Lessons Learned from a Helium Gas Recovery System Incident

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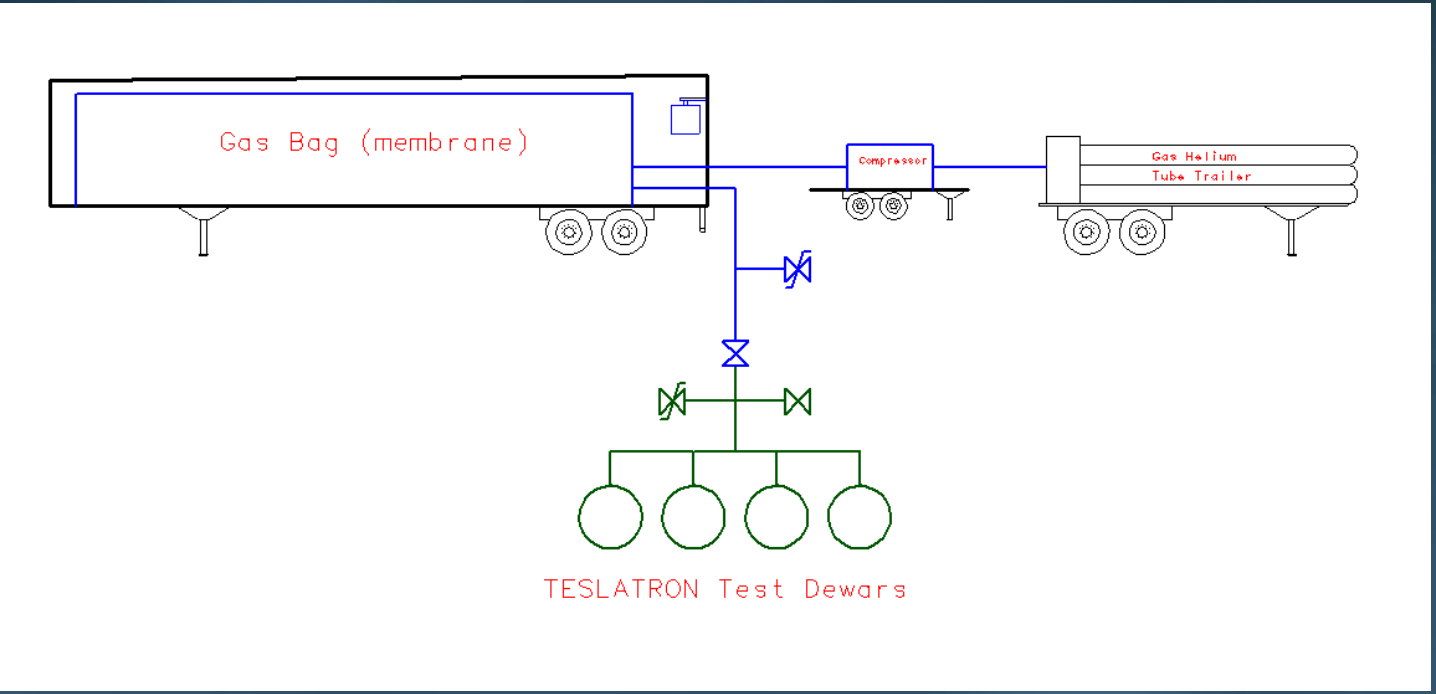
Superconducting Materials Lab

- Four test dewars for testing superconducting materials under a variety of conditions
- Test dewars are fed by 500 liter LHe dewars in either a batch or continuous mode
- Operational since August 2011
- Boil-off helium originally vented to atmosphere
- High cost of helium initiated discussion of helium recovery options

Facility Helium Recovery

- Final helium recovery system will reuse piping from the Tevatron to send the helium to a Tevatron purification and storage system
- Pending completion of the final system, a temporary system was implemented
- The temporary system was considered a possible laboratory resource
- Fermilab already had a trailer mounted high pressure compressor and helium tube trailers. The remaining major component was a gas bag

