DEPARTMENT OF THE NAVY
NAVAL POSTGRADUATE SCHOOL
1 UNIVERSITY CIR
MONTEREY, CA 93943-5000

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From: President, Naval Postgraduate School
To: Lithium Battery Managers and Operators, Naval Postgraduate School

Subj: NAVAL POSTGRADUATE SCHOOL STANDARD OPERATING PROCEDURES FOR RECHARGEABLE LITHIUM BATTERIES

Ref: (a) Commander, Naval Sea Systems Command ltr 9070 Ser 05Z/472 of 25 Aug 21

Encl: (1) NPS Rechargeable Lithium Battery Standard Operating Procedures v1.0 of 15 Oct 21

1. Reference (a) outlines a process for Naval Research and Development Establishment (NR&DE) including Naval Postgraduate School (NPS) to develop and establish certification processes of small lithium-ion batteries and lithium-ion battery powered systems.

2. Enclosure (1) supersedes and replaces NPS Standard Operating Procedures (SOP) Safety & Usage Procedure for Lithium Polymer Batteries v1.4b, captures all formats of rechargeable lithium batteries, captures contemporary developments of lithium battery safety technology, and reflects the guidance of reference (a) as it can be applied to NPS. This updated SOP will expand support of a safe and agile lithium battery environment for all NPS missions.

3. This Rechargeable Lithium Battery SOP will be a critical element for NPS to meet the criteria for application of NR&DE Lithium Battery Safety Certifications. The NR&DE rechargeable lithium battery certification processes will increase NPS mission agility as proper locally applied safety controls, certification of rechargeable lithium batteries of all chemistries that are less than 1,000 watthours may be completed in days instead of months or years.

ANN E. RONDEAU, Ed.D
Vice Admiral, U.S. Navy (Ret.)

Rechargeable Lithium Battery
Standard Operating Procedures

Naval Postgraduate School (NPS)
Version 1.0
15OCT21

This supersedes and replaces NPS Standard Operating Procedures (SOP) "Safety & Usage Procedure for Lithium Polymer Batteries" Version 1.4b of January 2016

Enclosure (1)

Record of Review and Approval for

Rechargeable Lithium Battery Standard Operating Procedures

Naval Postgraduate School
Version 1.0
15OCT21

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Submitted: ______________________
Scott Giles, Safety Engineer

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Reviewed: ______________________
CAPT Edward McCabe, USN, Assistant Chief of Staff for Aviation Activities

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Antolino Colon, Occupational Safety and Health

Reviewed: ______________________
CAPT Philip Old, USN, Chief of Staff

Contents

Purpose

This SOP defines and standardizes safety controls of rechargeable (secondary) lithium battery systems, specifically Lithium-ion (Li-ion), Lithium Polymer (LiPo), Lithium Iron Phosphate (LiFe or LiFePO4 or LFP), and Lithium Titanate (LiTO) batteries. Adopting these controls into Naval Postgraduate School (NPS) culture will greatly reduce the probability, and often the severity of a battery system failure. Adoption and adherence to these standard procedures is a pre-requisite for required Naval Sea Systems Command (NAVSEA) system reviews, and of expedited NAVSEA certification for operations through Naval Research and Development Enterprise (NR&DE) certification application processes.

References

- OPNAVINST 5100.23H (5Jun20), Navy Safety and Occupational Health Program
- NAVSEAINST 9310.1C (12Aug15), Navy Lithium Battery Safety Program
- NAVSEA S9310-AQ-SAF-010 Rev 3 (03Nov20), Navy Lithium Battery Safety Program: Responsibilities and Procedures
- Implementation of the Criteria for application for Naval Research and Development Establishment Lithium Battery Safety Certification (NAVSEA Ser 05Z/472 25Aug21)

Background

OPNAV 5100.23H specifically assigns NAVSEA as the responsible agent for the Navy Lithium Battery Safety Program. NAVSEA guidance is detailed in NAVSEAINST S9310.1C and NAVSEA S9310 (TECHMAN). In 2014 NPS developed and adopted an SOP for Lithium Polymer (LiPo) format batteries to secure a certification to use LiPo batteries at NPS and at shore range facilities for Unmanned Air Vehicles (UAV), Unmanned Undersea Vehicles (UUV), and Unmanned Ground Vehicles (UGVs). Together, these groups of systems are referred to as UXVs. In 2015 the SOP was revised and expanded to include marine research operations and high voltage LiPo formats.

Lithium battery growth has progressed rapidly. Other rechargeable Li-ion formats are becoming common, and applications are expanding well beyond UXVs. NPS successfully extrapolated the LiPO SOP beyond UXVs and to other battery formats "as might be applicable" through 2021. The publication of the proposed NAVSEA NR&DE certification process in August of 2021 revealed it was necessary for NPS to formally expand the definitions and standardization of the LiPo SOP to all rechargeable lithium-ion formats, and all NPS working areas including space, high altitude, air, underground, shore, undersea, surf, and surface research environments.

Hazard

Li-ion batteries have the potential to ignite through thermal runaway – energy captured or generated is accelerated by increasing temperature. An increase in temperature changes the conditions in a way that causes a further increase in temperature, potentially leading to a destructive result. It is uncontrolled positive feedback. A key enabler of thermal runaway is the thin barriers that separate energetic lithium ions lose effectiveness when they get hot.

Thermal runaway can be started by the stored energy in the battery. Manufacturing defects of the ionic separators, trauma that fails the separating structures, or the internal resistance of the battery under high electrical current all can allow conversion of the potential chemical energy of the cell into battery heat at any temperature.

Thermal runaway can be started by any external source of heat. A short circuit might not only heat the internal battery parts with very high current, but the connecting wires will heat and add energy to the battery internals by close conduction. Any environmental heat from conduction, convection, or radiation can raise cell temperatures. Sunlight can raise battery temperatures above safe operating levels.

Any combination of internal and external heat sources such as defects, normal operations, charging, nearby hot components, direct sunlight, short circuit, or hot circulating air will accelerate temperature-induced ion-barrier breakdown and aggravate other barrier defects, that generates heat right at the ion-barriers, decreasing barrier effectiveness further and allowing more energy to escape.

A thermal runaway can result in an explosion and fire. A single cell might explode and vent plasma for 60 seconds and then be done. If many cells are together, heat from one cell can propagate to neighbors. In a pack of cells, this can result in a train of failures, fires, sustained plasma jetting, or explosions so long as the thermal runaway propagates to more cells.

