:

1. Read and sign Safety Overview (this page). Bring a signed copy to the lab you are working in.

2. ______ (initials): Read and review Navy Lithium Battery Safety: http://goo.gl/xmr2mQ

3. ______ (initials): Read and review NPS Standard Operating Procedure "Safety and Usage Procedures for Lithium Polymer Batteries Version 1.4b January 2016"

4. ______ (initials): Read and review Capacity Limited Lithium Battery Site Clearance for NPS**: http://goo.gl/NyPhZI**

5. ______ (initials): Review your project's Li Battery manufacture specifications and manuals (if any)

6. ______ (initials): An introduction to the specific lab facilities and equipment by the Lab manager

Summary of SOP Procedures:

(Note: most coin, phone, and laptop batteries are excepted from these additional LiPo battery controls by Chapter 3 of **NAVSEA S9310-AQ-SAF-010 Second Revision** – however, **all batteries must be marked HAZMAT at time of purchase, and disposed of through the Safety coordinator or HAZMAT Representative)**

***** This checklist is a reminder** of NPS SOP procedures detailed in "Safety and Usage Procedures for Lithium Polymer Batteries Version 1.4b January 2016". This checklist is **not a substitute for the proper application of all the details in the SOP**, nor will it substitute for completion of the training specified above.

Be aware of danger of battery **ignition**
Be aware of the potential for **swelling** to lead to ignition
Be aware of the **hazards of over-discharging below 3.2V**

Normal disposal: DO NOT PUNCTURE UNLESS SPECIFICALLY DIRECTED

- Contact HM representative (project specific who): ________________, Phone #: ___________
- Drain to 3.8V/cell or note otherwise to HM representative

Material criteria hazards requiring disposal:

- Punctures
- Significant deformation
- Swelling of any one cell
- Total voltage less than 3.2V per cell
- An imbalance exceeding 0.1V after a charge that cannot be balanced per manufactures instruction
- Bare wires that create risk of shorting
- Electrolyte smell
- Unexplained heating
- Pouch discoloration (discoloration of the aluminum layer or the cell case)

Repair criteria

- Damage limited to heat-shrink wrapper that does not penetrate any cell
- Bare leads that do not pose a significant risk of shorting
- Damaged connectors leads that do not pose a significant risk of shorting

Acquisition

- Note as HAZMAT in NPS purchasing system

- Inspect for material hazards. Deficiency = return. Do not repair new batteries.
- Check charge of each individual cell (3.4V-4.0V) if possible
- Check imbalance not greater than 0.1V
- Designate with unique identifier and date (project specific) and begin Log

Adding or changing connectors: See SOP 3.1.3.1-2 for checklist details

Repairs

- Heat shrink can be repaired with electrical tape
- Bared leads can be resoldered and treated with heat shrink one at a time.
- Log repair event

Charging

- Shall not be charged in aircraft or vehicle unless:
  - Battery built in as shipped by manufacturer
  - Battery Management System (BMS) to manage cell charging and balance
- Check temperature as ambient
- Check pack cell count and voltage before recharge
- Only use charger qualified according to manufactures specifications
- On variable chargers check cell count and voltage selected properly– verify cells and voltages match
- For any standalone multicell, charge with a balancer or balancing charger
- Post an attendant
- Maintain standoff of non-attendants and potentially flammable materials
- If not charge rating specified, charge at 1C (one times the capacity)
- If using a balancer, balance per manufacture instructions
- Log duty cycle and charge event

Storage

- For short term (two weeks or less), at least 3.5V/cell
- For longer storage 3.8V-3.9V/cell, inspect voltage every 3 months, recharge if required
- 40-70F (no refrigeration)
- Metal HAZMAT storage cabinet away from combustible materials on ceramic tiles
- Labeled "Lithium Battery Storage Only"
- 6 inches clearance between top of battery and next shelf
- Log storage event

Retrieval from storage

- Inspect for material hazards. Deficiency = dispose
- Check charge of each individual unit (3.2V-4.2V)
- Check imbalance not greater than 0.1V.
- Repair only if no material hazard criteria evident.
- Log events

Inventory

- Log each event – acquisition, duty cycle, crash, repair, charge anomaly, etc

Transport

- 20-150F degrees for transport purposes only
- Sealed hard case, only batteries
- Multiple batteries per case OK, but damaged batteries must have own case for isolation.
- Do not mix charging with transport
- No direct sunlight for extended periods

Fire Emergency

- Use ABC fire extinguisher for non-battery items
- If charging remove power from charger

