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Functional & Operational Requirements Document

Building 1012, Battery and Energy Storage Device Test Facility, Sandia National Laboratories, New Mexico

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Abstract

This report provides an overview of information, prior studies, and analyses relevant to the development of functional and operational requirements for electrochemical testing of batteries and energy storage devices carried out by Sandia Organization 2546, Advanced Power Sources R&D. Electrochemical operations for this group are scheduled to transition from Sandia Building 894 to a new Building located in Sandia TA-II referred to as Building 1012. This report also provides background on select design considerations and identifies the Safety Goals, Stakeholder Objectives, and Design Objectives required by the Sandia Design Team to develop the Performance Criteria necessary to the design of Building 1012. This document recognizes the Architecture-Engineering (A-E) Team as the primary design entity. Where safety considerations are identified, suggestions are provided to provide context for the corresponding operational requirement(s).

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NOMENCLATURE

A-E	Architect-Engineer
IH	Industrial Hygiene
kWh	kilowatt hour
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
OEA	Occupational Exposure Assessment
R&D	Research and Development
SNL	Sandia National Laboratories
SPFE	Society of Fire Protection Engineers

1. INTRODUCTION

Non-abuse electrochemical battery and energy storage device testing at Sandia National Laboratories has traditionally been carried out in Sandia Building 894. As battery and storage device manufacturing has evolved, so have the testing requirements in support of these devices.

Sandia has determined that Building 894 is no longer adequate to support some future testing. Subsequently, a new facility has been proposed for these operations. A *performance-based* design approach and/or *alternate means and methods* of design has been proposed for those portions or elements of the new building not specifically covered by the Model Building Codes (e.g., Test Bays, functional areas assigned for environmental chambers). Performance-based design develops building performance requirements based on known operational characteristics and subsequent design goals.

This approach is implemented through the use of an integrated team of experts from Sandia's Facilities Organization, Department 4822, Project and Construction Management, and the Design Architects and Engineers (A-Es) supporting the Facilities Organization; Sandia Organization 2546, Advanced Power Sources Research & Development (R&D) – the Line Organization responsible for these operations; Department 4879, Sandia Fire Protection, and Department 4126, Sandia's Safety Basis Organization. Consultation with other Sandia subject-matter-experts also takes place as needed (e.g., Sandia Organization 1532, Fire and Aerosol Sciences, Organization 2501, Performance Assurance, and Sandia Organization 4127, Industrial Hygiene).

1.1. Purpose

The purpose of this document is to consider the functional requirements and potential operational hazards of *non-abuse* testing of batteries and energy storage devices as part of the performance-based design and construction of Building 1012, planned for Technical Area II, west of Building 905, Sandia National Laboratories, KAFB, New Mexico.

Although aspects of this document address safety goals, stakeholder objectives, and design objectives, this document does not include every element traditionally found in a performance-based design. Rather, it seeks to focus designers on select elements of the Users' operational requirements that require performance-based design solutions to avoid or mitigate low probability-potentially high consequence fire hazard and overpressure events.

1.2. Scope

The scope of this document includes the characterization of battery and energy storage device test operations proposed for Building 1012, and development of safety goals, and stakeholder and design objectives. The Sandia's A-E Design Team will provide performance criteria with review by Sandia Fire Protection personnel, Stakeholders, Facilities Management, and Subject Matter Experts. Planning and design elements of interest to this review include but are not limited to the following:

- Siting and functional layout (avoidance of local and adjacent hazard areas/situations; and sensitive environmental resources).
- Structural (Functional area design, equipment layout, future growth; material ratings/design).
- Mechanical systems (e.g., airflow, exhaust systems, material ratings; avoidance or minimizing environmental releases).
- Electrical systems, (i.e., fire detection and alarm; instrumentation and monitoring systems for life safety).
- Plumbing (systems in support of fire suppression).