Explosions can eject hot battery plasma, battery parts, or system parts onto people or the working environment. Plasma jets and fire can destroy the system and ignite nearby combustible material. The electrolytic fluids inside the battery are oxygenated and when hot enough will burn without air and emit hot, toxic smoke and fumes. The chemical energy of burning oxygenated electrolytic fluids can add up to 10x the rated energy content of the battery.

A deliberate hazard analysis of battery induced structure fires, battery induced forest fires, of explosion damage to people, of people ingesting ignition products, and the program risk of failing to get batteries certified is in Appendix D.

<u>SOP Limitations</u>

This SOP cannot cover all possible applications. The following situations require additional in-depth controls, and command case-by-case attention. This SOP may serve as a reference from which to build or deviate, but it is not designed to include:

- Batteries in the environment of fuels, unless ONLY during fueling or defueling.
- Batteries greater than 100 Volts Direct Current (VDC)
- Batteries with ordnance
- Primary battery systems

Battery systems for these cases should review NAVSEA 9310.1C (12Aug15) and NAVSEA S9310-AQ-SAF-010 Rev 3 (03Nov20) for comprehensive management requirements not included in this SOP.

Battery systems that are

- Greater than 1000 Watt-hours (Wh)
- Manufactured by NPS

are specifically not intended to be included in the NAVSEA NR&DE certification process, but shall be managed by this SOP and the standard NAVSEA test and review processes.

<u>Acquisition</u>

All lithium batteries and lithium battery systems require management and safety controls detailed in NAVSEA 9310.1C and the NAVSEA S9310 TECHMAN including acquisition reporting and possibly recycling or disposal commitments during the acquisition phase.

All lithium and lithium battery systems that are purchased at NPS shall be marked with the Commodity Code "Lithium Batteries" in Kauli Financial System (KFS) to route for Safety review, data recording, acquisition reporting, KFS documentation, and acceptance. Safety review will include ensuring the purchasing end-user has sufficient infrastructure such as storage space, charging equipment, fire controls, hazard awareness, and an end-of-use re-purpose, recycle, or disposal plan. Safety shall review for the possibility of counterfeits, and if a threat of counterfeit cannot be reasonably avoided Safety shall coordinate with the end user for an inspection upon delivery.

Systems not covered by TECHMAN exceptions, NR&DE exceptions, or existing NPS system exceptions for NAVSEA directed review and test shall be advised of details of the safety program, infrastructure requirements, management processes, and review request processes. These acquisition requests shall be held by Safety until

- The Principal Investigator (PI) has submitted mature DRAFT request paperwork to Command Admin for any required NAVSEA reviews

- The PI presents an infrastructure plan that meets the requirements directed by the TECHMAN and NPS SOP
- The sum of all mitigations is expected to align with intent of the appended deliberate hazard analysis.

Lithium batteries acquired through a competitive contracting process may lack exact specification required for acquisition data recording and reporting requirements. In these cases, lithium batteries or lithium battery systems in competitive acquisition may be contractually specified to be "NAVSEA S9310 compliant". This should ensure almost all batteries are less than 100Wh and have been tested for consumer safety by an independent third party. If either of these are not the case upon delivery, then the supplier is contractually obligated to change the batteries for compliant batteries, or secure NAVSEA compliance through the TECHMAN S9310 test and review process.

<u>Acceptance on Delivery</u>

Upon receipt of a new battery, inspect for signs of physical damage such as punctures, broken heat shrink, bare wires, dents, scratches, and swollen or ruptured cells. If more than 2 cells in series and it is known that pack has no internal or system Battery Management System (BMS), the pack must have a balancing lead that provides a means to monitor individual cell voltages.

<u>Battery Pack Configuration – soldering connectors</u>

If necessary to add a connector, only a female connector shall be soldered to the battery leads.

Check individual cell voltages before work. They should be about 3.8Volts (V), but must be in the range of 3.4V to 4.0V with no imbalance across the cells exceeding 0.1V.

Expertise and skill are required to avoid accidental shorting the battery leads, to capture techniques that promote proper integrity of the solder, and to create a solid electrical connection on heavy gage wiring. If not familiar with the techniques, it is required to be mentored by a person experienced with battery lead soldering techniques.

<u>Danger</u>: Extreme care must be taken to never expose both leads simultaneously. Exposing both leads present an unacceptable risk for an inadvertent shorting. A clamp or jig shall be 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.

<u>Caution</u>: Heat from solder iron or heat gun can damage the battery.

Adding a female connector:

1. Remove the factory installed heat shrink from the positive (red) lead only.
   <u>Danger</u>: 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. Check the connection for solder integrity and good electrical contact.
6. Slide the heat shrink into place such that no exposed metal remains and shrink it securely around the solder joint.
7. Repeat for the negative lead.

Changing an existing connector:

1. Remove the heat shrink from the positive (red) solder joint only.
   <u>Danger:</u> 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 female connector. Check the connection for solder integrity and good electrical contact.
7. Slide the heat shrink into place such that no exposed metal remains and shrink it securely around the solder joint.
8. Repeat for the remaining lead.

<u>Storage</u>

All Lithium batteries shall be stored **either:**

- In a metal container lined on the bottom of each shelf with ceramic tiles. The cabinet will be dedicated and placarded for "Lithium Battery Storage Only". Flammable rated cabinets that comply with Occupational Safety and Health Administration (OSHA) and National Fire Protection Association (NFPA) standards shall be used for packs with a capacity over 1kWh. Examples are in Appendix A.
- Or if less than 100Wh, in a Lithium Battery Safety Bag on ceramic tiles, concrete, or other ceramic substance like granite. More than one bag may be stored together not exceeding 1kWh total capacity in the same location. Example is in Appendix A.

All lithium batteries shall be stored

- In a temperature-controlled environment between 40 Fahrenheit (F) and 70F, but never in a refrigerator
- With a minimum of 4 inches vertical clearance between the top of a stored battery and the bottom of the next shelf
- In an area protected by an automatic sprinkler system
- Away from combustible materials (flashpoint >100F) and at least 5 feet from flammable materials (flashpoint <100F)
- With minimal additional fuel like cardboard packaging or this SOP.
- Near a fire extinguisher designed to fight Trash, Wood, Paper, Liquids, Electrical Equipment (ABC)
- In uninhabited spaces
- Away from HAZMAT
- Charged to at least the minimum battery recommended storage charge state. For many lithium-ion packs this is 3.5V/cell.
- Inspected for integrity and state of charge at least every 3 months.