Temporary Helium Recovery System

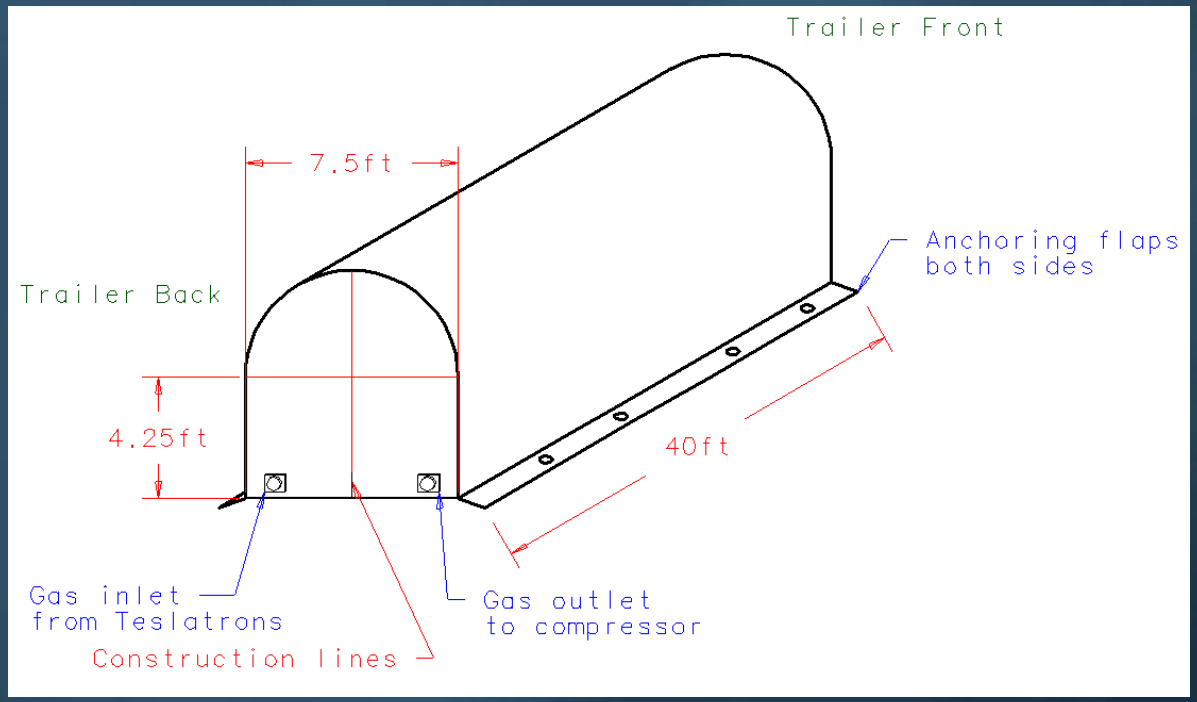


- Gas bag mounted in a insulated rented trailer with an electric heater to keep gas bag pliable during the winter
- Protected by 0.75 psi relief valve

