# LBNF Target Hall $H_2$ and $^{41}Ar$ Gas Control System Design

# Technical Design Review
# Dune-doc-20934

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December 18 , 2020

# Overview

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- Hydrogen Flammability
- System design
  - General
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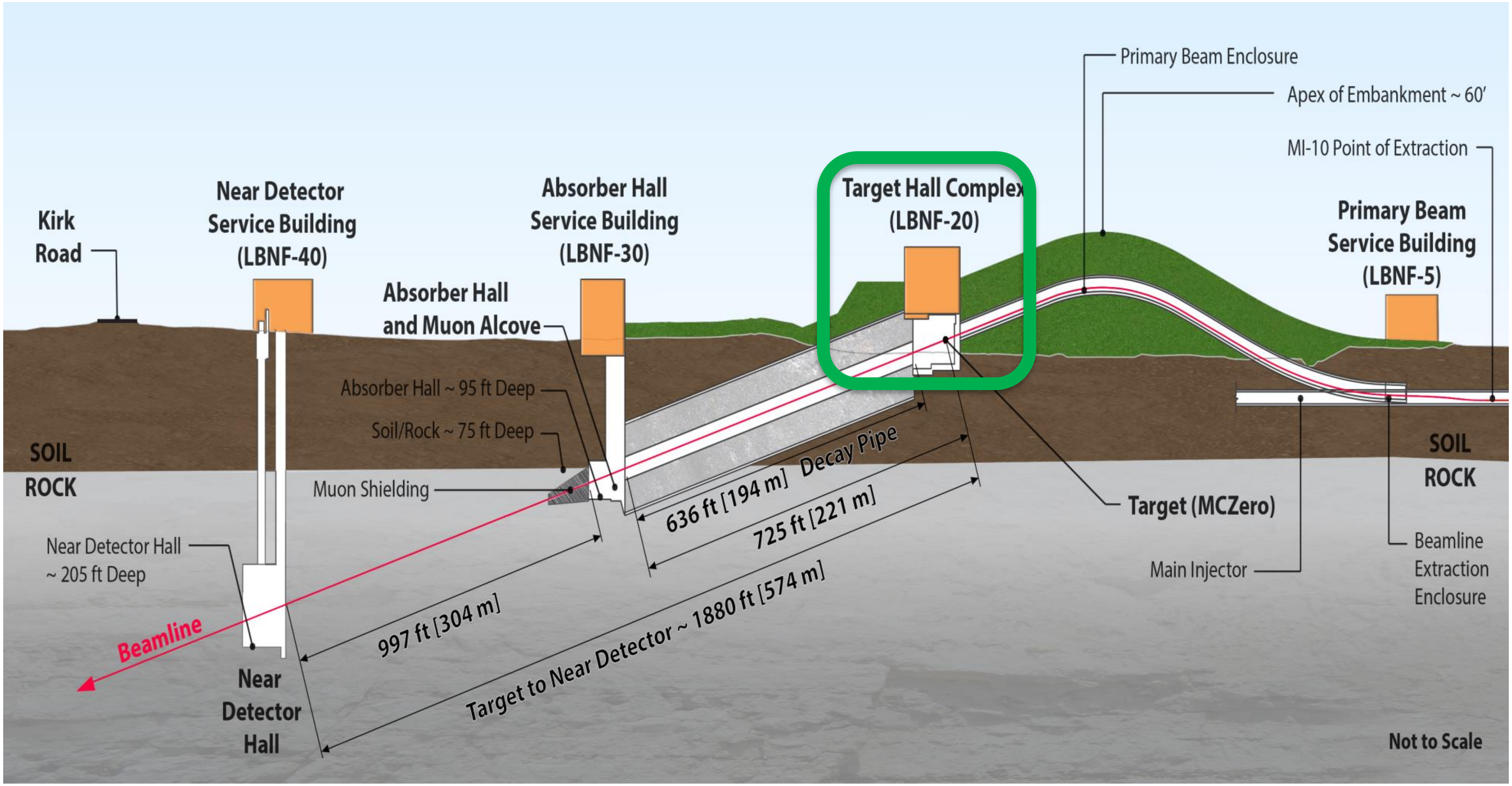
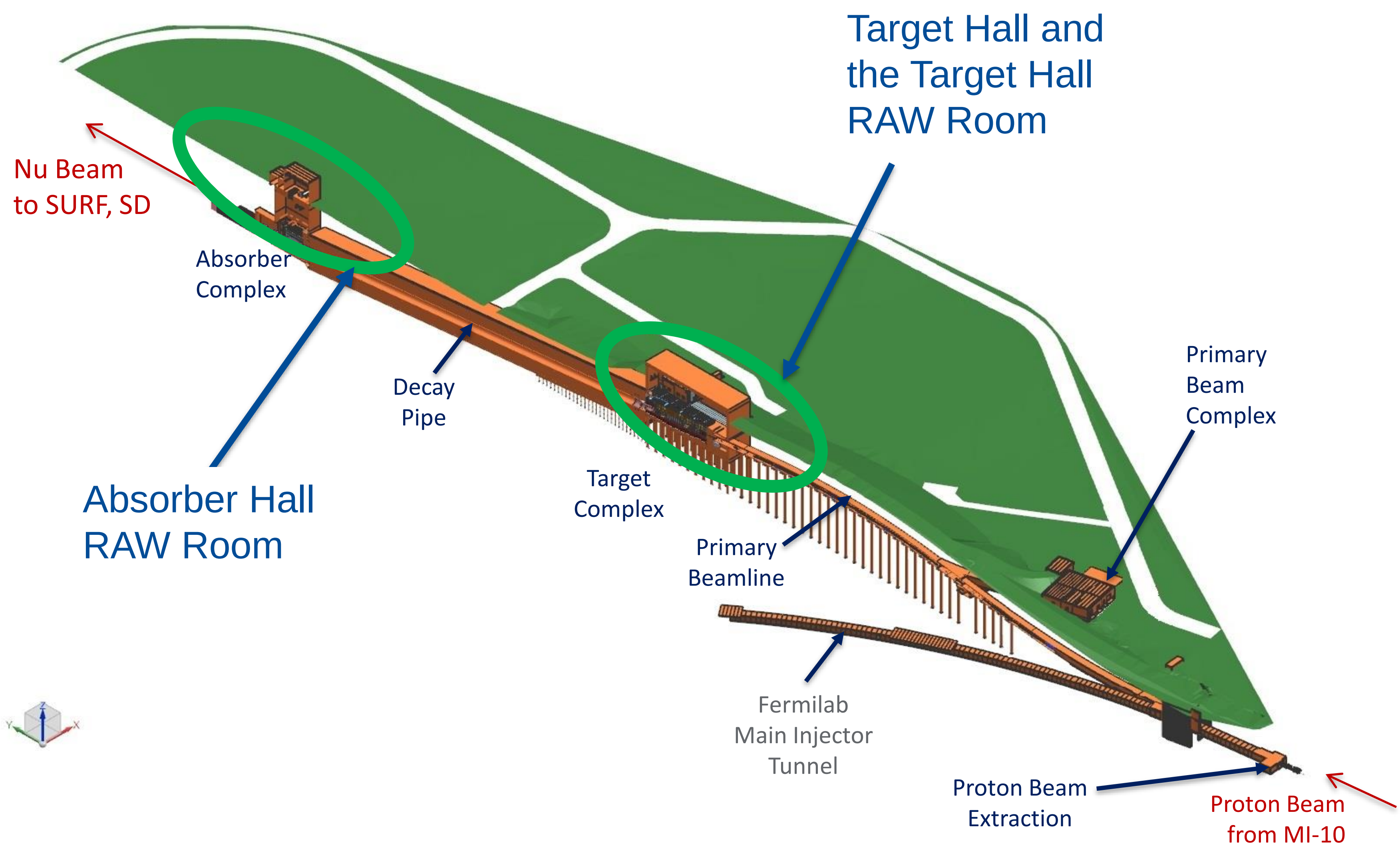
# Overview