All lithium batteries should be, and for ND&RE certification processes shall be

- Stored in an OSHA and NFPA flammable rated cabinet
- Aggregated such that the maximum energy content does not exceed
  - 1kWh for cabinets with at least 4-gallon volume
  - 3kWh for cabinets with at least 12-gallon volume
  - 7kWh for cabinets with at least 30-gallon volume

- 10kWh for cabinets with 45-gallon volume or greater

All lithium batteries should be

- Compartmentalized by vertical ceramic barriers if total content exceeds 4kWh
- Stored at no more than the maximum battery recommended storage charge state. For many lithium-ion cells this is 3.9V.
- Inspected for integrity and state of charge every 2 weeks if stored at the minimum battery recommended storage charge state.

Charging

Inspect the battery for integrity before attempting charging. The battery pack shall:

1. Not show punctures or deep scratches to individual cell casings. Dispose.
2. Not show significant deformation from crashes or handling trauma. Dispose.
3. Not show swelling in any cell, which may indicate internal damage. Dispose.
4. Not show a total voltage equivalent to less than battery minimum for safe operations (usually 3.2V per cell for Li-ion), and the voltages from each cell shall not vary more than 0.1V. Balance or dispose.
5. Not show bare wires or leads that create risk of shorting the pack. Dispose.
6. Be free of the smell of electrolyte, which would indicate poor sealing or leaking. Dispose if the smell of electrolyte is detected.
7. Be ambient temperature. No hot packs from operations, storage conditions, sun heating, transportation, or unexplained heating. Let it cool in a controlled environment and re-assess.

Charging shall not be conducted in the same metal storage cabinet unless it is one solitary battery.

Secondary lithium batteries shall be charged

- With an Emergency Response plan on location – general Emergency Response guidance is below
- Only with equipment specifically designed for the battery pack
- At no faster than manufacturer recommended rate (usually 1C or less)
- With cell balancing for multicell packs, in case there is some option to not do this
- On ceramic tiles, concrete, or other ceramic substance like granite or bedrock earth.
- With a knowledgeable attendant in or around the charging space. No unattended charging. No unattended overnight charging.
- With the capability of jettisoning the system to a safe area, or alternatively where occupants can easily abandon the space by a clear exit path
- Be clearly placarded, signed, or briefed to everyone in the space so they are aware that lithium battery charging is taking place. This should include the egress plan for thermal runaway, the location of any emergency alert devices such as pull fire alarms, and dial (9)911.
- Protected by an automatic sprinkler system if indoors
- In a temperature-controlled environment between 40F and 70F if indoors
- Protected from temperature extremes if outdoors, no less than 32F, no more than 120F.
- Near a dousing water source or ABC fire extinguisher
- More than 5 feet from combustible or flammable materials
- Away from any valuable equipment

Secondary lithium batteries should be charged

- In a lithium safety bag
- With placard indicating the PI, type of battery, power applied, emergency instructions, and contact numbers

- With consideration of an emergency ventilation plan to dump smoke
- With consideration to isolate the Heating, Ventilation, and Air Conditioning (HVAC) system from the charging space

If multicell, the battery must be balanced to 0.1V at the end of a charge to be used for operations. The battery shall be inspected again for integrity and abnormal indications after charging and before operations.

Emergency Response

Danger: Gases released from combustion of batteries include sulfurous and halide gases that will form acid gases upon contact with eyes, skin, and lung tissue. Combustion of organic solvents will generate carbon dioxide and carbon monoxide. Carbon dioxide displaces breathable air and can cause asphyxiation. Carbon monoxide reduces the ability of the blood to transport oxygen. Hydrogen chloride and sulfur dioxide byproducts will form acid gases that will damage and scar lung tissue and will cause internal fluid accumulation in the lungs, decreasing the ability to absorb oxygen. Combustion products of plastics and other ancillary materials are also potentially toxic.

If evacuation is required, muster meet point will be the same as for fire drill or fire alarm. Expect to meet emergency responders at the meet point. Emergency responders should have knowledge of lab hazards but make it a point tell them "Lithium battery fire".

For field operations, bring or source ABC fire extinguishers, ceramic vessels (flower pot), lithium battery safety bags, and a shovel or protective gloves.

An ABC fire extinguisher or dousing water shall be kept readily accessible where batteries are being charged, stored, or in operations. For field operations where water is not practical a fire extinguisher shall be maintained near the batteries during charging, and at the field operations site, so more than one may be required.

Battery Ignition While Charging

Most lithium batteries present an elevated risk for ignition while charging. In the event of a battery ignition during charging:

1. Plan to let the battery finish its ignition – usually no more than 60 long seconds. Unplug the charger at the wall or its external power source if possible.
2. See and avoid the hot toxic fumes
3. If unable to see and avoid the fumes, vacate the area and call fire emergency services. Tell them "Lithium battery fire". This is highly encouraged. You are likely not a professional first responder or fire fighter. Let the professionals do their job.
4. Only if easy to avoid the smoke and fumes, use the fire extinguisher to prevent the spread of fire.
5. Only if easy to avoid the smoke and fumes, use water available to douse the lithium battery
6. After the ignition is complete and all fire out, monitor the battery for 45 minutes.
7. After 45 minutes extract the battery to a ceramic vessel (tile or flowerpot) or Lithium battery safety bag and set it in a safe place.
8. After at least 24 hours, dispose of battery remains as any battery at end of life.

Battery Ignition in Storage

Lithium batteries do not frequently ignite while in storage, but on rare occasions they do. Risk is elevated if a pack has damage, immediately after operations, and after charging while a pack is still "hot".

To minimize risk to storage facilities, it is recommended to allow a 45-minute observation period after operations or charging.

1. Plan to let the battery finish its ignition – usually no more than 60 long seconds.
2. If there is the slightest danger to the surrounding structures or property, contact emergency services immediately (9)911. Tell them "Lithium battery fire".
3. If unable to see and avoid the fumes, vacate the area and then call fire emergency services if not done already. Tell them "Lithium battery fire". Let the sprinkler system and professionals do their job.
4. Only if easy to avoid the smoke and fumes, use the fire extinguisher to stop fire spreading
5. Only if easy to avoid the smoke and fumes, use water available to douse the lithium battery
6. After the ignition is complete and all fire out, monitor the battery for 45 minutes.
7. After 45 minutes carefully move the battery to a safe location and store in a ceramic vessel (flowerpot), on a ceramic tile, or Lithium battery safety bag.
8. Leave the battery in a safe location for at least 24 hours prior to disposing of battery remains.