Gas Bag

- Membrane material, 0.050” single-ply modified vinyl based polymer

- Trailer inside dimensions
  - 47 ¼’ long
  - 9’ high
  - 8 ¼’ wide



Gas Bag Failure

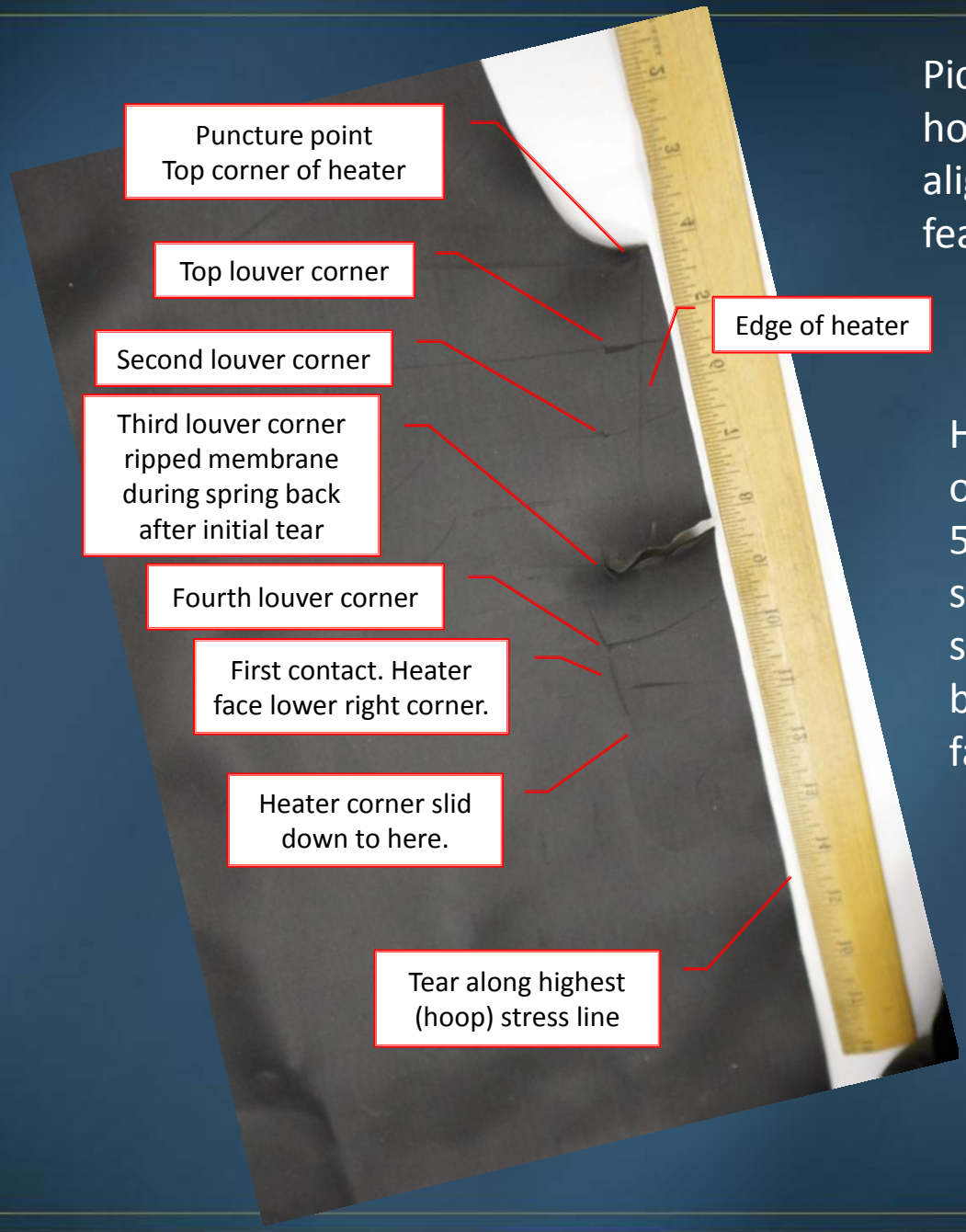
- A high boil-off rate test was performed
- 1 ¾ hours into the test, a large boom was heard
- System was secured
- 79” tear in gas bag end
- False wall rotated outward
- Equipment damage
  - Gas bag
  - Semi trailer (bowed walls and ceiling)
- No personnel injured

Gas Bag Technology

- Bags are not meant to be pressurized beyond that necessary to lift the weight of the membrane material (~0.01 psi)
- Overfill protection strategies
  - Size bag to handle all possible inventory
  - Install a volume limiting control
    - Volume limiting relief
    - Limit switches to activate compressor or valves

Gas Bag Failure Investigation

- The gas bag failed due to a puncture caused by the top-right corner of the electric heater