- Call emergency services
- Ignition of water quenchable battery – quench with water
- Ignition of non-water quench battery – let the battery ignite to completion
- After fire out, watch smoking area for 45 minutes, if charging disconnect the charger
- Keep in safe place for 24 hours prior to disposing of remains

Unmanned Aircraft Systems (UAS) Special Procedures: See Appendix A of NPS SOP
Multipack Requirements: See Appendix B of NPS SOP
Use in Marine Research: See Appendix G of NPS SOP

SAFETY PROGRAM OVERVIEW

LITHIUM BATTERY SAFETY PROGRAM

The Navy's Lithium Battery Safety Program (LBSP) is structured around four steps:

1. Submission of a Safety Data Package by the requesting program manager.
2. Safety Testing of the battery by LBSP approved personnel.
3. Safety Review of the data package and test results by the LBSP's designated technical agents.
4. Approval: formal recommendation, by the LBSP manager, for approval of the proposed battery's use by the requesting program manager.

The NPS Lithium Polymer safety program complies with the Navy Lithium Battery Safety Program. Clearances have been requested and approved only after submitting the above required Safety Data Packages to the LBSP technical agents. On 11 August 2014, "use of lithium ion batteries limited to less than 300 watt-hours during research efforts (unmanned aerial systems (UAS), unmanned underwater vehicles (UUV , and robotics) at the NPS and research operations under their supervision conducted at controlled airspace at shore facilities" was granted by the Naval Ordnance Safety and Security Activity (NOSSA).

Part of this approval was consideration of elements of the President's requesting letter, which cited that participating researches will receive training on the NPS Lithium Polymer SOP (#3 above) and will be accountable for procedures in that document as well as restrictions delineated in the requested clearance document (#4 above).

This Safety Orientation ensures your acknowledgement of those documents, the Navy LBSP, the NPS LiPo SOP, plus a general review of Lithium Battery Safety to raise your awareness and apply to your research effort.

PLEASE COMPLETE THE FOLLOWING:

Having read the safety guidelines above and those contained in the manufactures reference materials, I am fully aware of the Lithium battery safety guidelines of the Navy, NPS, and the laboratory I am working in.

Name:________________________ **Signature:** ________________________ **Date:** ________

Project Supervisor: ________________ **Signature:** ________________________ **Date:** ________

Bring a copy of this document to:
NPS Research Safety: POC - Scott Giles, Research Safety Department, x7568, 285 Halligan

NPS Safety Engineer: ________________ **Signature:** ________________________ **Date:** ________
NPS Safety POC: Scott Giles, Research Safety Department, x7568

Appendix I
Special Instructions for High-Voltage Lithium Polymer Batteries

Several manufacturers are offering so-called High-Voltage Lithium Polymer packs (e.g., Advance Energy/ThunderPowerRC and FMA/Revolectrix). The cells are typically rated for slightly higher voltage. Instead of a peak voltage of 4.205 V/cell, they have peak voltages of 4.27 and 4.35 V/cell available at the present time. The higher voltage could translate to higher performance of motors where RPM is proportional to voltage. They also may offer higher specific energy for low-power, long-endurance applications. The energy densities are claimed to be on the order of 205-215 Wh/kg.

Charging:

To accommodate higher voltage, special chargers (or chargers with special firmware) are required. High-voltage packs must be charged using specified chargers from the manufacturer of the batteries. Peak voltage and charge rates must be in accordance with manufacturer specifications.

Storage:

Storage procedures are the same as normal Lithium Polymer batteries.

Use:

Voltage ranges under use should follow manufacturer recommendations.
The low voltage cutoff should be adjusted by the same delta as the peak voltage. For example, for an HV pack with a 4.35 peak cell voltage, the delta is 4.35 V – 4.2 V = 0.15 V. Therefore the low-voltage cut-off should be 3.2 V + 0.15 V = 3.35 V per cell. For a 3S pack this would result in a low-voltage cut-off of 3 x 3.35 V = 10.05 V.

Care must be taken when combining HV packs with operational electronics from other manufacturers that may have features programmed for non-HV LiPo packs. Many ESCs have an automatic cell count program that dictates the automatic low-voltage cutoff. The higher pack voltage may cause the ESC to think there is one more cell than there really is. For non-programmable ESCs this could cause a premature cutoff. For example, a 3S HV pack with a peak voltage of 13.05 V will register as a 4S pack, and the logic in the ESC will then cut off power at 4 x 3.2 V, or 12.8 V. This could cause a premature shutdown, which is operationally safe for the batteries, but potentially constraining. On programmable ESCs, the cell-count option should be disabled, and a total pack voltage for cut-off should be entered.