Transportation and Shipping

Transportation on public thoroughfare requires the cells be tested and pass transportation criteria specifications of UN Manual of Tests and Criteria Standard for Transportation Testing of Lithium Batteries (UN38.3). Transportation by contract carrier such as United Parcel Service (UPS), or Federal Express (FedEx) requires preparations and packaging in accordance with DOT 49 CFR 172.101, 172.102, and 173.185, and the carrier directions. The contract carrier directions follow the Department of Transportation (DOT) 49CFR173.185. There are exceptions, but plan and expect that contract carriers will not ship large lithium batteries by air.

- DOT 49CFR173.185
- FedEx guidance as of April 2019
- United States Postal Service (USPS) guidance as of May 2019

Transportation by passenger air carrier is controlled by the Federal Aviation Administration (FAA) and the specific airline may have additional controls. Check with the airline of interest.

- FAA Pack Safe Batteries, Lithium

Generally, the FAA guidance states lithium ion and lithium metal batteries must be carried in carry-on baggage. The battery terminals must be protected from short circuit. Carry on lithium rechargeable batteries are limited to 100Wh per battery. With airline approval, passengers may carry up to two spare larger lithium rechargeable batteries up to 160Wh. No quantity limit is detailed, except the batteries must be for use by the passenger. Damaged or recalled batteries are prohibited.

Batteries transported by NPS conveyance shall.

1. Be disconnected from all electrical systems and have the leads protected
2. Either be in the system (with power disconnected), or be within a hard case with padded packaging inside
3. Packed separate from metal and heavy items that could damage or short.
4. Shielded from prolonged direct sunlight
5. Be temperature controlled greater than 20F and less than 150F. **Danger**: Lithium rechargeable batteries held at temperatures greater than 170 F for more than 2 hours may cause thermal runaway and ignition.

More than one battery may be transported in any hard case. Keep multiple batteries separated by packaging and the leads protected.

Damaged or suspect batteries may be transported after a completely uneventful 45-minute observation period and shall be transported in isolation in a ceramic vessel (flower pot) or lithium battery safety bag.

A battery that is damaged or suspect and charged shall be discharged by normal means if possible before transport. Battery carcasses that have ignited are required to have 24 hours in a safe place before transportation. It is recommended damaged or suspect batteries be allowed 24 hours in a safe place before transportation.

Rechargeable lithium batteries deployed to marine research or naval vessels shall be declared at least 30 days prior or at any earlier pre-sail meeting.

- The PI is responsible for ensuring the NPS requirements for storage, charging, disposal, and emergency response are communicated to the ship Captain and Chief Engineer.
- The PI is responsible for capturing, understanding, and being prepared to comply with the vessel's storage, charging, use, disposal, and emergency response requirements.
- At a minimum, at least 30 days prior, it shall be required to know
    - The exact batteries and how many
    - The size and form of storage that is required for these batteries by NPS and the vessel
    - The way the batteries will be delivered
    - The space the batteries will be stored aboard the vessel, and if NPS shall be supplying storage infrastructure
    - The vessel procedure if the batteries ignite in storage
    - The vessel battery charging plan and processes
    - The vessel procedure if the batteries ignite while charging
    - The plan to move batteries from storage to charging to operations and back
    - The vessel procedure if the batteries ignite during operations
    - A disposal plan for damaged, suspect, or end-of-life batteries
- For Navy warships, a NAVSEA certification will be required after a formal review by NAVSEA 05Z34 technical agents.

Additional discussion summarized from University-National Oceanographic Laboratory System (UNOLS), Woods Hole Oceanographic Institute (WHOI), and the "Navy Ships Technical Manual Chapter 555 V1 Surface Ship Fire Fighting" is in Appendix C

<u>Disposal</u>

Lithium batteries are managed as universal waste under the U.S. Code section 42 U.S.C. §6901. Any battery that shows evidence of leakage, spillage, or damage that could cause leakage under reasonably foreseeable conditions is managed as hazardous waste.

At end-of-use, rechargeable lithium batteries often have recycling value. NPS has purchased battery recycling services from <u>Big Green Box</u>

Green drop boxes are positioned throughout campus and strategically located near many labs. A discharged dead battery with the leads protected by tape can be dropped in these green boxes. Please write "Fully Discharged" on the pack or cell.

If the battery cannot be discharged, thoroughly protect the leads with tape and contact your Hazardous Materials representative for a pick-up by Naval Support Activity Monterey. Note the state of charge on the battery pack.

If the pack is leaking, place the battery in a strong plastic bag or container. Place enough absorbent in this container to completely absorb all liquid contained in the battery. Label the container "HAZARDOUS LEAKING LITHIUM BATTERY FOR DISPOSAL". Contact your Hazardous Materials representative for an immediate pick-up by Naval Support Activity Monterey.

Do not puncture and sink in salt water. Puncturing can cause an ignition.

<u>Reporting and Responsibilities</u>

The NPS President shall ensure the Safety Department is resourced to

- Support all NPS lithium battery compliance oversight required by this SOP and the S9310 TECHMAN
- Collect and report acquisition data as specified by Chapter 4 and Appendix E of the S9310 TECHMAN
- Assist and lead NPS PIs with any formal review requests and associated safety data packages detailed in Chapter 4, Chapter 5 and Appendix D of the S9310 TECHMAN.
- Report mishaps in accordance with OPNAV 5102.1 and S9310 TECHMAN Chapter 1-9.2

The Safety Department shall

- Generate and submit Initial Procurement Reports (IPR) required by the S9310 TECHMAN Chapter 4 and detailed in TECHMAN Appendix E for all lithium batteries and lithium battery systems. The Safety Department shall collect all IPR data during acquisition reviews usually through public domain research, collaboration with the PI, or collaboration with the supplier. IPR data for competitive sourced requirements may be collected by inspection of the system upon delivery. This process and reporting govern most small batteries and Commercial-Off-The-Shelf (COTS) battery systems up to 100Wh.

- Generate and submit reports required by NR&DE Certifications as detailed in the Reporting Requirement section of the NAVSEA letter Ser 05Z/472 of 25 Aug 21 "Application for Naval Research and Development Establishment Lithium Battery Safety Certification". This process and reporting govern larger COTS rechargeable batteries and battery systems up to 1000Wh.
- Educate PIs, review system mission and materials, and support generating formal standard NAVSEA review requests and associated safety data packages detailed in Chapter 4, Chapter 5 and Appendix D of the S9310 TECHMAN. This process and reporting govern all other lithium batteries and lithium battery systems.
- Review infrastructure, hardware, and processes with PIs for compliance and effectiveness of controls and mitigations
- Lead mishaps investigations for lithium battery mishaps, then generate and submit all reports in accordance with OPNAVINST 5102.1 and S9310 TECHMAN Chapter 1-9.2.

