I2SL Annual Conference 2025

I1: Decarbonization | Decarbonization Evolution

PNNL Grid Storage Launchpad: Designing for the Next Generation of Battery Technologies

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Skye Smith, Kirksey Architecture

Kirksey ARCHITECTURE ARUP

LEARNING OBJECTIVES

Understand the benefits and limitations of passive (NFPA 68) and active (NFPA 69) deflagration prevention systems and the analysis the project team performed to validate the proposed system was fit for purpose when considering a wide range of potential battery types.

Learn about architectural & structural design elements implemented in the project to mitigate risk of damage to the adjacent laboratory structure due to deflagration of a battery in thermal runaway.

Understand the design elements included in the project to allow the Owner the flexibility to test novel (and unknown) battery chemistries without substantial future renovation to the testing facility.

Understand the functional safety implications of implementing a grid-scale NFPA 855 system, focusing on the unique system design and commissioning processes required to certify the system as a Safety Instrumented System (SIS) per IEC 61511.

GRID STORAGE LAUNCHPAD

PACIFIC NORTHWEST NATIONAL LAB

Client: U.S. Department of Energy Office of Science / Battelle Memorial Institute

Completion Date: March 2024

Total Construction Cost: $75 million (tax-payer funded)

Project Address: 3370 Stevens Drive, Richland, Washington 99352

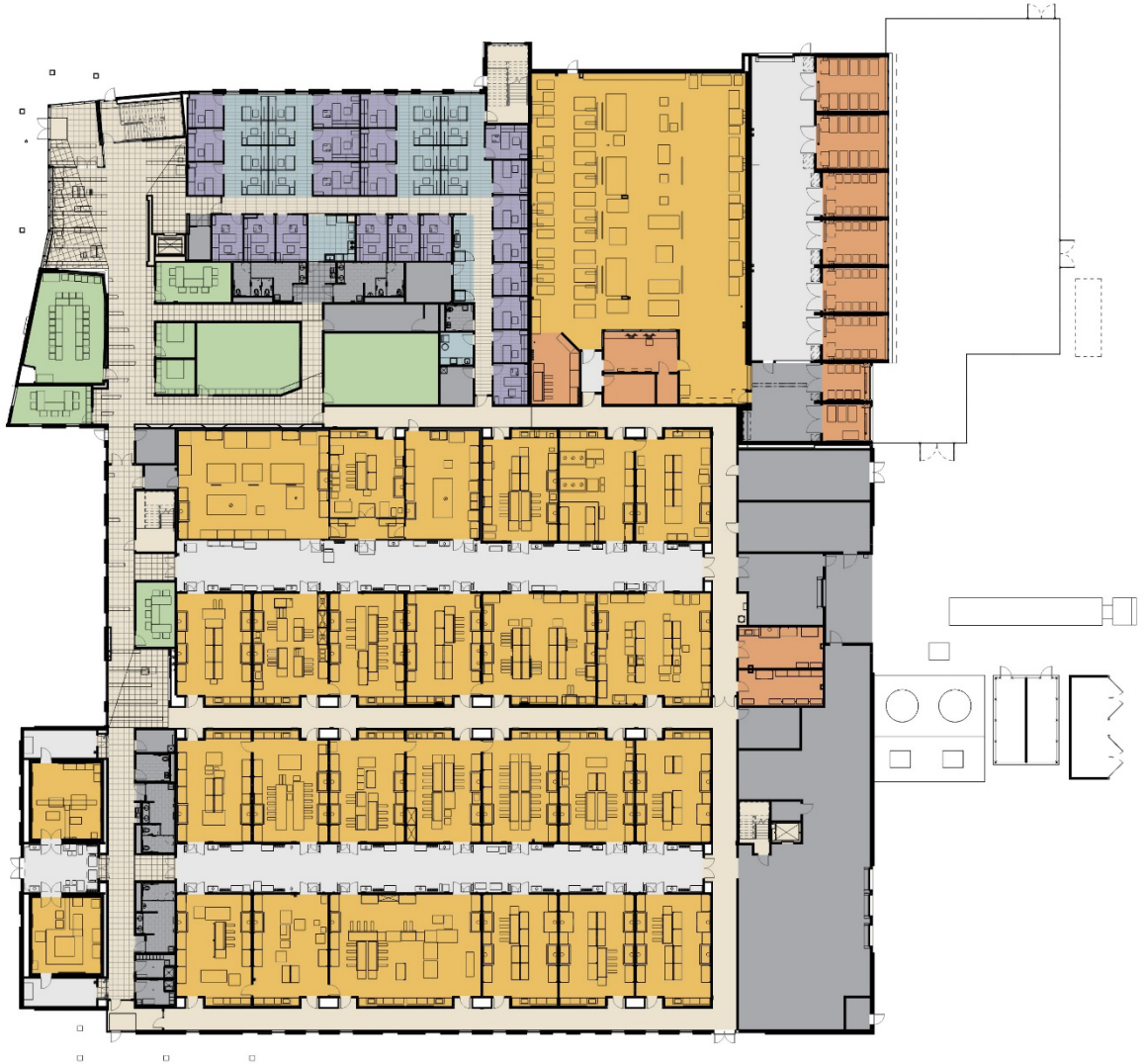
Gross Area: 90,600 sf / 8,400 m2

Net Area: 77,500 sf / 7,200 m2

Net Area of Lab and Lab Support: 35,000 sf / 3,250 m2

Percentage of building net area that is lab area: 45%


GRID STORAGE
LAUNCHPAD
HEAT TRANSFER
BUILDING
ENVIRONMENTAL
MOLECULAR SCIENCES
LABORATORY
ENERGY
SCIENCES
CENTER




OFFICE
OFFICE SUPPORT
CONFERENCE ROOMS
LAB
LAB SUPPORT
MECH/SERVICE
SERVICE CIRCULATION
PUBLIC CIRCULATION

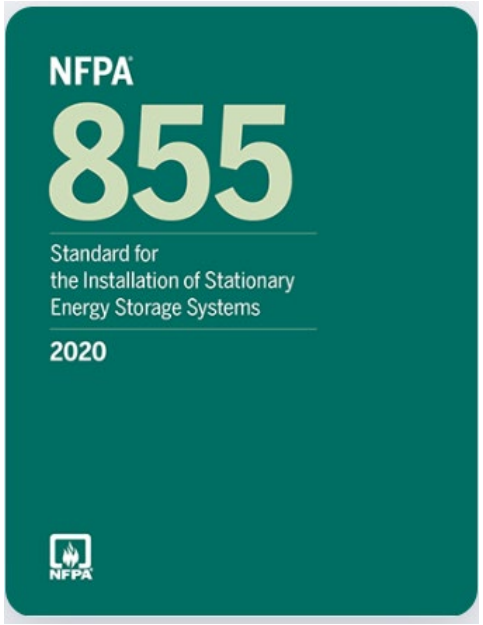
CODES

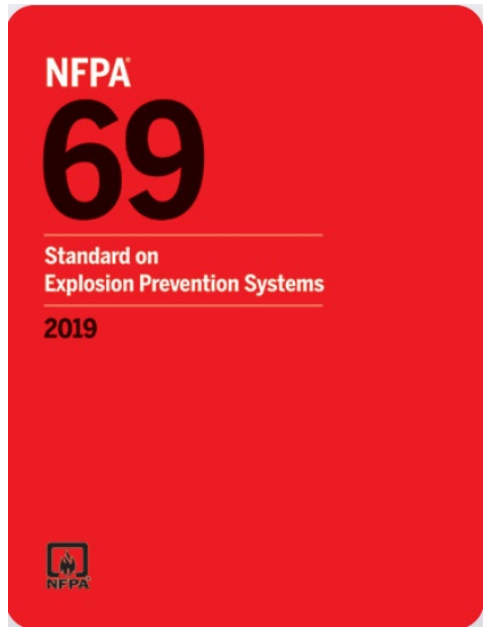
NFPA 855 – Standard for Installation of Stationary Energy Storage Systems (2020)

NFPA 68 – Standard on Explosion Protection by Deflagration Venting (2018)

NFPA 69 – Standard on Explosion Prevention Systems (2019)

- Chapter 8 Deflagration Prevention by Combustible Concentration Reduction





DEFINITIONS

Explosion – a sudden, rapid release of energy that produces potentially damaging pressures.

Deflagration – a deflagration is an explosion where the flame speed is slower than the speed of sound.