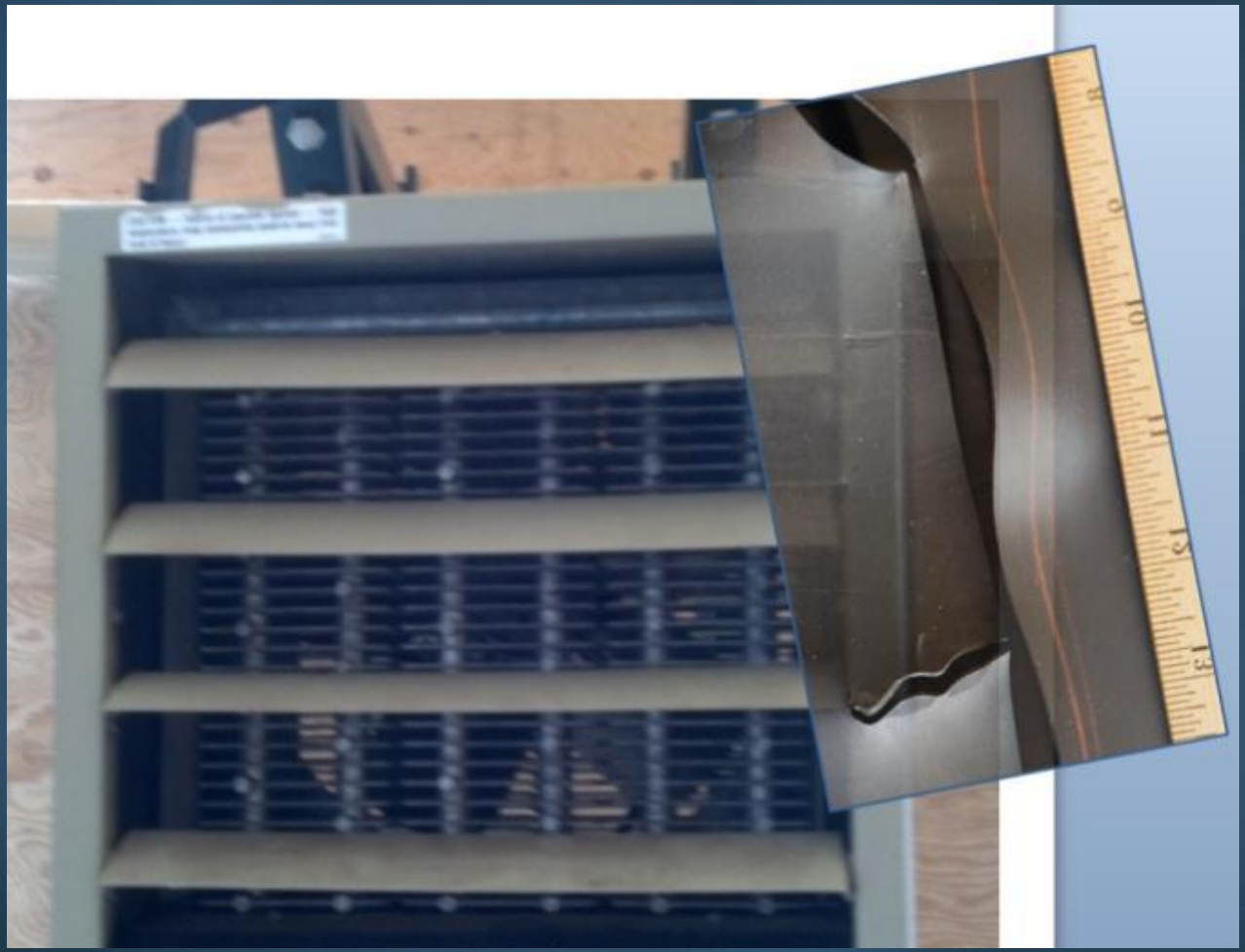


Picture flipped horizontally to align with heater features

Heater features on membrane are 50% scaled, suggesting a 200% stretching of the bag end wall facing the doors