2. BATTERY AND ENERGY STORAGE DEVICE TEST OPERATIONS

Background. On October 26, 2012, Sandia Department 2546, Advanced Power Sources R&D, was performing authorized battery abuse testing in Test Bay 1105F of Sandia Building 905 located on Kirtland Air Force Base (KAFB) in Albuquerque, New Mexico. During the testing of a 1.2 kWh lithium ion battery, thermal runaway, ignition and fire took place – all anticipated events. In this instance, the fire event was somewhat larger than anticipated and resulted in a chain of events that drove an environmental excursion in wastewater pH outside of the permitted limits for the building.[1] During the investigation that followed this occurrence, much was learned about the battery and energy storage test operations carried out at Sandia. Discussions with Fire Protection Engineers, Architect-Engineers, Sandia User Organizations and Safety Basis Hazard Analysts focused on identifying design elements that would result in better building performance in support of these and similar operations. This document seeks to build upon the lessons learned and previously identified design opportunities.

2.1 Battery Test Operations Proposed for Building 1012

The battery test operations proposed for Building 1012 differ from those occurring at Building 905 in that no energy storage device is intentionally abused to failure. Operations proposed for Building 1012 fall into a category of non-abuse electrochemical testing conducted within manufacturer's specifications. For properly designed and constructed batteries and energy storage devices, testing of the nature proposed for Building 1012 should not represent hazards of the nature or frequency of those common to battery abuse testing. *However, similar hazards to those experienced in battery abuse testing could be encountered with improperly designed or constructed batteries or energy storage devices submitted to Sandia for testing.* The following provides a description of the types of batteries and energy storage devices currently evaluated by Sandia through electrochemical testing.

2.2. Battery and Energy Storage Device Test Types

Batteries and energy storage devices and ranges of energy levels that may be tested in Building 1012 include, but may not be limited to those provided in **Table 1**.

[1] SNL, 2013, *Causal Analysis Report on Lithium Ion Battery Overcharge Test Leading to pH Excursion at Building 905*, February 14, 2013, Sandia National Laboratories, New Mexico

Table 1 Battery and Energy Storage Device Types and Energy Levels

	Type of Battery or Energy Storage Device	Representative Range of Energy Storage-Energy Level (Wh)	Comment(s)/Warnings
1.	Lithium		
	Thionyl chloride (Li/SOCl2)*	40 Wh/cell (300 Wh/pack)	*Li/SOCl2 devices carry high safety concerns limit use in civilian applications; can explode when shorted.
	o Lithium Bromine Chloride		
	• Manganese dioxide Li-Mn02	20 per cell	
	• Li (CF)x Carbon fluoride compounds	5 Wh 20 (200 Wh per pack)	
	• Li/S02 **		**Li/S02 devices require safety vents; may explode under some conditions-high energy density
2.	Lithium ion		None additional
	• Lithium iron sulfate	60	
	• Lithium titanate	30-170	
	• Lithium Cobalt-Nickel oxide	10	
	• Lithium iron phosphate	60- 450	
3.	Flow Batteries		None additional
	• Zn Bromide	10,000	
	• Vanadium-redox	10,000	
	• Nickel Zinc	250	
4.	Lead Batteries		None additional
	• VRLA AGM	70 550 150 24000	
	• VRLA gell	150	
	• Hybrids	24000	
5.	Super-capacitors	Not applicable; varied capacitance values	None additional
6.	Novel chemistries	Chemistry and Manufacturer dependent	None additional
7.	R&D Batteries	Chemistry and Manufacturer dependent	None additional

VRLA-Valve-regulated Lead-acid Absorbed Glass Mat; gell – as a *gelled* electrolyte
Source: Ferrerira, S., SNL Dept. 2546, Sandia National Laboratories, New Mexico, June 2013

2.3. Electrochemical Testing-Batteries and Energy Storage Devices

In electrochemical testing, the energy storage device is connected to a test channel or other apparatus to measure and/or control the device (e.g. a power supply, voltmeter or a galvanostat-potentiostat). The unit is monitored while controlling temperature, voltage, and/or current, as a function of time.