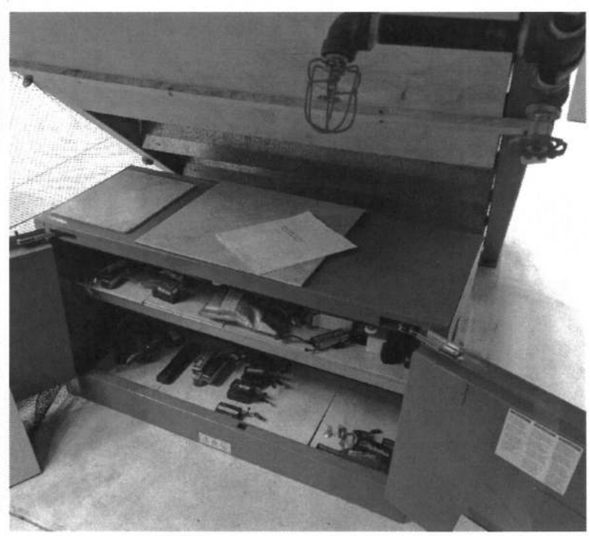
The NPS Command Administrative Department shall serialize and finalize for Presidential signature DRAFT formal Authorization Review Letters (ARL) submitted by the Safety Department or a PI.

PIs are ultimately responsible for operating lithium batteries and battery systems in accordance with the Navy Lithium Battery Safety Program as detailed in NAVSEA S9310.1C, the S9310 TECHMAN, the NR&DE Certifications process, and this SOP. This includes:

- Resourcing sufficient infrastructure
- Training and equipping operators
- Submitting lithium battery acquisitions for review in KFS
- Championing initial procurement reporting requirements and processes
- Championing review request and data packages if required
- Obtaining certifications before operations

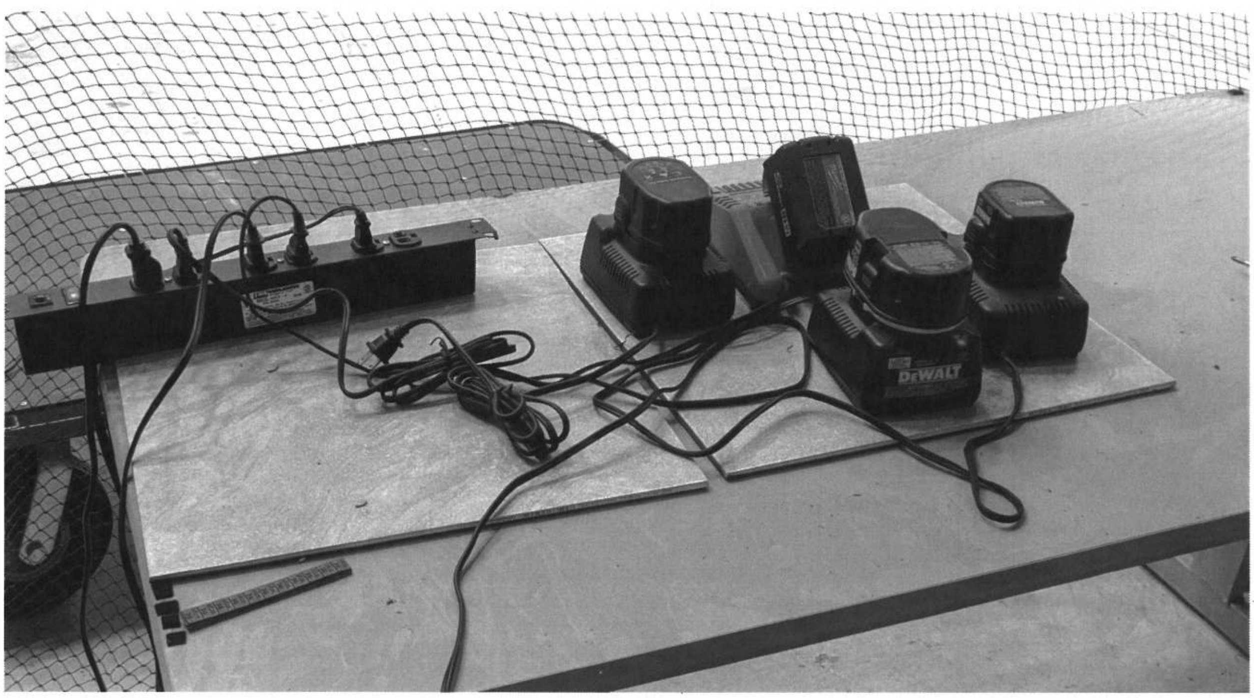
Appendix A
Storage and Charging Station Examples

Metal Cabinets



Lithium Battery Safety Bags Storage (total energy less than 100Wh/bag, no more than 5 packs/bag)

Charging Station



Appendix B
Unmanned Systems (UXS) Specialized Procedures for LiPo and Li-ion packs

Charging

If deployed, field swappable batteries shall not be charged inside of an unmanned system.

Systems specifically designed to be charged inside the unmanned system may be charged inside the system.

Check the pack voltage and temperature before charging. Do not attempt to charge if detectably warmer than ambient by touch. Do not attempt to charge any pack if the total unloaded voltage is less than 3.2V/cell. For example, do not charge a 2-cell pack if below 6.4V. Do not attempt to charge any pack if the unloaded voltage of any individual cell is less than 3.0V.

Post Flight

Upon recovery and normal system power-down, inspect 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, connect the balance leads to a battery pack checker to ensure that each cell is in the range 3.2V to 4.2V and that the cell imbalance is less than 0.1V. For "High Voltage" cells, follow the manufacturer's recommendation for cell voltage minimums.

Crash with a battery ignition

1. If smoldering in a safe place, assign an attendant and allow the system to burn or cool to completion within the unmanned system.
2. If there is any danger to surrounding structures or property, contact emergency services. Be sure to tell them "Lithium Battery Fire".
3. If burning and easy to see and avoid the smoke and fumes, 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 unmanned system using a shovel or protective gloves.
6. Place remains in a ceramic vessel (flowerpot) or lithium battery safety bag
7. Leave the battery carcass in a safe location for 24 hours, then dispose.

Crash without a battery ignition

1. Cut power to the motors. Depower the system as much as possible remotely.
2. If in a safe place, let the unmanned system sit and monitor for 45-minutes
3. If not in a safe place, approach the crash site with caution, with an extinguisher, and upon inspection, determine if the unmanned system 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.
4. After 45 minutes without any notable activity recover the unmanned system and battery.
5. Inspect the battery thoroughly for integrity. If it passes and has cooled to ambient temperatures, place it back into service. If a log is maintained, note the crash data.