Gas Bag Failure Investigation

Gas Bag Failure Investigation

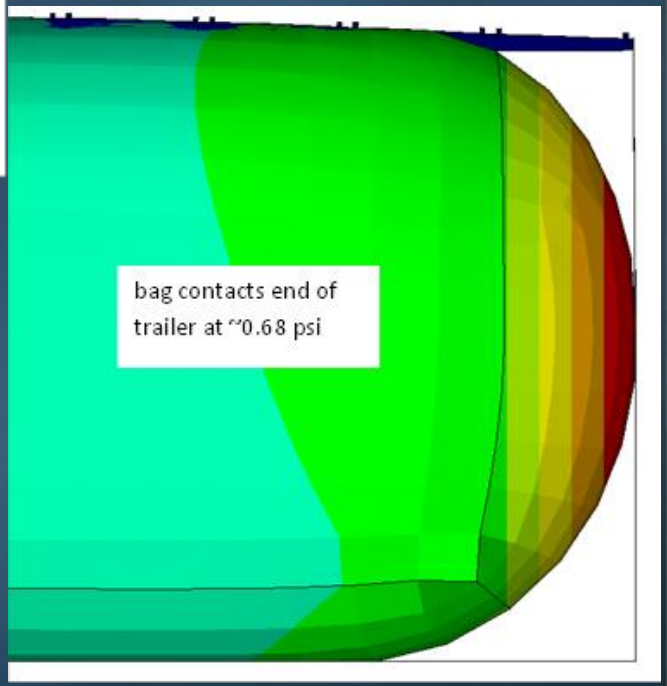


Gas Bag Failure Investigation

Force of bag on heater bent the top heater bracket. Bracket was constrained by bolts on the Unistrut®. Resulted in the top-right corner facing more forward

An imprint of the upper Unistrut® was observed in the membrane

Finite Element Analysis Verification



Pressures calculated using finite element analysis are consistent observations. The maximum membrane stress calculated was 640 psi.

Error Precursors

- System Design
  - Unfamiliar with gas bags
  - High work load, multiple projects
  - Lack of standards within FESHM specific to gas bag usage*
  - Lack of written vendor information*
  - Inaccurate mental picture related to assumption of 1 psi gas bag MAWP
  - Misleading information between laboratory engineers related to 1 psi MAWP*
  - Complacency leading to a minimalistic application of Fermilab Engineering Manual and Cryogenic Safety Panel Review

FESHM 5031.5

- Low Pressure Vessels
  - Defined as: any closed vessel pressurized to less than 15 psig
  - Excludes vessels with $P*V < 515$ psig-ft^3
- Many Lab engineers interpret “vessel” as only being metallic

Vendor Information

- Written information does not state that volume limiting controls are necessary
- Picture gives misleading impression of internal pressure
- Misleading temperature limit

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CORPORATION

Technical Specifications for
FLEXI-LINER FORMULATION
J-22

Material Description: Modified vinyl based polymer, including up to 3% polyvinylidene chloride, and polymeric non-migrating plasticizers. Black.

Available Thicknesses: 0.050, 0.065, 0.080, 0.100, 0.125, 0.187, 0.250 MILS. All single ply, extruded

Typical Applications: Extremely corrosion resistant against most inorganic acids, in a wide concentration range, against caustic, and a limited number of organic chemicals. To be used for almost all plating, etching, leaching solutions, all fertilizers, bleach steel pickling, for water reservoir lining, water purification, water treatment chemicals, paper chemicals, etc.