Testing maintains the battery within manufacturer specifications for normal operations. In addition to temperature, voltage, and current normal operations may include a variety of limit conditions, such as:

- Time between recharge
- Amp hour throughput between discharge
- Humidity, and/or other defined operational limits

> **Anticipated Results under Normal Operations**
>
> Results under normal operation include battery degradation or discharge, and may include anticipated venting, typically of small amounts of hydrogen gas.
>
> **Possible Results under Off-Normal Operations**
>
> Off-normal event results may be the same as occur with intentional thermal or electrical abuse such as thermal runaway, ignition/fire, leakage of electrolyte, rapid out-gassing leading to overpressure (SNL, Dept. 2546 Advanced Power Sources R&D, June 2013).

Long-term monitoring also includes logging applied test conditions and device response time, temperature, voltage, and current. This is carried out using temperature chambers, bench-top, and/or floor configurations dependent upon the scale of the test.

2.4. Prior Analyses

Following the Battery Abuse Test Occurrence at Sandia Building 905 two types of analyses were carried out to 1) predict heat and overpressure from a thermal runaway, and 2) characterize a pressure event. Both assumed a 1.2 kWh lithium ion battery, specifically the largest battery expected to be tested in the near term in the 1105 Test Bays. The first analysis involved fire modeling to estimate whether the concrete wall construction of the 1105 Test Bays would be damaged by the predicted heat flux. The second analysis involved Fuel-Air Explosion Calculations to determine whether the peak pressure would exceed the Test Bay Blast door design were a pressure event to take place within the cell involving the fuel source carried within a 1.2 kWh battery (i.e., approximately one (1) liter of solvent/electrolyte chemical in battery packaging (casing).

These prior analyses are relevant to the electrochemical testing operations proposed for Building 1012, because *the 1.2 kWh lithium ion battery also represents the single largest battery* of similar chemistry currently *planned for the 1012 Battery and Energy Storage Device Test Facility*. The following provides a summary of each of these analyses.

2.4.1 Fire Modeling Summary

> **Relationship of this Analysis to Design**
>
> Provides wall temperature of design event (1.2 kWh lithium ion battery fire) and points to survivability of concrete wall design for consideration during design.

Prior modeling analyses were performed with the objective of determining whether the concrete walls of the Building 905, 1105B Area Battery Test Bays could withstand (i.e., survive) additional thermal assault from fire. Modeling simulations were performed using the Fire Dynamics Simulator (FDS) code, a computational fluid dynamics code developed by the National Institute of Standards and Technology (NIST). The modeled battery was comprised of 20 cells of 15 Amp hours (Ah) each in a five parallel and four serial cell block configuration providing a total of 75 Ah and 16.6V (or 1.245kWh).

Liquid fuels typically have values of 2.0 - 2.5 MW/m^2. Given that the power of the Li Battery is estimated to be 5.2 times lower, the heat release rate was anticipated to be below that of the 1.2 kWh battery considered in the modeling simulation and planned operations. Because of this, two heat release rates per unit area were explored to cover potential higher heat release rates, specifically, 2.5 MW/ m^2 and 10 MW/ m^2 over an area of 0.042 m^2. This range was believed to *bound* the heat release rate values anticipated.

Each simulation specified a 180-second(s) duration fire known from prior testing to be indicative of actual test conditions (Note: Although diminished in intensity, the fire may continue well beyond the 180-seconds); the grid resolution was set at approximately two (2) inches. Representative wall temperatures at the surface of the concrete walls of the Test Bays and at a depth of 0.0254 m beyond the wall surface as a function of time were predicted for locations known to have been directly impacted by the 905 fire event. Model results indicated that the highest surface temperature predicted was 364 degrees C (≈687.2°F) at the surface, and 77 degrees C (≈170.6°F) at the 0.0254 m depth. This value was determined to not exceed temperatures that would result in a significant decrease in the compressive strength of reinforced concretes.[2] Critical temperatures for the specimens heated, ranged from 900°F (≈482 C) to 1200°F (≈649 C), depending on the type of concrete.[3]

[2] Luketa, Anay, Organization 1532, Fire and Aerosol Sciences, *Simulation of Results of Different Fire Scenarios for Building 905*, April 30, 2013, Sandia National Laboratories, New Mexico.
[3] Fleischman, C., *Analytical Methods for Determining Fire Resistance of Concrete Members*, Section 4, Chapter 5, SFPE Handbook of Fire Protection Engineering, p.4-204.