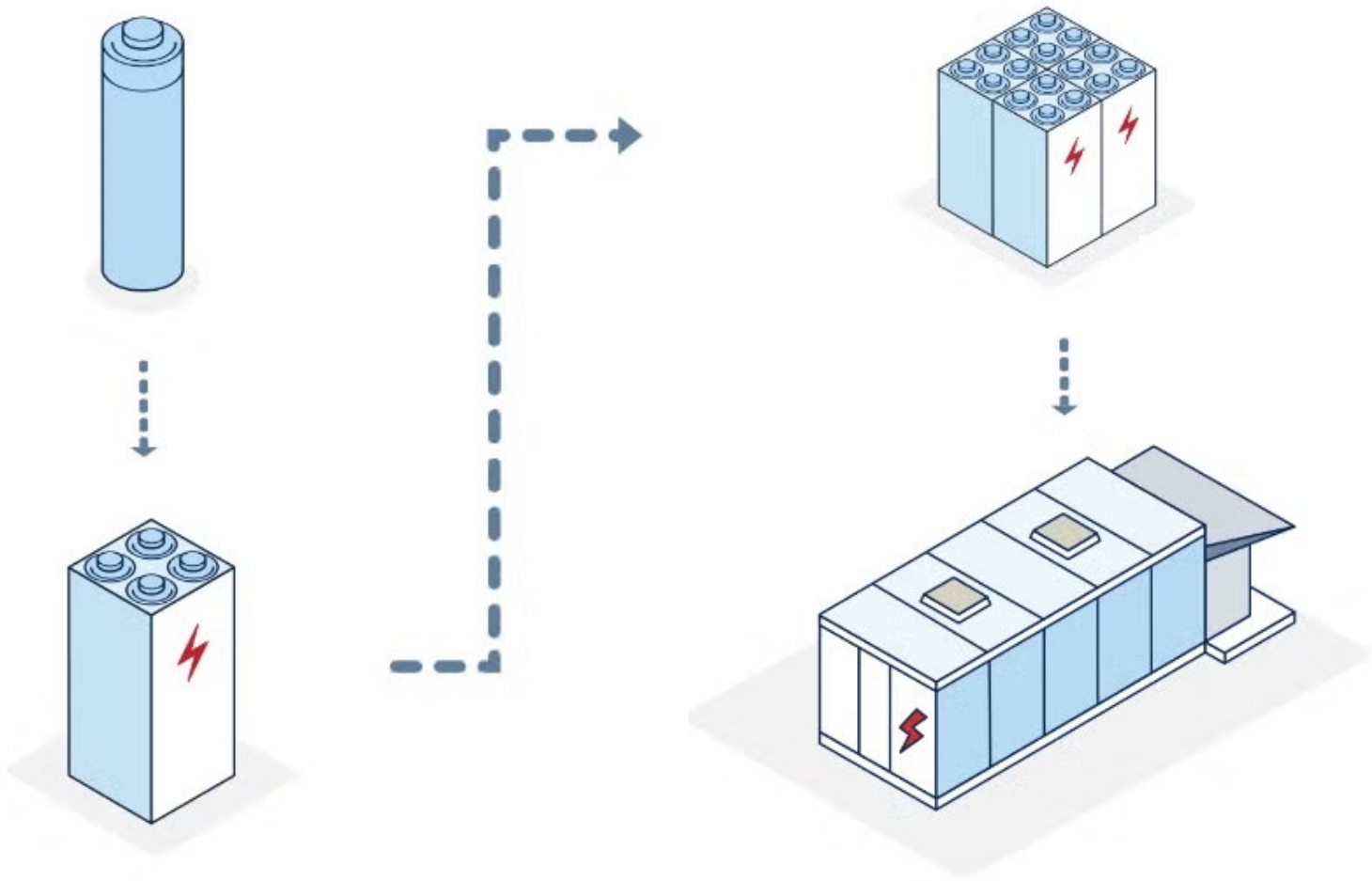
Detonation – an explosion where the flame speed is greater than the speed of sound.

Safety Integrity Level (SIL) – the relative level of risk reduction provided through a safety function and determine through a risk assessment.

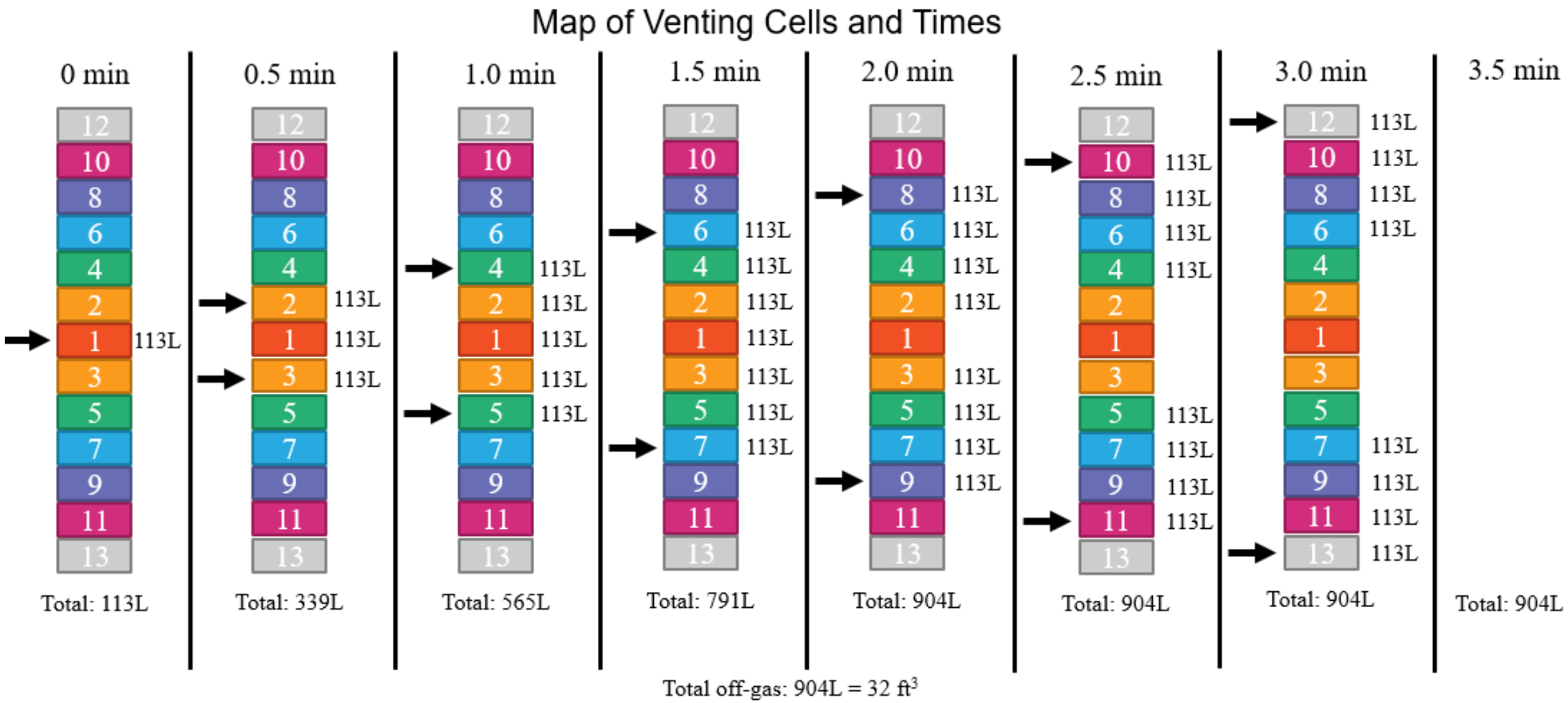
HAZOP – A Hazard and Operability (HAZOP) study is a structured and systematic examination of a planned or existing process or operation to identify and evaluate problems that may represent risks to personnel or equipment or prevent efficient operation.

THERMAL RUNAWAY

UL 9540A is the Standard Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.