Appendix C
Additional Guidance for Deploying Lithium Batteries to Marine Research Vessels

Guidance is best summarized for University-National Oceanographic Laboratory System (UNOLS) vessels in a "Lithium Battery Safety Information" memo of 10 May 2012 from the UNOLS Research Vessel Operating Committee (RVOC) - Safety Committee.

The UNOLS RVOC-Safety Committee references the Woods Hole Oceanographic Institute Lithium Battery Safety Procedures of 23 February 2011, which has extensive detail on the design, use, store, and dispose processes required for all Woods Hole Oceanographic Institute (WHOI) personnel

Surface Navy additional guidance may be collected from S9086-S3-STM-010, "Navy Ships Technical Manual Chapter 555 V1 Surface Ship Fire Fighting". A selection from the of 01 January 2010 edition is 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 Wh can produce significant thick, toxic smoke which will fill a compartment in seconds. Breathing equipment and a Naval Firefighting Thermal Imager (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 Aqueous Film Forming Foam (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, 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 self-contained breathing apparatus and firefighting ensembles 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 de-smoking of the affected compartment as soon as practicable during the casualty to remove heat, smoke and toxic gases. Active de-smoking can be initiated simultaneously with other actions.

Appendix D

NPS Lithium Battery Program
Deliberate Risk Analysis

31AUG21

Identify:

Battery fire catches NPS building on fire – storage or charging
Battery fire catches urban building on fire or starts a forest fire - operations
Battery fire injures personnel
Battery explosion or any loss of integrity impacts personnel
Battery materials from an explosion, fire, or any loss of integrity are ingested
NPS program is halted for unauthorized batteries (Programmatic Risk)

Assess:

Loss of NPS building or personnel in fire

- **Severity** is **Category I Catastrophic** - Major facility damage. Severe environmental damage. Mission-critical security failure. Unacceptable collateral damage.
- **Probability** is **Category E Unlikely** - Unlikely to occur, but possible in the service life of NPS. Overhead sprinklers will likely limit the severity of damage for all but historical situations.
- **Risk Assessment: I-E or Code 3 – Medium**

Loss of NPS lab due to a battery fire with nearby flammables, but contained to one room

- **Severity** is **Category II Critical** - Extensive damage to equipment or systems. Significant damage to property or the environment. Security failure. Significant collateral damage.
- **Probability** is **Category D Seldom** - Can reasonably be expected to occur sometime to an individual item or person, or several times over a service life for an inventory of items, or group
- **Risk Assessment: II-D or Code 3 – Medium**

Forest Fire

- **Severity** is **Category I Catastrophic** - Death or permanent total disability. Severe environmental damage. Mission-critical security failure. Unacceptable collateral damage.
- **Probability** is **Category C Occasionally** - Expected to occur several times to an individual item or person; or frequently over a service life for an inventory of items or group.
- **Risk Assessment: I-C or Code 2 – High**

Urban fire outside of NPS

- **Severity** is **Category I Catastrophic** - Death or permanent total disability. Severe environmental damage. Unacceptable collateral damage.
- **Probability** is **Category E Unlikely** - Unlikely to occur, but possible in the service life of NPS. This requires a battery fire that spreads from a mobile, likely remote and unmanned system offsite but in or around flammable structures or materials
- **Risk Assessment: I-E or Code 3 – Medium**

Personnel sustain explosion or material contact injury

- **Severity** is **Category II Critical -** Permanent partial disability or severe injury or illness.
- **Probability** is **Category D Seldom** - Can reasonably be expected to occur sometime to an individual item or person, or several times over a service life for an inventory of items, or group

- **Risk Assessment: I-E or Code 3 – Medium**

Personnel ingest hot toxic fumes

- **Severity** is **Category II Critical -** Permanent partial disability or severe injury or illness.
- **Probability** is **Category B Likely** - Expected to occur frequently to an individual item or person, or continuously over a service life for an inventory of items or group.
- **Risk Assessment: II-B or Code 2 – High**

NPS program is halted for unauthorized batteries – Programmatic Risk (Cost Schedule, Performance)

- **Severity** is **Category II Critical** - Significantly degraded mission capability or academic readiness.
- **Probability** is **Category A Frequent** - Continuously experienced to an individual item or continuously over a service life for an inventory of items.
- **Programmatic Risk Assessment: II-A or Code 1 – High**

Make Risk Decisions:

Identify Control Options –

A. Follow controls of the Navy lithium Battery Safety Program as detailed through OPNAV 5100.23H, NAVSEA 9310.1C, and TECHMAN S9310-AQ-SAF-010 Rev3.
B. Accept risk of ignoring higher level guidance but manage batteries by each PI and NPS SOP.

Determine Control effects –

A. The Navy Lithium Battery Safety Program greatly **decreases the probability** of all hazards to **Unlikely (E)**. The storage and charging controls **decrease the severity** of a battery fire that spreads during these periods to **Moderate (III)**. The operational controls and system reviews, which may involve engineering changes to NPS systems, **decreases the severity** of explosions or fire in an NPS lab to **Moderate (III)**. The application of the Navy Lithium Battery Safety Program, after budgeting for the cost and schedule of the review process, **decreases the probability** of a program halt to **Unlikely**, and **decreases the severity** of a program halt to **Moderate (III** – Programmatically $20K, a few months delay).
B. Just NPS SOP and PI training, awareness and diligence will **decrease the probability** of fires, and personnel injuries to **Unlikely (E).** The storage and charging controls **decrease the severity** of a battery fire that spreads during these periods to **Moderate (III)**. There are no engineering controls hazard effects, nor programmatic hazard benefits.

Determine Risk Decision – Adopt Control Option A, which is a superset of Control Option B.

Implement Controls:

Make Implantation Clear – Publish an NPS SOP for lithium battery systems at NPS. In the SOP identify the details of the NPS adoption of NAVSEA 9310.1C, and TECHMAN S9310-AQ-SAF-010 Rev3. Include a training brief, and gouge sheets.

Establish Accountability – In the SOP clearly identify the PIs as ultimately responsible for the safety of lithium battery systems.

Provide Support – Identify and designate an NPS Lithium Battery Safety Officer as the process champion for the President. Empower direct Presidential communication of the NPS Lithium Battery Safety Officer to the President for Critical or Catastrophic battery matters. Train and equip the NPS Lithium Battery Safety Officer with ½ work year to administer processes, manage records, and facilitate PI efforts. Enforce a review for all lithium battery acquisitions (KFS) to ensure PIs have proper infrastructure and training to manage systems requested for procurement. Resource the NPS Lithium Battery Safety Officer to take a lead role in the Interagency Advanced Power Group (IAPG) to help steer Government-wide policy to the benefit of NPS safety and NPS research programs.