Combustion Products. During the investigation following the Building 905 Occurrence, combustion products were derived from scientific literature. These were scaled to represent the quantity of products estimated for the 1.2 kWh lithium ion battery fire event summarized above. *These do not represent regular emissions but rather emissions that could be anticipated in an off-normal fire event.* It is important to note that the modeling report accompanying the Fire Modeling Analysis recommended that monitoring of actual test conditions take place going forward to validate model assumptions and results; this has been planned.

Species	Grams
Carbon dioxide (CO_2)	3,636
Carbon monoxide (CO)	192
Hydrocarbon	696
Nitrogen oxide (NO_x)	21.6
Sulfur dioxide (SO_2)	24
Hydrochloric acid (HCl)	2.64
Hydrogen fluoride (HF)	82.8
Fluoroethane (C2H5F)	91.2
Hydrogen (H2)	687.6

Source: Orendorff, C., SNL Dept. 2546, May 2013

2.4.2 Fuel-Air Explosion Summary - 1.2 kWh Lithium-ion Battery Electrolyte

A Fuel-Air Explosion Over-Pressure Analysis was also performed for the same 1.2 kWh battery to determine if the Test Bay Blast doors of the 1105B Area would be able to contain the predicted pressure event.[4]

> **Relationship of this Analysis to Design**
>
> Provides baseline performance for Test Bay door design predicted to withstand a Fuel-Air Explosion Over-Pressure event consistent with a 1.2 KWh lithium ion battery; assumes one event in bay.

Worst-case assumptions and two (2) adiabatic reactions were used in the calculation based on the dimensions of Test Bay 1105-F. The 1.2kWh lithium ion battery was assumed to include one (1) liter of solvent/electrolyte composed of 80-percent diethyl carbonate (DEC: the highest fuel limit/milliliter [ml]), and 20-percent ethylene carbonate (EC: a major alternate component), assumed at the altitude of Albuquerque, New Mexico, and at an atmospheric pressure of 0.812 bar (≈ 750 Torre.).

The differential peak pressures shown below were calculated within the 1105-F Test Bay with the Bay door closed and open:

- Reaction entirely in Test Bay 1105-F preceding abrupt expansion into 1105B corridor (*door closed*) – 0.277 bar
- Reaction in Test Bay 1105-F (*door open*): 0.26 bar

Implications to Blast Doors. The blast doors in use on the 1105 Test Bays are designed to withstand long duration blast loads with peak reflective overpressure of 2.0 bar in the elastic range of the involved materials. In rebound direction, the doors resist negative blast forces equal

[4] Averill, William A., Advanced Power Sources R&D, Dept. 2546, *Fuel-Air Explosion Over-Pressure: 1.2 kWh Battery Electrolyte,* Sandia National Laboratories, New Mexico, May 6, 2012 – Official Use Only, Statuary Exemption #5 privileged inter-agency or intra-agency memorandum. May be exempt from public release.

to 0.25 bar static pressure. The doors also resist a mechanical shock transmitting through the installation wall with rapid change in velocity of approximately 1.5 m/s corresponding to an acceleration force of 30 g. The blast doors are designed to function within the operating temperature range of -20 to 80+ degrees C. The peak pressures created by the overpressure associated with a Fuel-Air Explosion of the type analyzed for the 1105-F Test Bay was determined to be *substantially less* than that which would challenge the design of the doors.

3. DESIGN CONSIDERATIONS

Where the model building codes define minimum requirements to safeguard building occupants during both natural phenomena design events (e.g., seismic, flood, wind) and anticipated operational events *performance-based design* seeks to create a specific set of unique requirements for each building based on assumptions driven by design goals (e.g., safety, stakeholder). These requirements routinely include conventional code requirements, yet are also consistent with operational requirements and events. Structural engineers employ design to size structural members for bridge support, and loads anticipated to occur from snow, wind, earthquake, or other phenomena given the location and purpose of a structure. For example, fire protection engineers design to ensure that possible fires in a designed compartment with anticipated amounts of combustibles do not proceed to flashover and spread to other areas of a structure, potentially exposing building occupants to fire, smoke, and heat and/or impeded safe egress.[5] [6]

A fire protection focused performance-based approach is used to supplement conventional prescriptive design for Building 1012 due to the nature and hazards of the testing proposed to include the potential for fire, smoke, varied combustion products, and overpressure in the absence of any codes specific to the planned activities. The following provides the Goals and Objectives developed for the planned facility.