THERMAL RUNAWAY



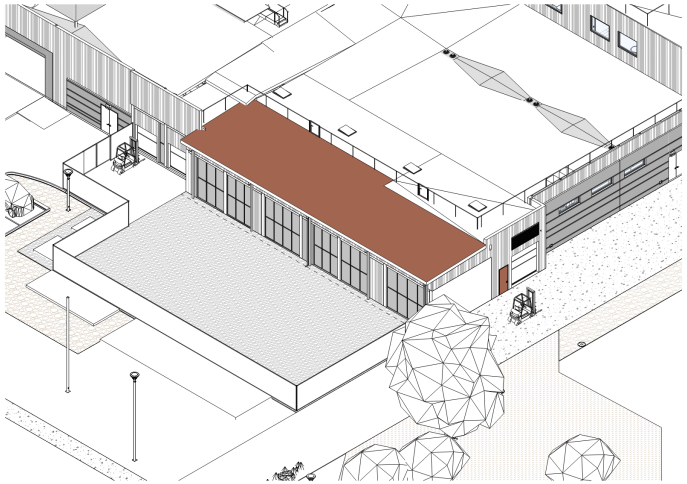
NFPA 68

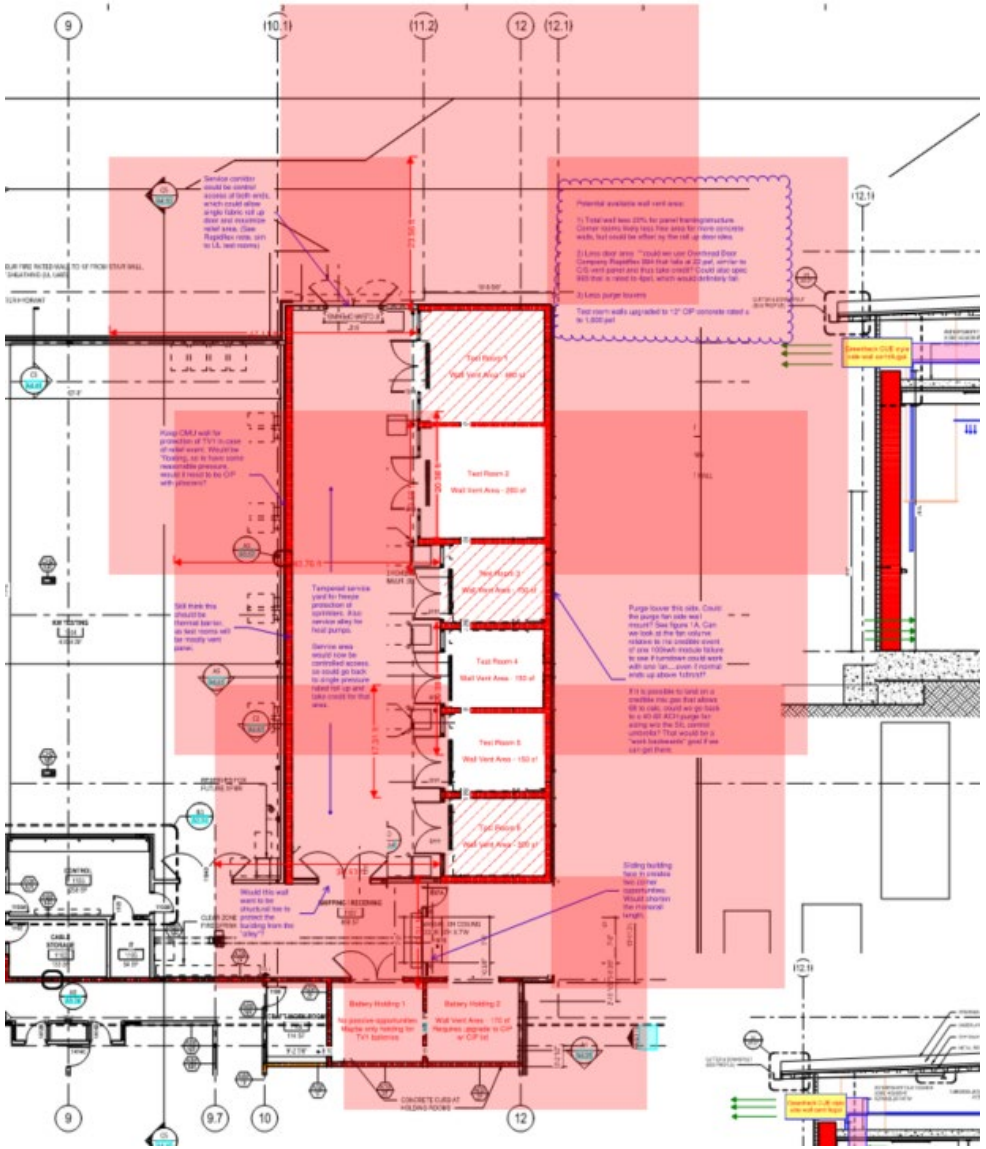
NFPA 68 Strategy for Hardened Concrete

- Large/Small Available ~ 464 sf / 370 sf
- Large/Small Partial ~ 213 sf / 130 sf
- Large/Small Full Propane ~ 167 sf / 102 sf

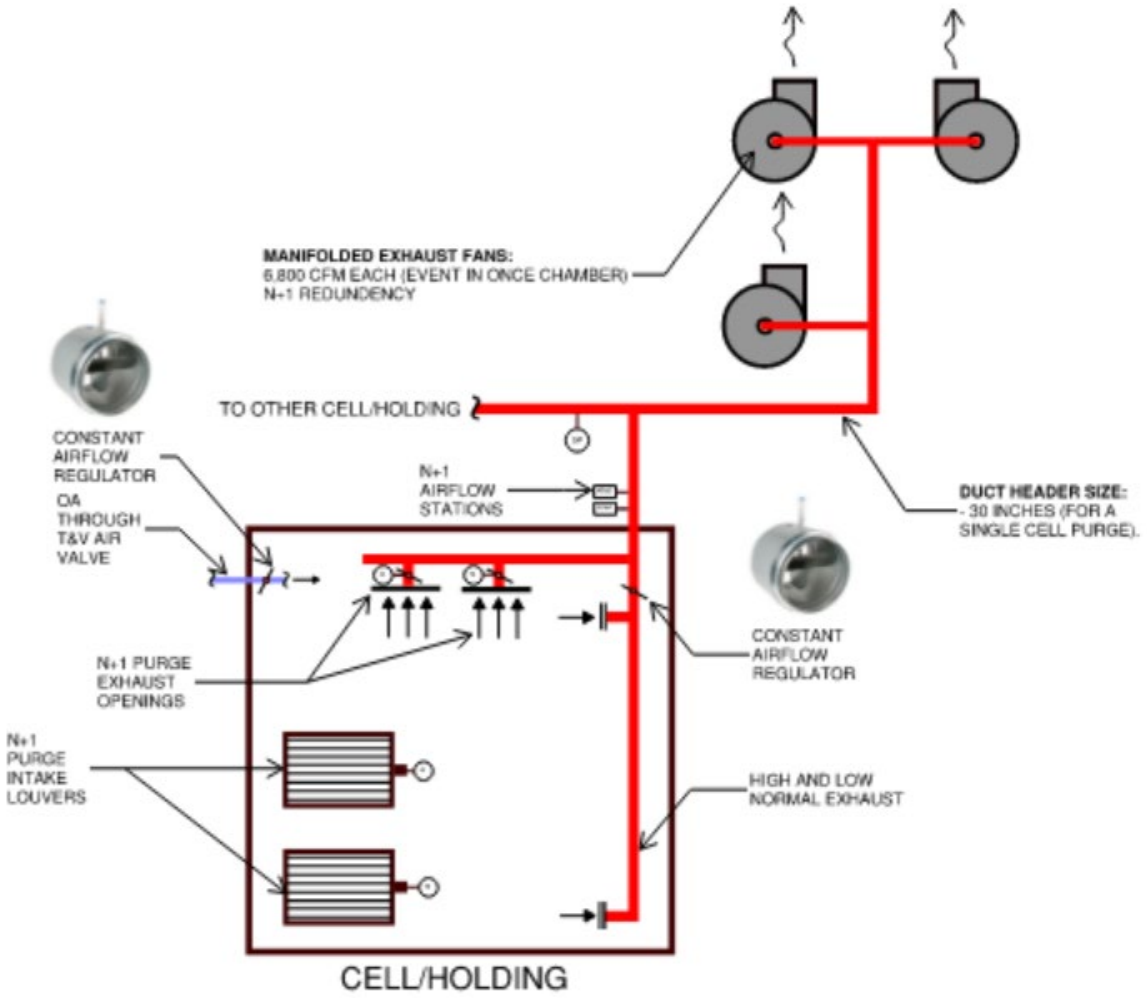
Pressure extrapolation in Battery Yard for Samsung scenario

- Vent panels relieve at 22 psf. Yard ~ 14x volume of test room, would then build pressure until roof vents relieved at 22 psf. 22 psf to 90 mph wind.