Supervise:

Monitor – Presidential signature and review of all NAVSEA system review requests. Chief of Staff review of all Lithium Battery Safety procurement reports. NPS Lithium Battery Safety Officer quarterly self-assessments.

Review – Since this is a mature program, review the NPS SOP as the Navy Lithium Battery Safety Program evolves, or if demand surges or disappears.

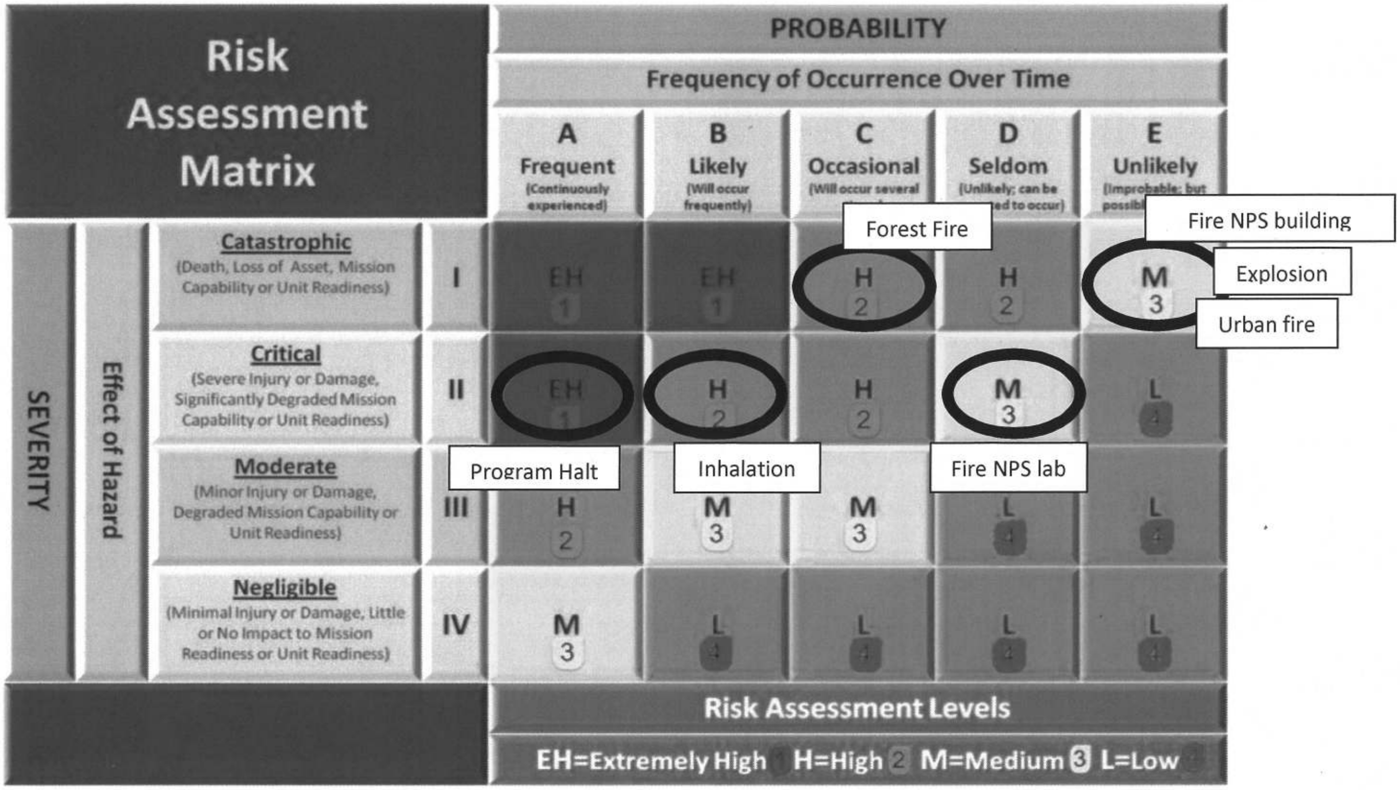
Feedback – NAVSEA Navy Battery Safety Program Managers and NSWC Technical Agents provide continuous safety and administrative feedback with each review and report. Presidential signature on review request is endorsement. Chief of Staff passive review of procurement reports is endorsement.

Recommendations:

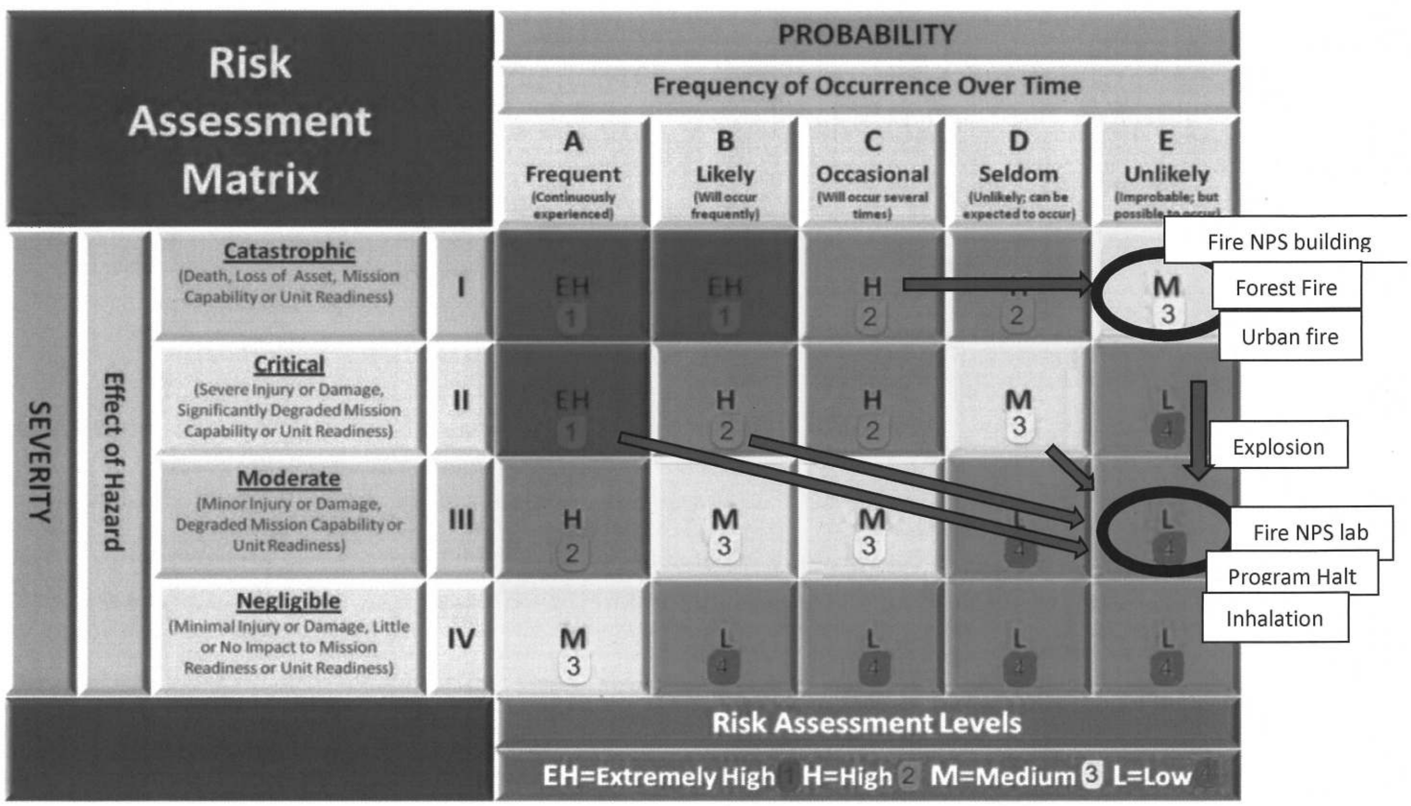
- Follow controls of the Navy lithium Battery Safety Program as detailed through OPNAV 5100.23H, NAVSEA 9310.1C, and TECHMAN S9310-AQ-SAF-010 Rev3.
- Identify and designate an NPS Lithium Battery Safety Officer as the process champion for the President.
- Empower direct Presidential communication of the NPS Lithium Battery Safety Officer to the President for Critical or Catastrophic battery matters.
- Train and equip the NPS Lithium Battery Safety Officer with ½ work year to administer the processes, manage records, and facilitate PI efforts.
- Enforce a review for all lithium battery acquisitions (KFS) to ensure PIs have proper infrastructure and training to manage systems requested for procurement.