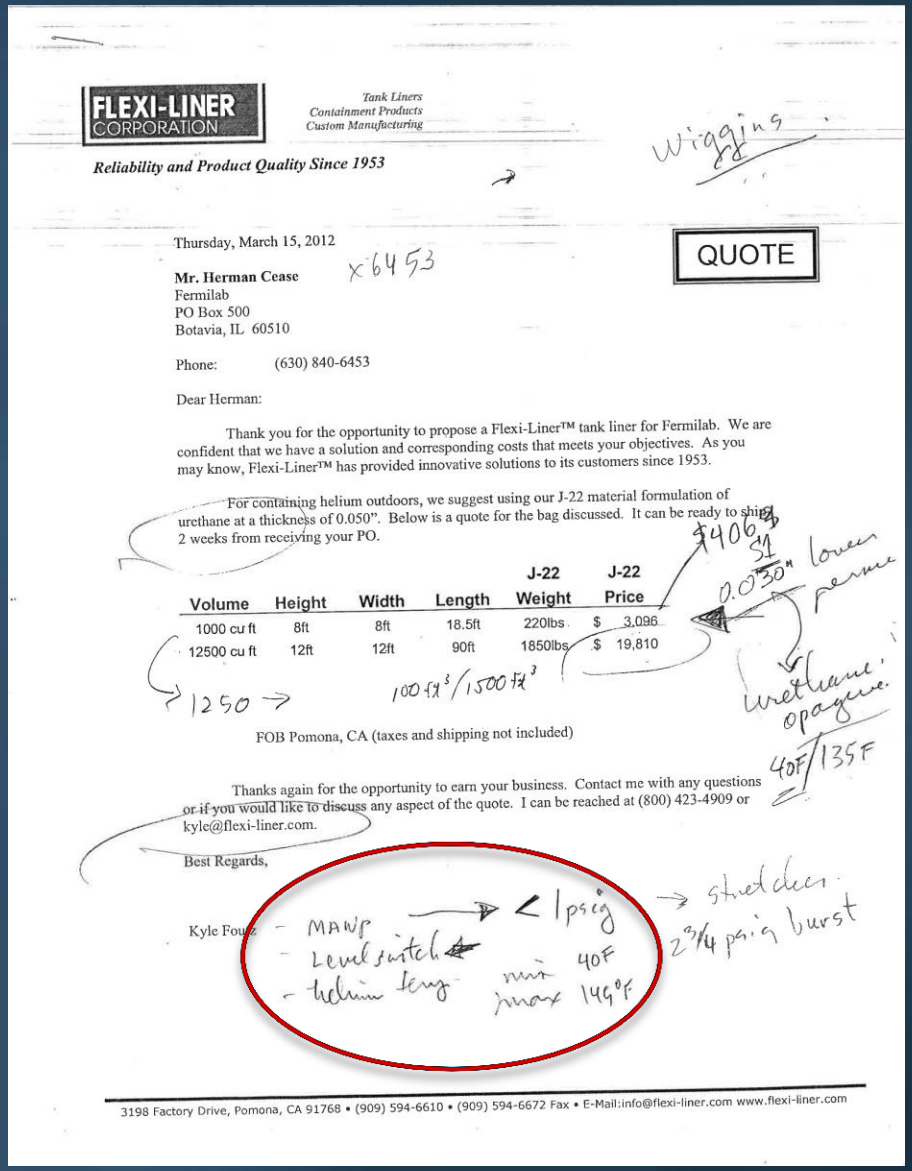
PROPERTY	ASTM OR TEST METHOD*	VALUE
Specific Gravity	D-12-27	1.28 - 1.32
Durometer Hardness "D"	D-676	62 - 67
Tensile Strength, psi	D-412	3000
Modulus at 300% elongation, psi		2100
Elongation at break, %	D-638	325
Graves tear, lbs./in.	D-624	420
Low temp. brittleness point	D-746	-32° F.
Distortion point		350° F.
Maximum temp. continuous operation		150° F.

Extraction: Loss <1% to 120,000 leach cycles in salt water 10% concentration at ambient temperature. Flexi-Liner test L-2. Modified D1239-55.

Water Vapor < 1 cubic foot per 24 hours per 1,000 square feet at 50 mil thickness. Test performed at

Misleading Communication

- Handwritten notes between Lab engineers misinterpreted



FLEXI-LINER CORPORATION

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Reliability and Product Quality Since 1953

Wiggins

Thursday, March 15, 2012

x6453

QUOTE

Mr. Herman Cease
Fermilab
PO Box 500
Botavia, IL 60510

Phone: (630) 840-6453

Dear Herman:

Thank you for the opportunity to propose a Flexi-Liner™ tank liner for Fermilab. We are confident that we have a solution and corresponding costs that meets your objectives. As you may know, Flexi-Liner™ has provided innovative solutions to its customers since 1953.