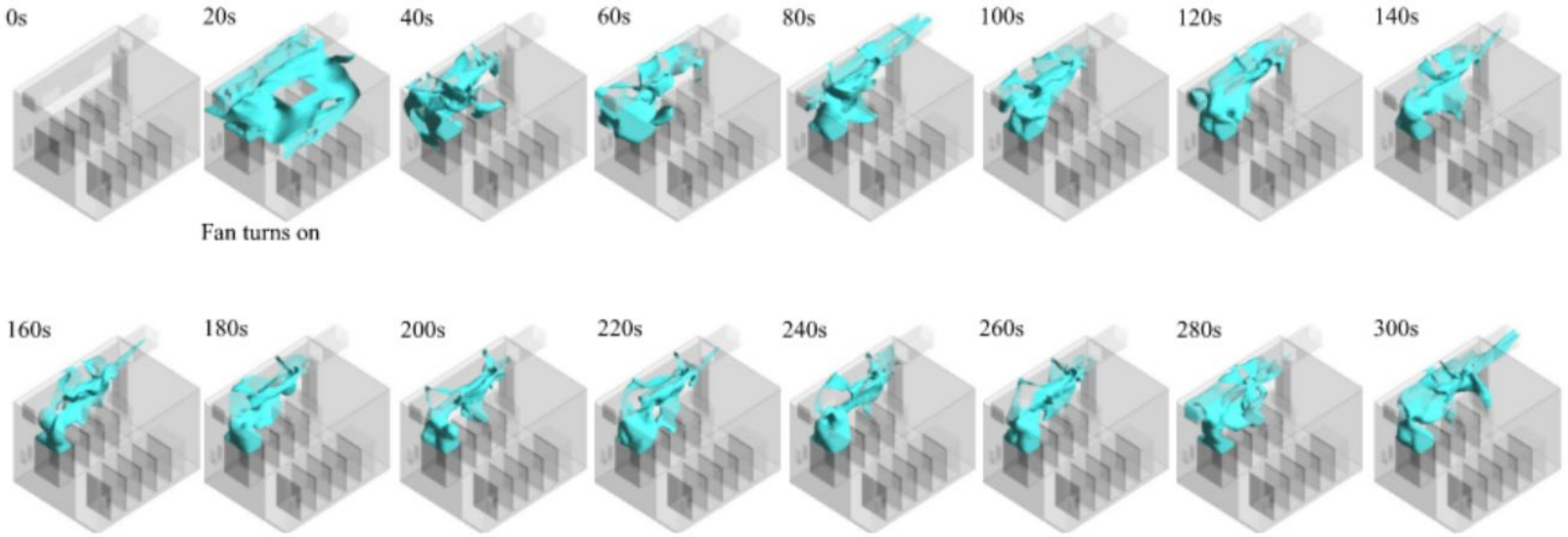
NFPA 69

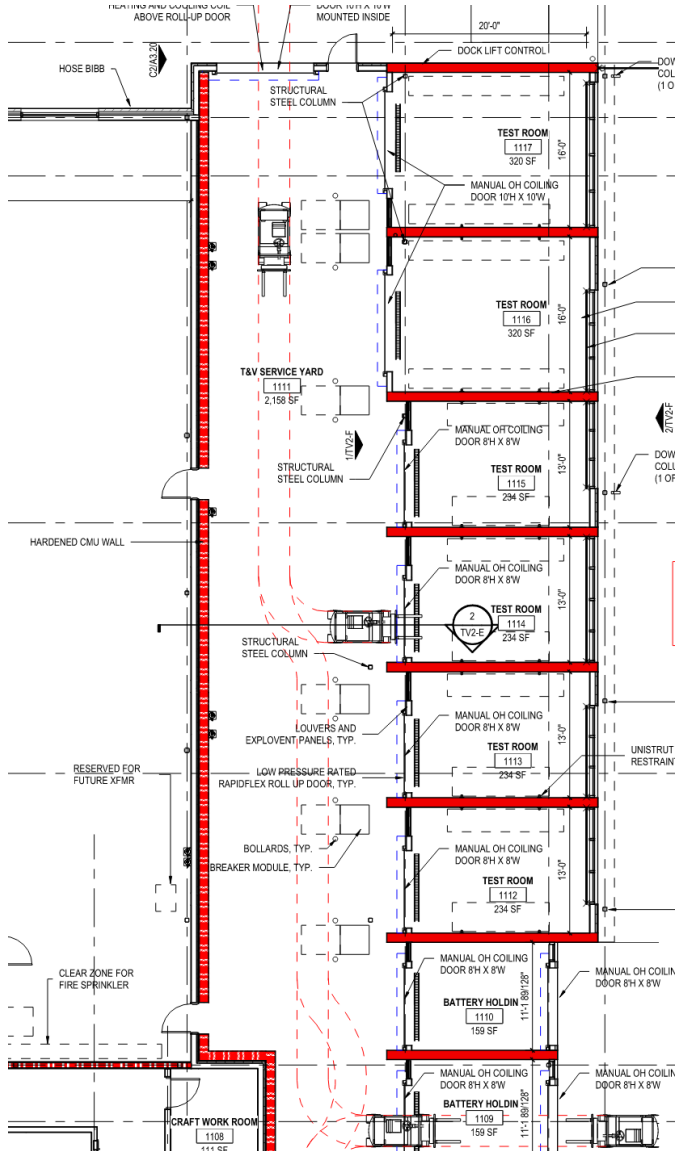

MANIFOLDED EXHAUST FANS:
6,800 CFM EACH (EVENT IN ONCE CHAMBER)
N+1 REDUNDENCY
TO OTHER CELL/HOLDING
CONSTANT AIRFLOW REGULATOR
OA THROUGH T&V AIR VALVE
N+1 AIRFLOW STATIONS
DUCT HEADER SIZE:
- 30 INCHES (FOR A SINGLE CELL PURGE).
CONSTANT AIRFLOW REGULATOR
N+1 PURGE EXHAUST OPENINGS
N+1 PURGE INTAKE LOUVERS
HIGH AND LOW NORMAL EXHAUST
CELL/HOLDING

NFPA 69

Transient Results

Large Test Room, Battery 6 – Isosurface at H2=0.85% (25% LFL)





LABORATORY ENVIRONMENT

Thirty (30) labs throughout the facility:

- Materials Synthesis Labs
- Prototyping/Fabrications Labs
- Nuclear Magnetic Resonance Labs (2)
- Dry Room Labs (4)
- High Performance Instrument Labs
- Wet Chemistry Labs

Service Corridor

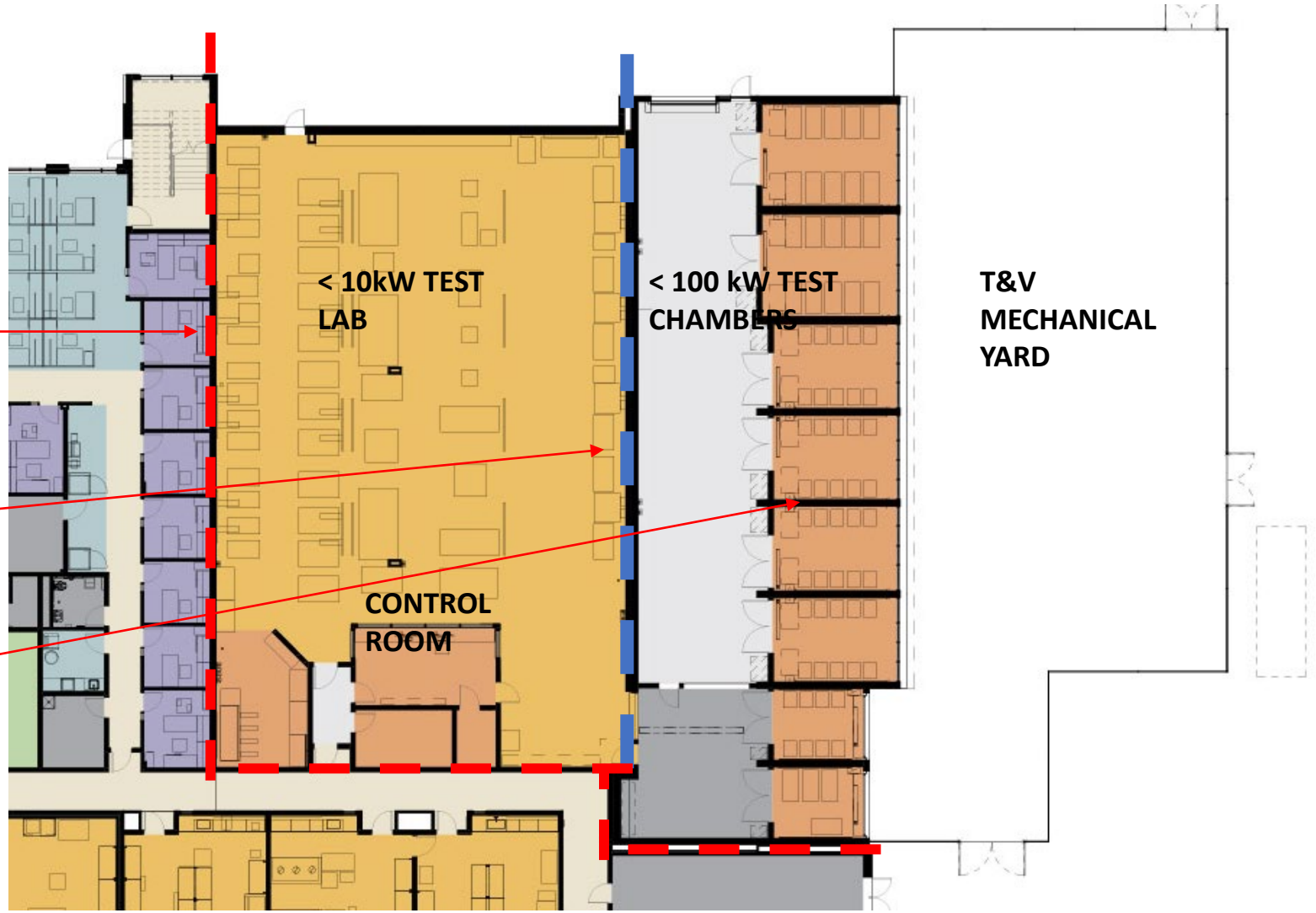
- 14’ (4.2 m) to underside of deck
- Continuous, unobstructed clear zone, 6’ (1.8m) wide, 8’ (2.4m) high for circulation and egress.
- Gas cylinder cabinets – sprinklered/ ventilated.
- Every lab module - dedicated electrical panel, vacuum pot, & service electrical for planned equipment.