Amplifying data:

- **Without mitigation**, the Program Risk is II-A Extremely High, and the System Safety Risk is risk is II-B or I-C High.
- **Adopting all mitigations and Recommendations** the Program Risk is III-E Low, and the System Safety Risk is risk is I-E Medium.



Initial Risk Assessment



Residual Risk Assessment after all Recommendations

Category	Description
I - Catastrophic	Loss of the ability to accomplish the mission. Death or permanent total disability. Loss of a mission-critical system or equipment. Major facility damage. Severe environmental damage. Mission-critical security failure. Unacceptable collateral
II - Critical	Significantly degraded mission capability or unit readiness. Permanent partial disability or severe injury or illness. Extensive damage to equipment or systems. Significant damage to property or the environment. Security failure. Significant collateral damage.
III - Moderate	Degraded mission capability or unit readiness. Minor damage to equipment, systems, property, or the environment. Minor injury or illness.
IV - Negligible	Little or no adverse impact on mission capability or unit readiness. Minimal threat to personnel, safety, or health. Slight equipment or systems damage, but fully functional and serviceable. Little or no property or environmental damage.

Category	Description
A - Frequent to occur	Continuously experienced to an individual item or person or continuously over a service life for an inventory of items or group.
B - Likely to occur, immediately or within a short period of time	Expected to occur frequently to an individual item or person; or continuously over a service life for an inventory of items or group.
C - Occasionally will occur in time	Expected to occur several times to an individual item or person; or frequently over a service life for an inventory of items or group.
D - Seldom may occur in time	Can reasonably be expected to occur sometime to an individual item or person; or several times over a service life for an inventory of items, or group
E - Unlikely it will occur in time	Unlikely to occur, but possible in the service life for an inventory of items, or group.

Appendix E Table of Acronyms

ABC fire extinguisher	Designed to fight Trash, Wood, and Paper (A), Liquids (B), and Electrical Equipment (C)
AFFF	Aqueous Film Forming Foam
ARL	Authorization Request Letter
BMS	Battery Management System
C rating	1 hour x the rate of charging (Coulombs/sec) / battery capacity Amp-hours (Coulombs*hours/sec)
CFR	Code of Federal Regulation
CoS	Chief of Staff
COTS	Commercial-Off-The-Shelf
DOT	Department of Transportation
F	Fahrenheit
FAA	Federal Aviation Administration
FEDeX	Federal Express
HVAC	Heating, Ventilation, and Air Conditioning
IAPG	Interagency Advanced Power Group
IPR	Initial Procurement Reports
KFS	Kauli Financial System
kWh	Kilowatt-hour
LiFe	Lithium Iron Phosphate
LiFePO4	Lithium Iron Phosphate
Li-ion	Lithium ion
LiPo	Lithium Polymer
LiPo SOP	NPS "Safety & Usage Procedure for Lithium Polymer Batteries" Version 1.4b
LiTO	Lithium Titanate
NAVSEA	Naval Sea Systems Command
NAVSEA S9310-AQ-SAF-010 Rev 3	Navy Lithium Battery Safety Program: Responsibilities and Procedures
NAVSEAINST 9310.1C	Navy Lithium Battery Safety Program
NFPA	National Fire Protection Association
NFTI	Naval Firefighting Thermal Imager
NPS	Naval Postgraduate School
NR&DE	Naval Research and Development Enterprise
OPNAVINST 5100.23H	Navy Safety and Occupational Health Program
OSHA	Occupational Safety and Health Administration
PI	Principal Investigator
RVOC	Research Vessel Operating Committee

S9310 TECHMAN	Navy Lithium Battery Safety Program: Responsibilities and Procedures, NAVSEA S9310-AQ-SAF-010 Rev 3
SOP	Standard Operating Procedures
TECHMAN	Navy Lithium Battery Safety Program: Responsibilities and Procedures, NAVSEA S9310-AQ-SAF-010 Rev 3
UAV	Unmanned Air Vehicles
UGV	Unmanned Ground Vehicles
UN38.3	UN Manual of Tests and Criteria Standard for Transportation Testing of Lithium Batteries
UNOLS	University-National Oceanographic Laboratory System
UPS	United Parcel Service
USPS	United States Postal Service
UUV	Unmanned Undersea Vehicles
UXS	Unmanned Systems - Shore, Underground, Air, High Altitude, Undersea, Surf, or Space
V	Volts
VDC	Volts Direct Current
Wh	Watt-hour
WHOI	Woods Hole Oceanographic Institute