3.1. Safety-Design Goals

The Safety-Design Goals identified for Building 1012 include fire protection design values and other safety goals and values consistent with the intended use of the facility (e.g., economic, environmental, mission):

LIFE SAFETY

1. Building design shall provide for life safety of occupants, and *maximize fire and explosive safety.*
2. Floor-plans shall provide code compliant and intuitive emergency egress.
3. Access by emergency responders shall be considered as part of the design process.
4. Emergency detection, annunciation, and suppression shall be designed to minimize injuries and prevent and/or minimize loss of life.
5. Siting analyses shall include consideration of *current* assignment of any adjacent explosive quantity distance arc(s) and ensure that emergency vehicle access, traffic

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[5] Lataille, J. I., P.E., FSFPE, *Factors in Performance-Based Design of Facility Fire Protection*, April 1, 2008, Fire Protection Engineering, Los Alamos National Laboratory, New Mexico
[6] SFPE, *Performance-Based Fire Protection*, Second Edition, National Fire Protection Association, 2007

circulation, and general parking is designed for areas *outside* local (Bldg. 1012) or adjacent (e.g., Bldg. 905) operational hazards (QDs, emissions).

6. Design shall consider wind direction(s) associated with adjacent and/or local building exhaust, air intakes, and corresponding stack heights where applicable to avoid exposure of Building 1012 occupants to emissions from any operation, either local or adjacent.

PROPERTY PROTECTION

- Damage to the structure from fire shall be minimized (protecting building contents) from potential local and/or adjacent building fire events.

CONTINUITY OF OPERATIONS

1. Mission and operating capabilities shall be protected through consideration of the proximity of functional areas one to another (including storage), and equipment layout; work spaces shall be designed consistent with functional areas.
2. Structural, mechanical, electrical, and other design elements shall consider separation and/or opportunities to combine functional areas, and systems, where safely compatible.
3. The loss of operations and business-related revenue from fire and/or other accident events shall also be minimized through design that considers the proximity of functional areas to one another and the need for future growth.

ENVIRONMENTAL PROTECTION

1. Impacts to the environment from fire combustion products and release of hazardous materials shall be avoided and/or limited.
2. Siting location and construction schedules shall be considered from the perspective of potential wildlife populations; all environmental regulations shall be considered early in the planning (e.g., National Environmental Policy Act) and design process.

3.2. Stakeholder-Design Objectives

Stake-holder-Design Objectives are identified as follows:

- Avoid adjacent hazards and environmental concerns when siting the facility
- Avoid and/or limit fire injuries beyond the room of fire origin, including smoke, and combustibles.
- Egress should be facilitated through layout of functional/operational areas, including proximity of storage to operating areas (e.g., tailor storage areas to planned material) and equipment layout.

- Fire, smoke, heat, particulates of combustion, hazardous materials (including gasses), and fire suppression chemicals and/or water shall be contained within the planned Test Bay in the event of a fire.
- Fire detection, annunciation, and suppression shall be designed consistent with functional area requirements.
- Emergency Response and other First Responder-personnel shall be included in the Design Process; engage emergency response personnel in the Design Reviews at Title I.
- Work area designs shall be consistent with functional area requirements (e.g., placement of associated work stations outside of the potentially hazardous equipment or activity they support).
- Life Safety monitoring equipment (e.g., oxygen, thionyl chloride, and/or other as applicable), shall be specified equipment installed at heights and locations applicable to their function and as determined through IH Occupational Exposure Assessments (OEA).
- Mechanical systems (e.g., duct work *[if any]**, other passive exhaust components) should be optimal for stated function yet sacrificial within Test Bay(s).
- Electrical systems (e.g., power, lighting) should be optimal for stated function yet sacrificial in Test Bay(s).
- Any passive exhaust design shall consider and decrease opacity during design event
- Test Bay(s) structural design and material ratings shall survive the design event fire with no reduction in fire resistance or loss of structural integrity.
- Consider equipment layout when designing to limit fire, smoke, and water damage from fire events in areas of high cost equipment and other capital assets (i.e., minimize damage to critical equipment through functional layout).
- Operational down-time from off-normal events shall be minimized through consideration of proximity of functional areas one-to-the-other and equipment layout (i.e., consider power points, and other utilities required by equipment).
- Future expansion should be considered wherever possible in terms of proximity fire walls, separation wall materials and ratings, electrical receptacles/boxes and maintenance access.