BATTERY TESTING AND VALIDATION

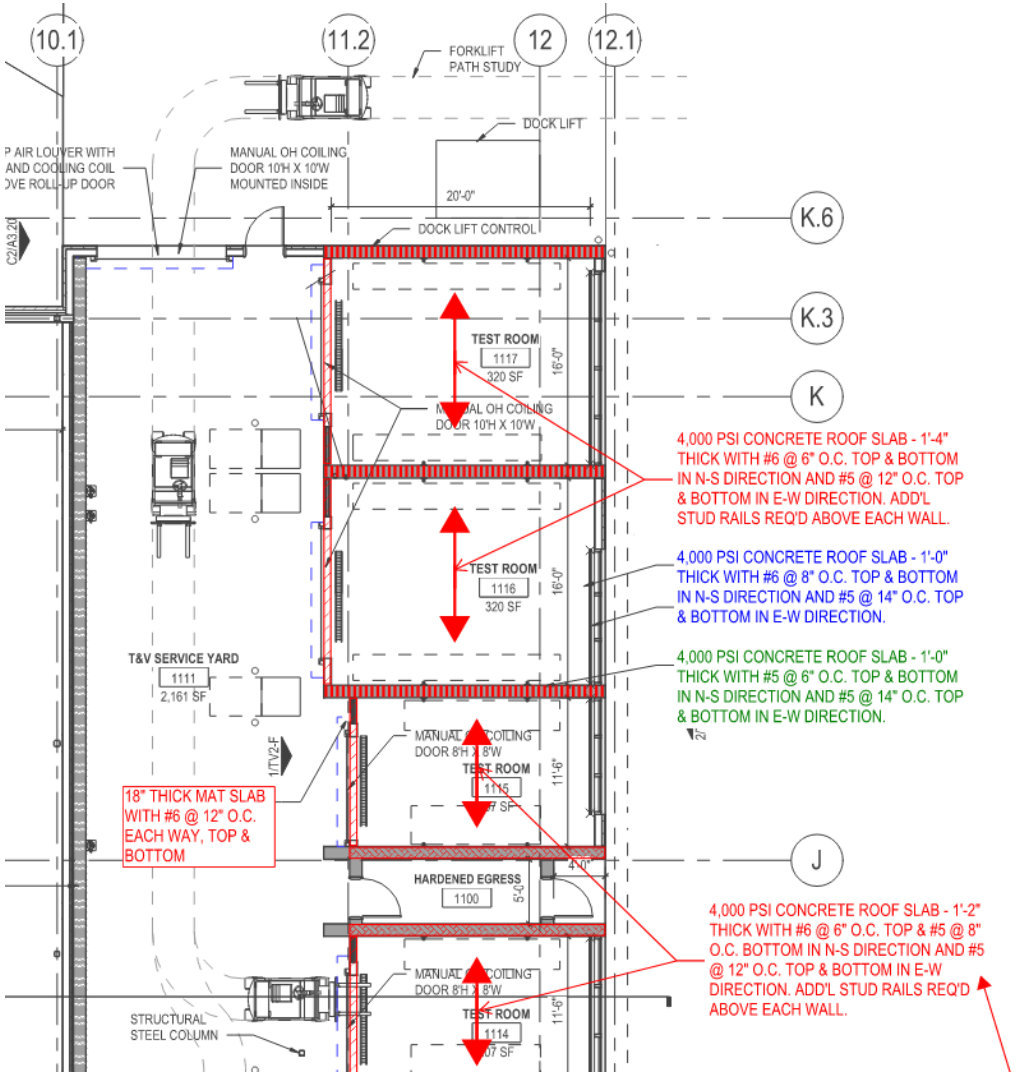
2-Hour Rated Fire Barrier

2-Hour Rated Hardened CMU

2-Hour Rated Concrete Shear Wall



BATTERY TESTING AND VALIDATION



1600 PSF CONCRETE WALL SCHEDULE

- 4,000 PSI CONCRETE WALL - 1'-2" THICK, 15-FT TALL WITH #8 VERT. @ 8" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE
- IF REQUIRED TO BE BLAST RESISTANT, 4,000 PSI CONCRETE WALL - 1'-0" THICK, 15-FT TALL WITH #8 VERT. @ 8" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE
- 4,000 PSI CONCRETE WALL - 1'-0" THICK, 15-FT TALL WITH #8 VERT. @ 7" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE

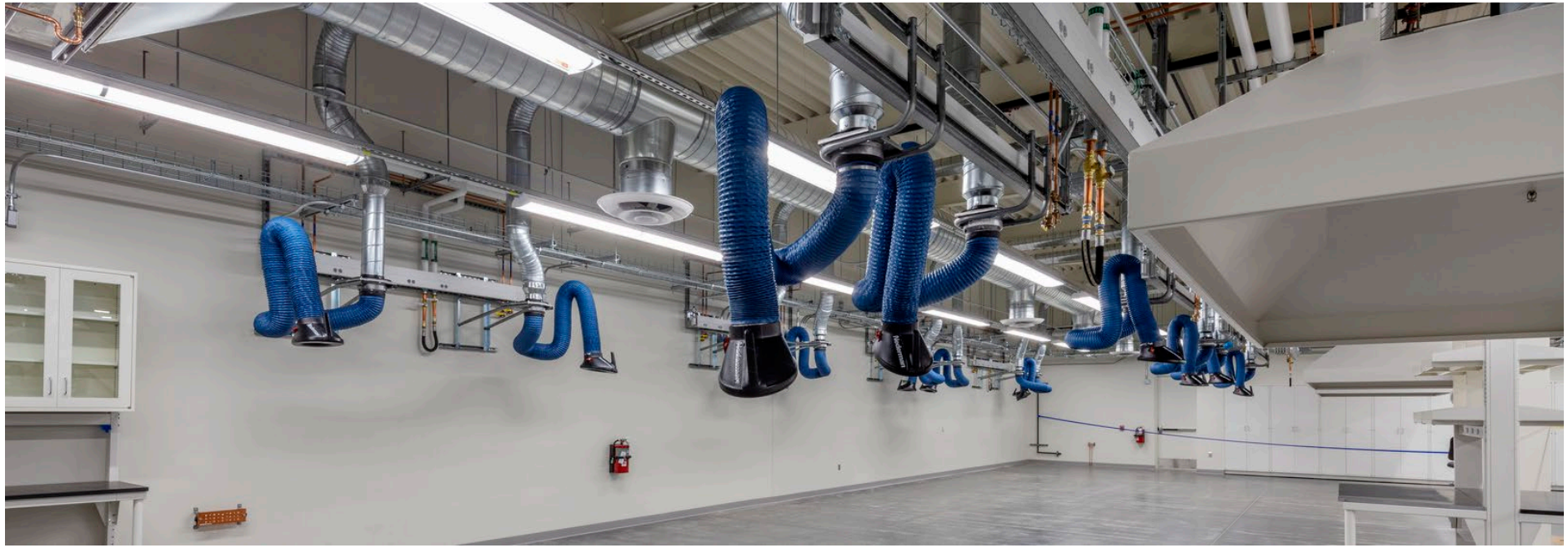
1200 PSF CONCRETE WALL SCHEDULE

- 4,000 PSI CONCRETE WALL - 1'-0" THICK, 15-FT TALL WITH #8 VERT. @ 9" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE
- IF REQUIRED TO BE BLAST RESISTANT, 4,000 PSI CONCRETE WALL - 10" THICK, 15-FT TALL WITH #8 VERT. @ 9" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE
- 4,000 PSI CONCRETE WALL - 10" THICK, 15-FT TALL WITH #8 VERT. @ 8" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE

1000 PSF CONCRETE WALL SCHEDULE

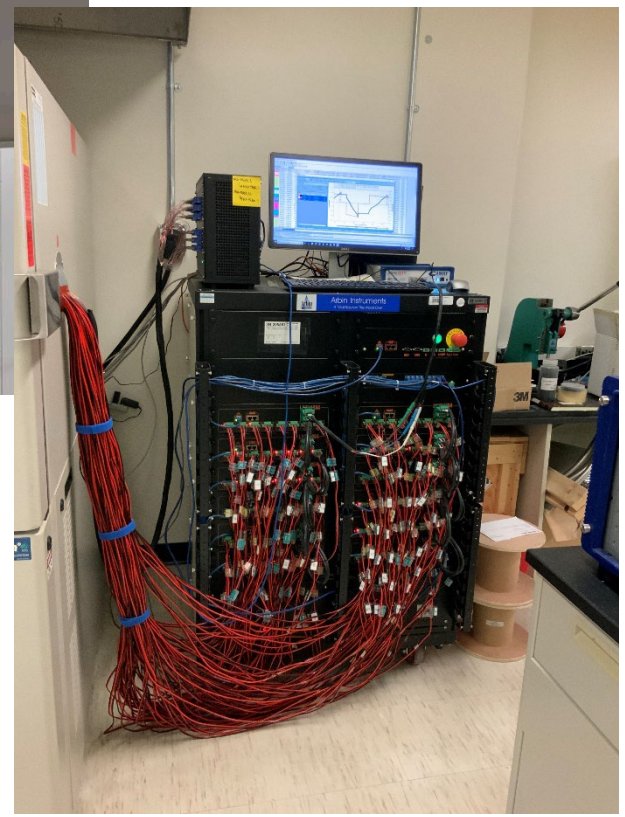
- 4,000 PSI CONCRETE WALL - 10" THICK, 15-FT TALL WITH #8 VERT. @ 9" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE
- IF REQUIRED TO BE BLAST RESISTANT, 4,000 PSI CONCRETE WALL - 10" THICK, 15-FT TALL WITH #8 VERT. @ 11" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE
- 4,000 PSI CONCRETE WALL - 1'-0" THICK, 15-FT TALL WITH #8 VERT. @ 9" O.C. EACH FACE & #5 HORIZONTAL @ 12" O.C. EACH FACE

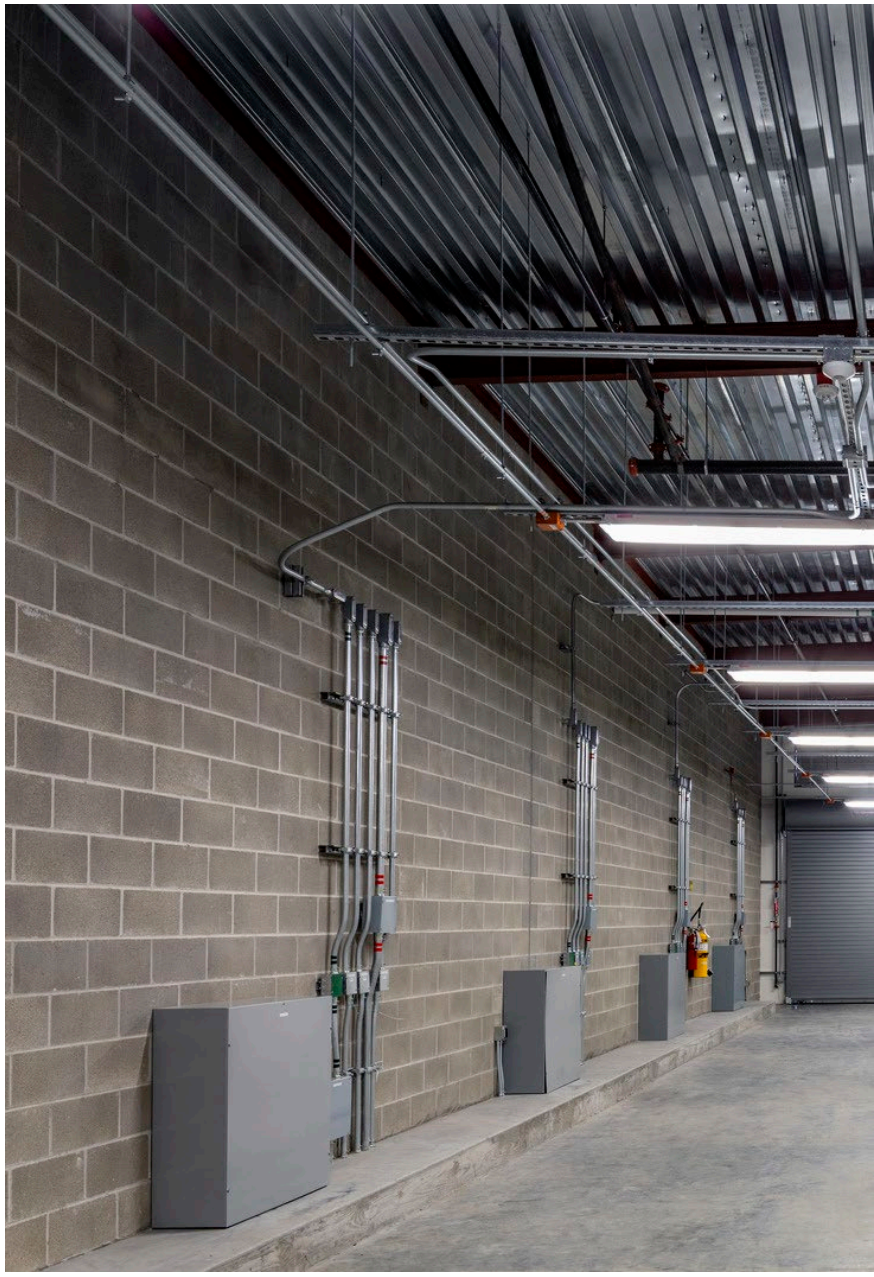
TESTING AREA 1 – 10 KVA AND LESS



- Designed for flexibility and growth
- Accommodates up to twenty (20) Battery Cyclers
- Ventilation system in accordance with NFPA 855
- Canopy hood at each test chamber
- Overhead utilities to facilitate connections to test chamber locations.