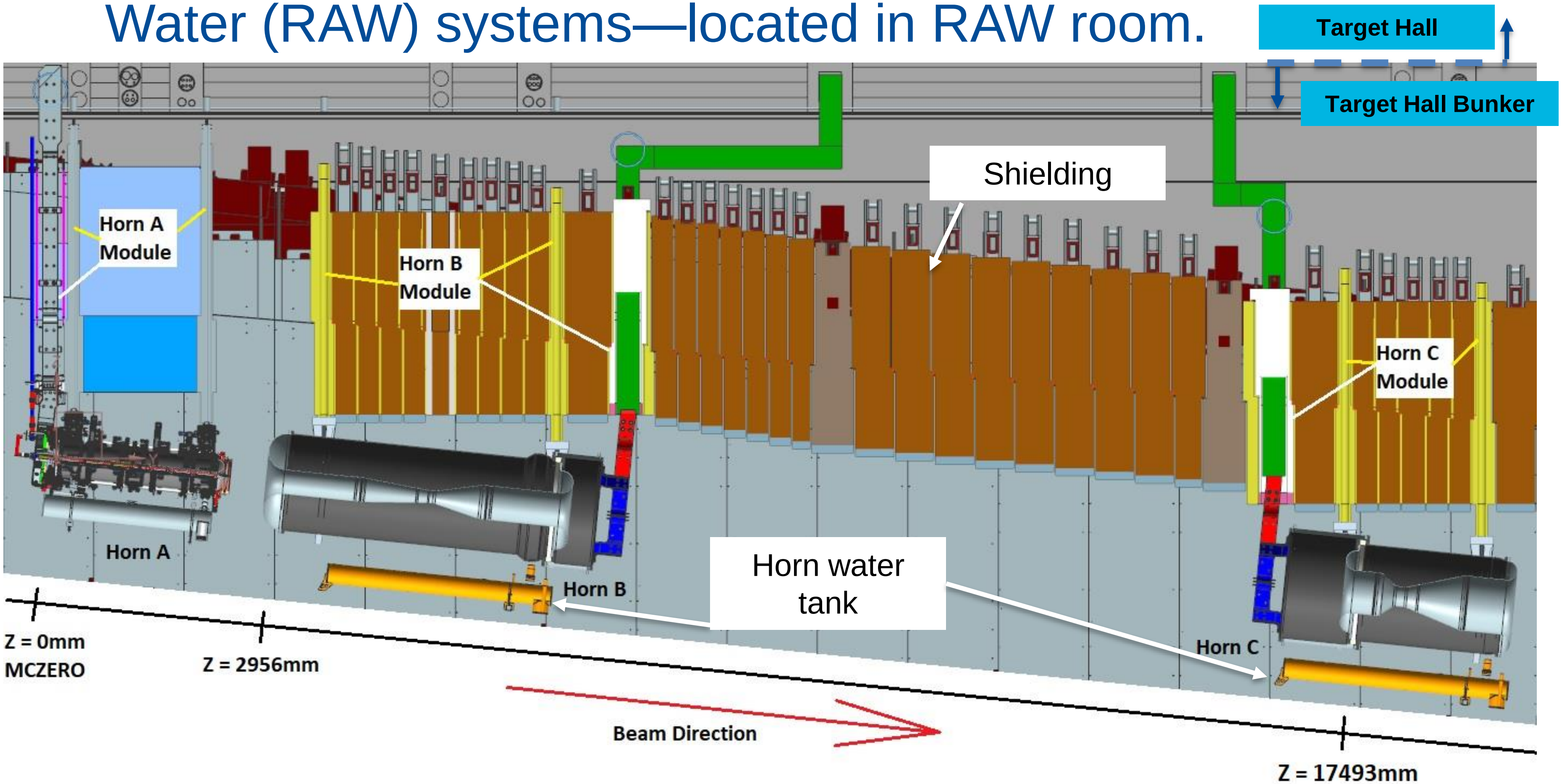
Primary Beam Enclosure
Apex of Embankment ~ 60'
MI-10 Point of Extraction
Kirk Road
Near Detector Service Building (LBNF-40)
Absorber Hall Service Building (LBNF-30)
Target Hall Complex (LBNF-20)
Primary Beam Service Building (LBNF-5)
Absorber Hall and Muon Alcove
Absorber Hall ~ 95 ft Deep
Soil/Rock ~ 75 ft Deep
Muon Shielding
SOIL
ROCK
Near Detector Hall ~ 205 ft Deep
Beamline
Near Detector Hall
997 ft [304 m]
636 ft [194 m]
Decay Pipe
725 ft [221 m]
Target to Near Detector ~ 1880 ft [574 m]
Target (MCZero)
Main Injector
Beamline Extraction Enclosure
SOIL
ROCK
Not to Scale