3.3 Safety Goals and Stakeholder Objectives

The following provides the Safety Goals and their relationship to Stakeholder Objectives.

TABLE 2 SAFETY GOALS AND STAKEHOLDER OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES
Life Safety	
1. Building design shall provide for life safety of occupants, and *maximize fire and explosive safety*	• Avoid and/or limit fire injuries beyond the room of fire origin, including smoke, and combustibles • Egress should be facilitated through layout of functional/operational areas, including proximity of storage to operating areas; tailor storage areas to planned material • Fire, smoke, heat, particulates of combustion, hazardous materials (including gasses), and fire suppression chemicals shall be contained within the Test Bay in the event of a fire • Fire detection, annunciation, and suppression shall be designed consistent with functional area requirements • Life Safety monitoring equipment (e.g., oxygen, thionyl chloride, and/or other as applicable), shall be specified equipment installed at heights and locations applicable to their function and as determined through IH Occupational Exposure Assessments (OEA)
2. Floor-plans shall provide code compliant and occupant intuitive emergency egress	• Egress should be facilitated through layout of functional/operational areas, including proximity of storage to operating areas; tailor storage areas to planned material
3. Access by emergency responders shall be considered as part of the design process	• Emergency Response and other First Responder-personnel shall be included in the Design Process
4. Work spaces shall be designed consistent with functional areas	• Work area designs shall be consistent with functional area requirements (e.g., placement of associated work stations outside of the potentially hazardous equipment or activity they support)
5. Structural, mechanical, electrical, and other design elements shall consider separation of functional areas and systems	• Mechanical systems (e.g., duct work, passive exhaust components) should be optimal for stated function yet be sacrificial in Test Bay(s) • Electrical systems (e.g., power, lighting) should be optimal for stated function yet sacrificial in Test Bay(s)

TABLE 2 SAFETY GOALS AND STAKEHOLDER OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES
6. Emergency fire detection, annunciation, and suppression shall be designed to minimize injuries and loss of life	• Fire detection, annunciation, and suppression shall be designed consistent with functional area requirements
7. Siting analyses shall include consideration of current assignment of any adjacent explosive quantity distance arc(s); and ensure that emergency vehicle access, traffic circulation, and general parking is designed for areas *outside* local (Bldg. 1012) or adjacent operational hazards	• Avoid adjacent hazards and environmental considerations when siting facility
8. Design shall consider wind direction(s) associated with adjacent and/or local building exhaust, air intakes, and corresponding stack heights where applicable to preclude exposure of occupants to emissions from any operation	• Avoid adjacent hazards and environmental considerations when siting facility
Property Protection	
• Damage to the structure from fire shall be minimized (protecting building contents) from potential local and adjacent building fire events	• Test Bay(s) structural design and material ratings shall survive the design event fire with no reduction in fire resistance or loss of structural integrity • Areas that include high-cost equipment should be segregated from areas of moderate-to higher potential fire events where possible – minimize damage to critical equipment through functional layout
Continuity of Operations	
1. Mission and operating capabilities shall be protected through consideration of proximity of functional areas one-to-the-another	• Operational down-time from off-normal events shall be minimized through consideration of proximity of functional areas one-to-another and equipment layout (i.e., consider power points, and other utilities required by equipment)
2. The loss of operations and business-related revenue from fire and other accident events shall be minimized through design that considers the proximity of functional areas one-to-the-other and the need for future growth	• Areas that include high-cost equipment should be segregated from areas of moderate-to higher potential fire events where possible – minimize damage to critical equipment through functional layout • Future expansion should be considered wherever possible in terms of proximity fire walls, separation wall materials and ratings, electrical receptacles/boxes, and maintenance access