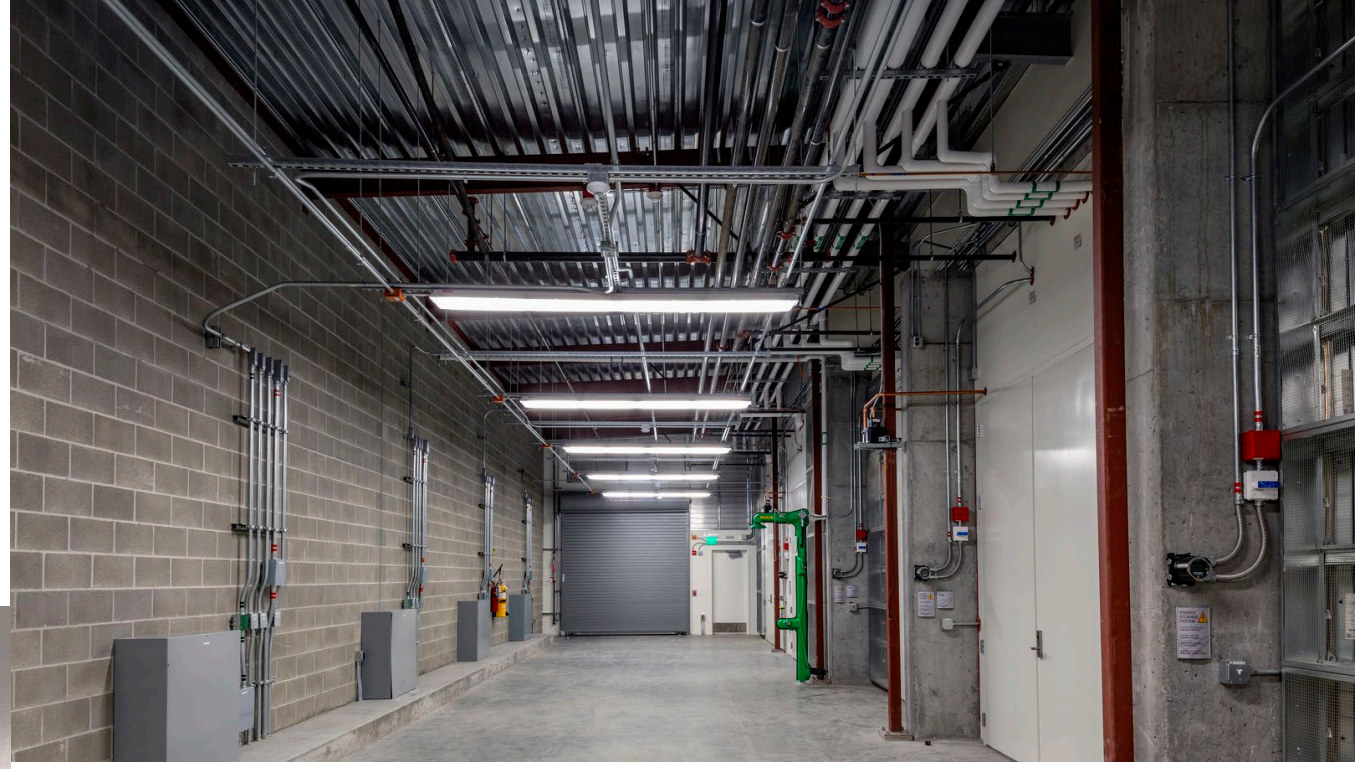
TESTING AREA 1 – 10 KVA AND LESS

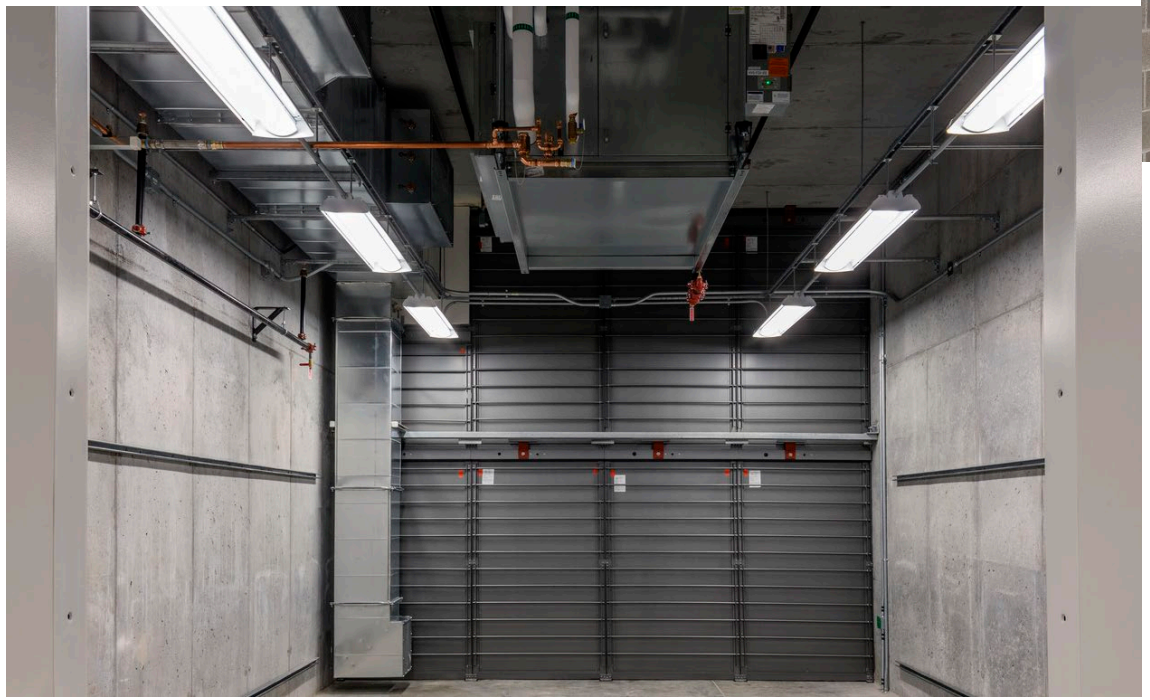




TESTING AREA 2 – UP TO 100 KVA

- Non-destructive Testing of Battery Cells
- Array of six (6) site-built test cells for different battery types
  - Four (4) small test cells, 12’x15’
  - Two (2) large test cells, 15’x15’





- Each test cell is designed to maintain testing without interruption from the adjacent test cells
- Electrical infrastructure to support various battery connections
- Continuous ventilation during normal operating mode
- Redundant Purge Fans and SIL-2 Control System
  - Provides nearly 120 ACH during emergency mode

DRY ROOM BATTERY TESTING

- Site-assembled, atmospherically controlled independent room structures
  - Perimeter walls consist of interlocking, sealed, vapor tight insulated metal clad, non-bearing system.
- Airlock vestibules constructed between dry rooms
- Anti-static Flooring

- Independent roof-top HVAC systems
  - Rotary wheel desiccant dehumidifier
  - Chilled water Coils
  - Direct Expansion Coils with Air-cooled Condensing Units
- Dry Room Performance
  - Temperature: 68 deg. F +/- 4 deg. F
  - Humidity: Less than 0.5% RH

HAZOP STUDY

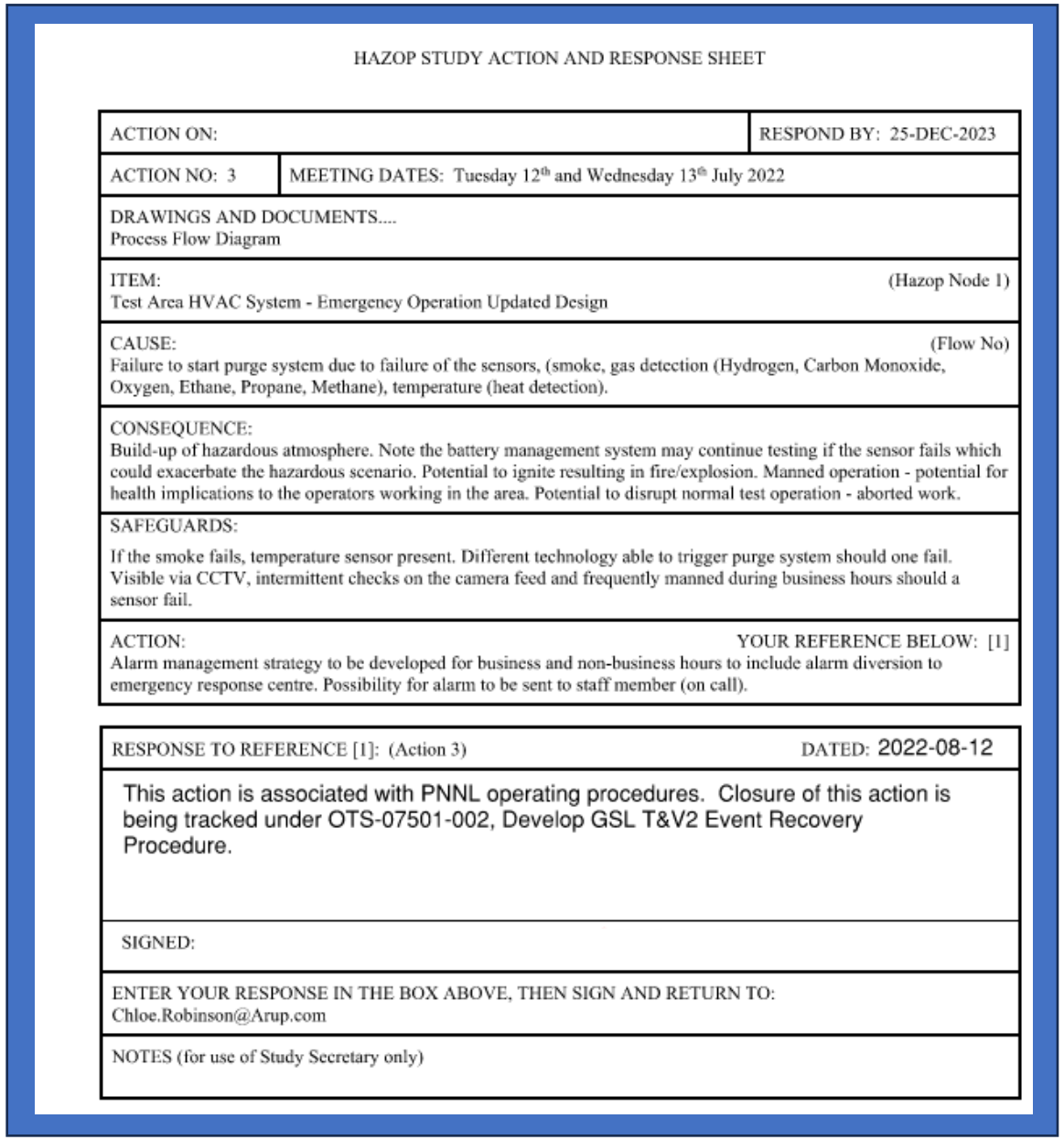
- Carried out in accordance with BS: IEC 61882:2001 and in line with IChemE guidance
- Independent, certified 3rd party consultant
- Two HAZOP sessions completed for the system under consideration as follows:
  - Session 1: Two days (November 22 and December 2, 2021). Design was subsequently updated, results superseded by second session.
  - Session 2: Two days (July 12-13, 2022) based on revised design.
- Deviation and actions identified by HAZOP team are included in conjunction with control philosophies and P&ID drawings for the installation.