# Introduction



# Introduction: Target Hall, Target Bunker, and the Horns

- The Target and the 3 Horns are in the Target Hall Bunker.
- The Horns are water cooled by closed loop Radioactive Water (RAW) systems—located in RAW room.




*Source: Cory Crowley*

# Introduction: Inside the Horn

- The water interacts with the ionizing radiation and dissociates to hydrogen and oxygen.
- The blue and red arrows indicate RAW water flow path.

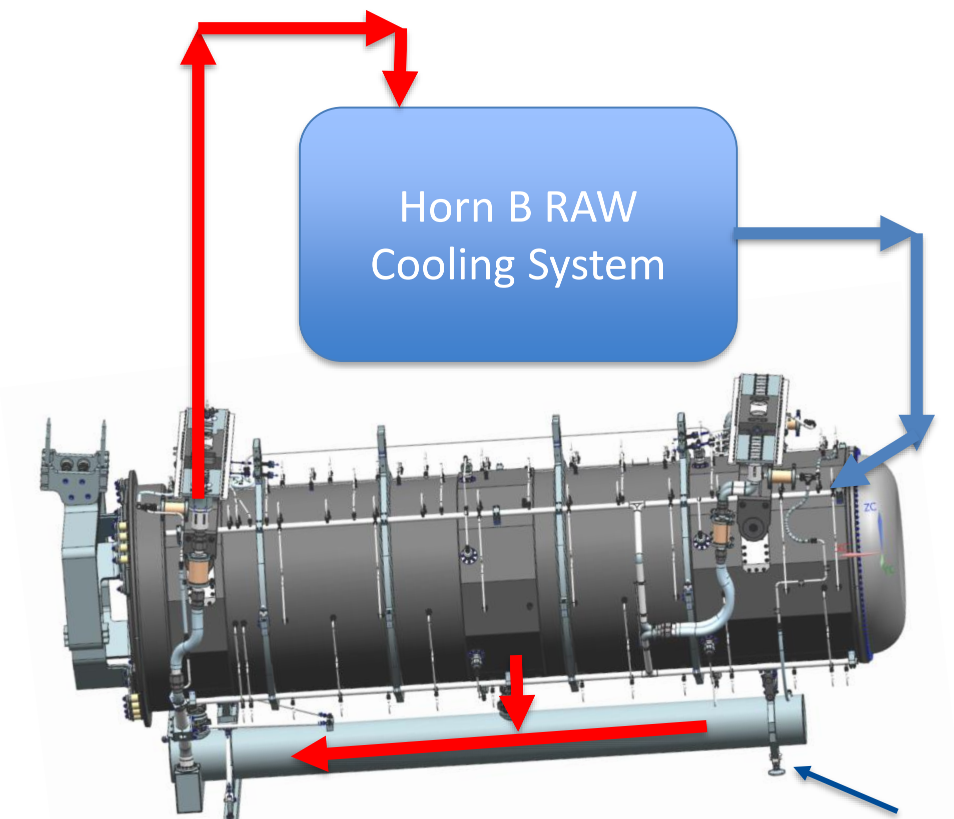
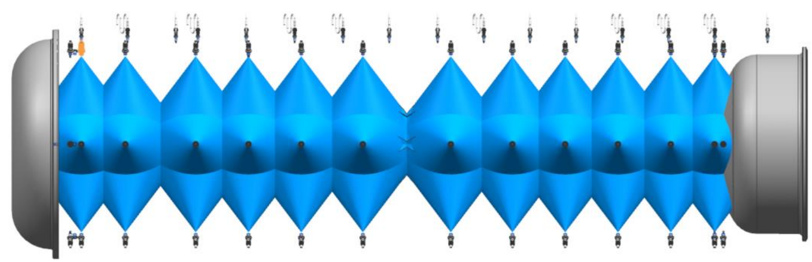