TABLE 2 SAFETY GOALS AND STAKEHOLDER OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES
Environmental Protection	
1. Impacts to the environment from fire combustion products and release of hazardous materials shall be avoided and/or limited	• Avoid adjacent hazards and environmental considerations when siting facility
2. Siting location and construction schedules shall be considered from the perspective of potential wildlife populations; all environmental regulations shall be considered early-on in the planning and design process	• Avoid adjacent hazards and environmental considerations when siting facility

3.4 Design Objectives

The following provides a matrix that identifies Design Objectives within the context of corresponding Safety Goals and Stakeholder Objectives. The Design Team will utilize this matrix to develop Performance Criteria for the project.

TABLE 3 DESIGN OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES	DESIGN OBJECTIVES
Life Safety		
1. Building design shall provide for life safety of occupants, and *maximize fire and explosive safety* .	• Avoid and/or limit fire and smoke injuries beyond the room of fire origin, including smoke, and combustibles • Minimize egress paths adjacent to hazardous areas • Fire, smoke, heat, particulates of combustion, hazardous materials (including gasses), and fire suppression materials shall be contained within the Test Bay in the event of a fire • Fire detection, annunciation, and suppression shall be designed consistent with functional area requirements	• Prevent flashover from room of origin; detect fire event early enough to enable Fire Department to respond, take action and prevent spread beyond room of origin • Ensure Egress distance and *estimated egress time* consistent with Occupancy • Detect fire or other event early enough that occupants can be alerted and egress made possible • Ensure segregated airflow between test and occupied areas, <u>including areas of environmental chambers and/or areas involved in the testing of Lithium Sulfur dioxide (Li/S02), and Lithium Thionyl chloride (Li/SOCl2) batteries</u>

TABLE 3 DESIGN OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES	DESIGN OBJECTIVES
	• Life Safety monitoring equipment (e.g., oxygen, thionyl chloride, and/or other as applicable), shall be specified equipment	• Ensure fire detection, alarm, and suppression are designed consistent with functional requirements; provide suitable means of fire protection run-off that considers response time of Emergency Responder; fill rate consistent with designed structural response • Design Team engage Sandia Industrial Hygiene personnel early-on (e.g., Title I) for revisions to OEAs and identification of monitoring equipment and placement within functional areas; OEAs should also include consideration of the types of electrolytes associated with the batteries identified in Table 1 of this document and the vent gas products that would be associated with them.
2. Floor-plans shall provide code compliant and occupant intuitive emergency egress	• Minimize egress paths adjacent to hazardous areas.	• None additional
3. Access by emergency responders shall be considered as part of the design process	• Emergency Response and other First Responder-personnel shall be included in the Design Process	• Engage Emergency Response personnel in Design Reviews at Title I
4. Work spaces shall be designed consistent with functional areas	• Work area designs consistent with functional requirements	• Ensure floor plan designed consistent with identified hazards of the required space
5. Structural, mechanical, electrical, and other design elements shall consider separation of functional areas, and systems	• Mechanical systems (e.g., duct work, passive exhaust components) should be optimal for stated function yet be sacrificial in Test Bay(s); although not a direct life safety consideration, it is consistent with Stakeholder objectives that seek to minimize operational down-time, impact to high-cost equipment, and ability to expand operations as cost-effectively as possible.	• *Consider whether chambers without overpressure safety features should be precluded from new space in 1012* or a cost acceptable structural design solution (such as chamber-door-high "pony-walls of sacrificial chip-board and metal stud construction-vertical release acceptable) should be identified to prevent worker exposure to overpressure; rack electrical above; chamber venting alarmed, and monitored for potential vent event (see also *Life Safety*)