NODE: 1			DATE REVIEWED: Tuesday 12th and Wednesday 13th July 2022		
ITEM: Test Area HVAC System - Emergency Operation Updated Design					
DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
3	Flow No	Loss of power.	Build-up of hazardous atmosphere. Potential to ignite resulting in fire/explosion. Manned operation - potential for health implications to the operators working in the area. Potential to disrupt normal test operation - aborted work.	Automated switch to standby generator in the event of a power failure. Purge fans and dampers operate on the standby generator only. In the event of a power failure the battery cyclers will stop testing - stop the potential for gas release. SIL system has battery backup.	Purge dampers to be fail open in the event of power loss.
	ACTION NO: 6 ASSIGNED TO: Daniel Spencer - Arup				
4	Flow No	Blockage of purge intake dampers due to operator mal-operation. e.g. storing equipment next to the damper.	Build-up of hazardous atmosphere. Potential to ignite resulting in fire/explosion. Manned operation - potential for health implications to the operators working in the area. Potential to disrupt normal test operation - aborted work.	Redundancy in damper and louver surface area. Regular walk-downs and maintenance of the damper and louver area. Appropriate training.	Consider signage/striping of damper and louver area to prevent placement of items in front of the louvers.
	ACTION NO: 7 ASSIGNED TO: Skye Smith - Kirksey				
5	Flow More	Mal-operation scenario when general exhaust fan operates during purge.	Increased air flow rate. Potential ignition source (from the general exhaust fan which is not electrically classified) if the LFL is exceeded.	SIL 2 rated emergency ventilation system.	Spec. general exhaust fan to mitigate this risk which may include non-sparking components, e.g. bearings.
	ACTION NO: 8 ASSIGNED TO: Daniel Spencer - Arup				

HAZOP STUDY

- Actions tracker template provided to assist in managing the close out of the identified actions
  - Ensures that the identified actions are responded to, are appropriately addressed, are signed off, and any changes are incorporated into the design

- Deviations identified include:
  - Failure of purge system to start due to failure of flammable gas detection system
  - Loss of power
  - Actuated valves or dampers fail to open
  - Loss of PLC communication
  - Accidental blockage of intake louvers
  - Low ambient temperature during purge

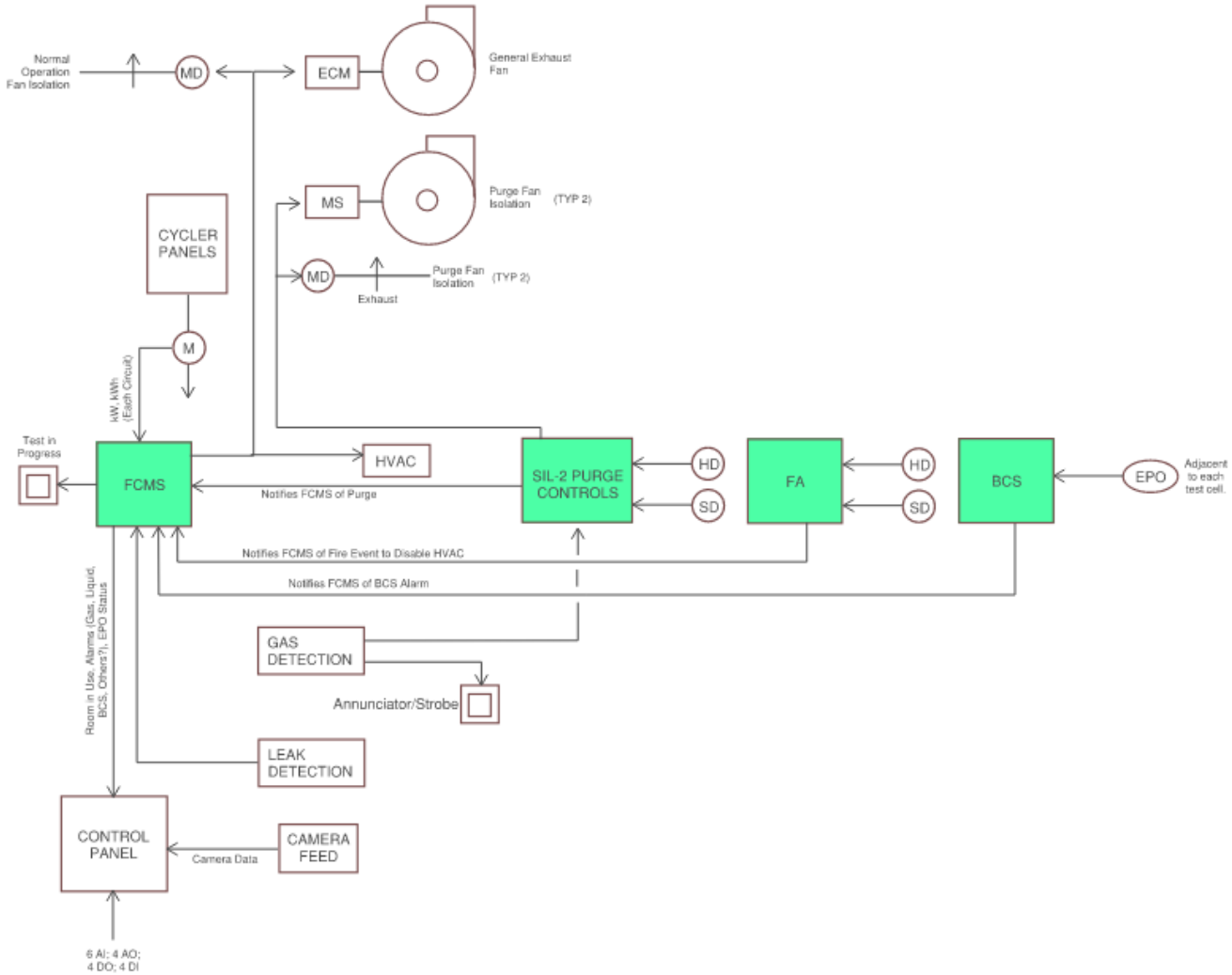


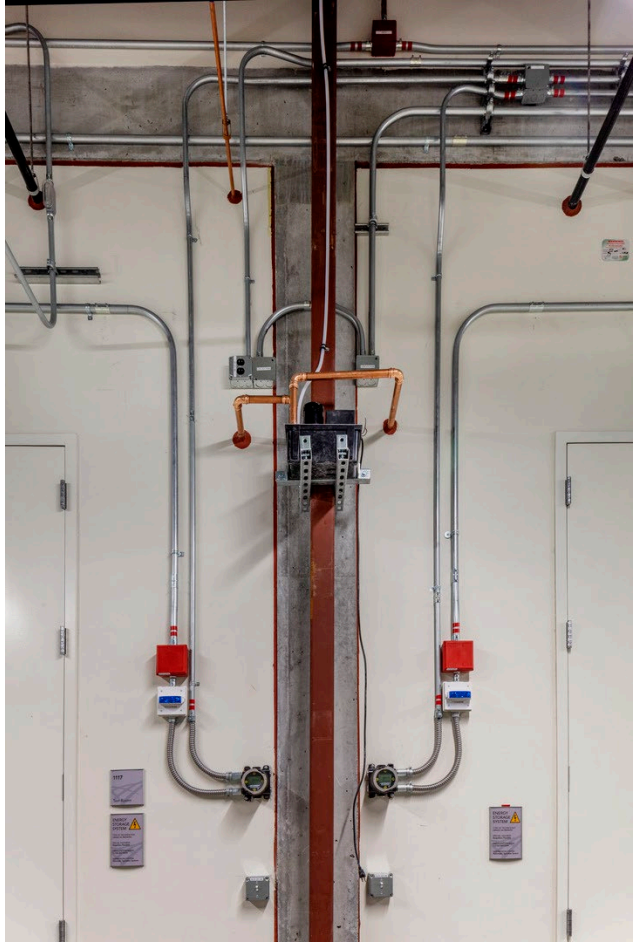
HAZOP STUDY ACTION AND RESPONSE SHEET

ACTION ON:	RESPOND BY: 25-DEC-2023
ACTION NO: 3	MEETING DATES: Tuesday 12th and Wednesday 13th July 2022
DRAWINGS AND DOCUMENTS.... Process Flow Diagram	
ITEM: (Hazop Node 1) Test Area HVAC System - Emergency Operation Updated Design	
CAUSE: (Flow No) Failure to start purge system due to failure of the sensors, (smoke, gas detection (Hydrogen, Carbon Monoxide, Oxygen, Ethane, Propane, Methane), temperature (heat detection).	
CONSEQUENCE: Build-up of hazardous atmosphere. Note the battery management system may continue testing if the sensor fails which could exacerbate the hazardous scenario. Potential to ignite resulting in fire/explosion. Manned operation - potential for health implications to the operators working in the area. Potential to disrupt normal test operation - aborted work.	
SAFEGUARDS: If the smoke fails, temperature sensor present. Different technology able to trigger purge system should one fail. Visible via CCTV, intermittent checks on the camera feed and frequently manned during business hours should a sensor fail.	
ACTION: YOUR REFERENCE BELOW: [1] Alarm management strategy to be developed for business and non-business hours to include alarm diversion to emergency response centre. Possibility for alarm to be sent to staff member (on call).	

RESPONSE TO REFERENCE [1]: (Action 3)	DATED: 2022-08-12
This action is associated with PNNL operating procedures. Closure of this action is being tracked under OTS-07501-002, Develop GSL T&V2 Event Recovery Procedure.	
SIGNED:	
ENTER YOUR RESPONSE IN THE BOX ABOVE, THEN SIGN AND RETURN TO: Chloe.Robinson@Arup.com	
NOTES (for use of Study Secretary only)	

SAFETY IMPLICATIONS FOR A GRID-SCALE NFPA 855 SYSTEM





- Design process requirements and commissioning requirements required to certify a Safety Instrumented System per IEC 61511
- Safety Integrity Level (SIL) 2

THANK YOU!

QUESTIONS??