For containing helium outdoors, we suggest using our J-22 material formulation of urethane at a thickness of 0.050". Below is a quote for the bag discussed. It can be ready to ship 2 weeks from receiving your PO.

Volume	Height	Width	Length	J-22 Weight	J-22 Price
1000 cu ft	8ft	8ft	18.5ft	220lbs	$ 3,096
12500 cu ft	12ft	12ft	90ft	1850lbs	$ 19,810

$406 ea
0.050" lower perm
urethane opaque
40F/135F
1250 →
1000 ft³/1500 ft³

FOB Pomona, CA (taxes and shipping not included)

Thanks again for the opportunity to earn your business. Contact me with any questions or if you would like to discuss any aspect of the quote. I can be reached at (800) 423-4909 or kyle@flexi-liner.com.

Best Regards,

Kyle Fou

- MAWP → < 1 psig
- Level switch
- helium temp

min 40F
max 140°F

→ steel deck
2 3/4 psig burst

3198 Factory Drive, Pomona, CA 91768 • (909) 594-6610 • (909) 594-6672 Fax • E-Mail:info@flexi-liner.com www.flexi-liner.com

Error Precursors, continued

- System Operation
  - Lack of communication (written or verbal) between lead engineer and operational personnel related to required actions when bag is full
  - Inaccurate risk perception (supervision not recognizing warning signs in picture of the bag lifting ceiling panels)*
  - Unclear goals, roles & responsibilities related to lead engineer not participating in system start-up (viewed role as ending with ORC)
  - Unfamiliar with task (first time with continuous fill leading to high boil-off rate and boil-off volumes exceeding capacity of the bag)
  - Lack of practical height or volume indication led to overfilling the bag (had to unlock and open trailer door)

Picture from operations 3 weeks prior to incident

- Ceiling tiles being lifted during previous operation

Error Precursors, continued

- Incident Response
  - Lack of proficiency / inexperience related to reporting an ORPS incident
  - Inaccurate risk perception related to entering the trailer without following proper confined space permit entry procedure
  - Mental shortcuts / professional judgment overruled procedure

Gas Bag Failure Root Cause

- Not incorporating a gas bag volume limiting control

Incident Contributing Factors

- Inadequate application of the Fermilab Engineering Manual
- Manager of engineering activities did not recognize problem
- Incomplete or misleading vendor written information
- Misinterpreted verbal and written information between lead engineer and a lab engineer with limited gas bag experience
- Misinterpreted verbal information from the vendor
- Lack of process controls available to implement automated control
- Inadequate system review (internal and external to the department)
- Inadequate Cryogenic Safety Panel review due to interpretation of FESHM chapters 5032 and 5031.5
- Line management failure to recognize a system problem photographed on March 13 during an inspection

Recommendations

1. Request that the Mechanical Safety Subcommittee (MSS) develop a new FESHM chapter covering gas bag usage as well as other fluid containments that are outside of the scope of existing chapters
2. Request that the Cryogenic Safety Subcommittee (CSS) revise FESHM chapter 5032 to make it clear that warm sections of a cryogenic process are within the chapter scope
3. Request that the MSS and CSS review FESHM chapters under their control with an eye on having a clear scope and identification of possibly hazardous conditions which are currently not within the scope of FESHM chapters

Recommendations, continued

4. Identify other fluid containments with significant energy or environmental hazard currently used at the lab that fall outside the scope of existing FESHM chapters and ensure that proper engineering was implemented
5. Ensure that TD Test & Instrument department management and engineering personnel understand and abide by TID–N-59 Engineering Work Process Guidelines
6. Ensure that the Fermilab Engineering Manual is properly followed