TABLE 3 DESIGN OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES	DESIGN OBJECTIVES
		• Test Bay design shall consider path of least resistance in overpressure event such as a Fuel-Air explosion, appropriate door blast rating for the Test Bay • Consider passive exhaust in test bay with cost-effective and sacrificial filter design solution to decrease opacity in the event of an unplanned release • Design Test Bay ductwork (if any) as sacrificial; ductwork not designed to survive fire event, or to resist corrosivity of any combustion products; replacement costs deemed acceptable given low assumed probability of fire event to non-abuse test activities (passive exhaust design may limit or preclude ducting)
6. Emergency detection, annunciation, and suppression shall be designed to minimize injuries and loss of life	• Fire detection, annunciation, and suppression shall be designed consistent with functional area requirements	• Ensure fire protection considerations designed consistent with functional area requirements and life safety design objectives identified earlier
7. Siting analyses shall include consideration of current assignment of any adjacent explosive quantity distance arc(s); and ensure that emergency vehicle access, traffic circulation, and general parking is designed for areas *outside* local (Bldg. 1012) or adjacent Bldg. hazards	• Avoid adjacent hazards and environmental considerations when siting facility	• No additional narrative; ensure design objective is consistent with safety goal and stakeholder objective
8. Design shall consider wind direction(s) and adjacent and/or local building exhaust, air intakes; corresponding stack	• Avoid adjacent hazards and environmental considerations when siting facility	• None additional.

TABLE 3 DESIGN OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES	DESIGN OBJECTIVES
heights shall be considered where applicable to preclude exposure of occupants to emissions from any operation (local or adjacent)		
Property Protection		
• Damage to the structure from fire shall be minimized (protecting building contents) from potential local and adjacent building fire events	• Test Bay(s) structural design and material ratings shall survive the design event fire with no reduction in fire resistance or loss of structural integrity • Consider equipment layout when designing to limit fire, smoke, and water damage from fire events in areas of high cost equipment and other capital assets	• Ensure bay structural materials and ratings are sufficiently robust to survive potential design fire event (i.e., model results indicated that the highest surface temperature predicted was 364 degrees C (≈687.2°F) at the surface, and 77 degrees C (≈170.6°F) at the 0.0254 m depth) for duration of estimated suppression response) • Segregate areas that include high-cost equipment from areas of moderate-to-higher potential fire events where possible – minimize damage to critical equipment through functional layout
Continuity of Operations		
1. Mission and operating capabilities shall be protected through consideration of proximity of functional areas one-to-the-other	• Maximum operational down-time from off-normal events should be minimized through consideration of proximity of functional areas one-to-another and prevention of flashover	• Ensure fire control areas are consistent with functional areas wherever possible to limit spread of fire from one functional area to another
2. The loss of operations and business-related revenue from fire and other accident events shall be minimized through design that considers the proximity of functional areas one to another and future growth	• Areas that include high-cost equipment should be segregated from areas of moderate-to higher potential fire events where possible – minimize damage to critical equipment through functional layout • Future expansion should be considered wherever possible in terms of proximity fire walls, separation wall materials and ratings, electrical receptacles/boxes and maintenance access	• *See Property Protection* - Consider equipment layout when designing to limit fire, smoke, and water damage from fire events in areas of high cost equipment and other capital assets • Consider design opportunities that would allow for cost-effective future expansion such as increased rating to side or rear wall of building in specific functional areas (e.g., storage)

TABLE 3 DESIGN OBJECTIVES

SAFETY GOAL	STAKEHOLDER OBJECTIVES	DESIGN OBJECTIVES
Environmental Protection		
1. Impacts to the environment from fire combustion products; hazardous materials shall be avoided or minimized	• Avoid adjacent hazards and environmental considerations when siting facility	• Ensure *predicted* operational emissions (if any) are adequately considered in design process
2. Siting location and construction schedules shall be considered for potential wildlife populations; all environmental regulations shall be considered early-on in the planning and design process	• Avoid adjacent hazards and environmental considerations when siting facility	• Ensure NEPA Checklist provides sited location and estimated construction schedule for review by NEPA SMEs and others as applicable

4. CONCLUSIONS

The goal of this review included the identification of prior information, and studies and analyses useful in understanding the functional and operational requirements associated with Electrochemical Battery and Energy Storage Device Testing. The Safety Goals, Stakeholder Objectives, and Design Objectives provided herein are intended as a tool for use in designing the new facility.

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