図 2　水の放射線分解スキーム

Y. Katsumura, Radiation Chemistry, No.81, 2-7 (2006)



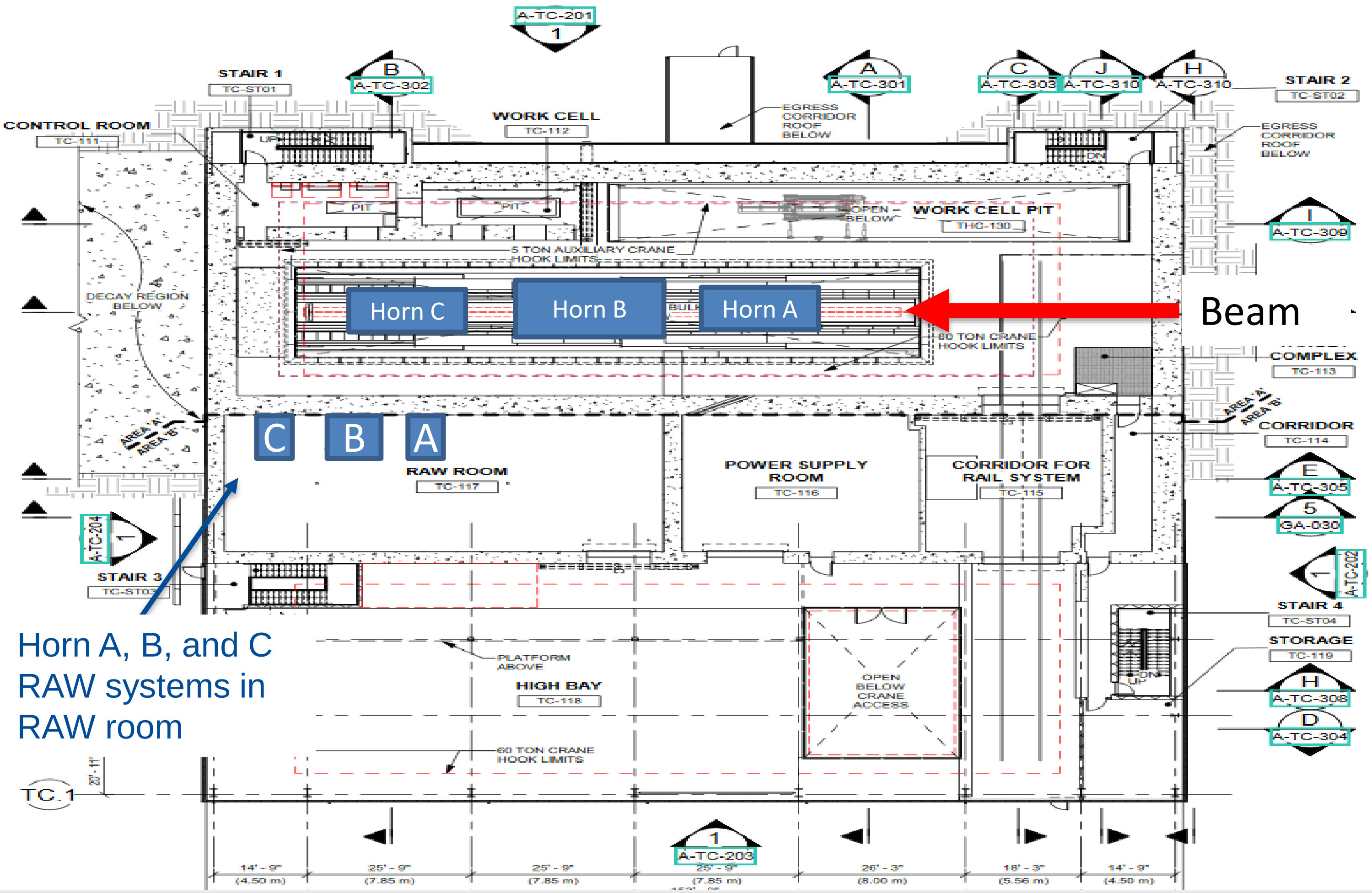
Spray of water inside the Horn

Spray gets collected into the Horn Tank and is sucked out and sent to the RAW system expansion tank

***Source: Nnamdi Agbo***

# Introduction: The RAW Room

- The Horns and their RAW systems in the RAW room are shown below:




*Source: Dune-doc-20744*

## Motivation

- Since the RAW systems are closed loop, there is a potential for $H_2$ gas build up to explosive limits.

- The Lower Explosive Limit (LEL) of $H_2$ in air is ~4%. This is the lowest concentration at which $H_2$ can become flammable in the presence of an ignition source in air at 14.69 Psia and 25 C (NFPA 55)—more on this later.

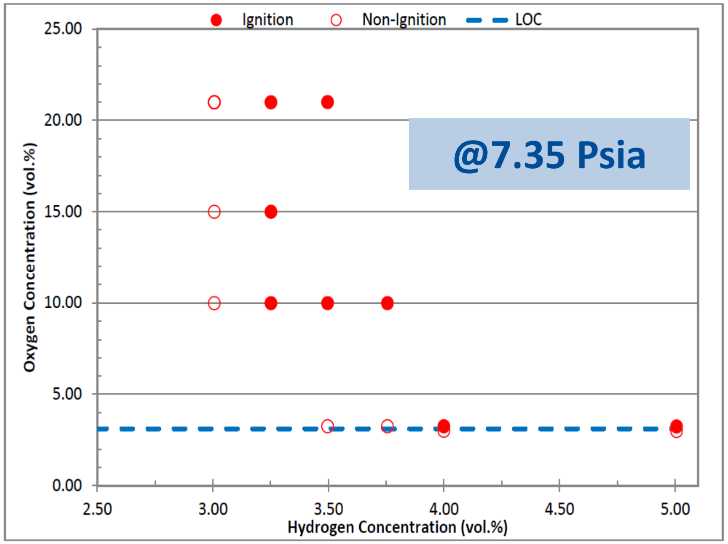
- The $H_2$ build-up is not a new problem. We have dealt with this in NuMI. In NuMI, fresh Ar gas is pumped into the Horns. It is then collected in RAW expansion tanks and vented back into Target Hall atmosphere.

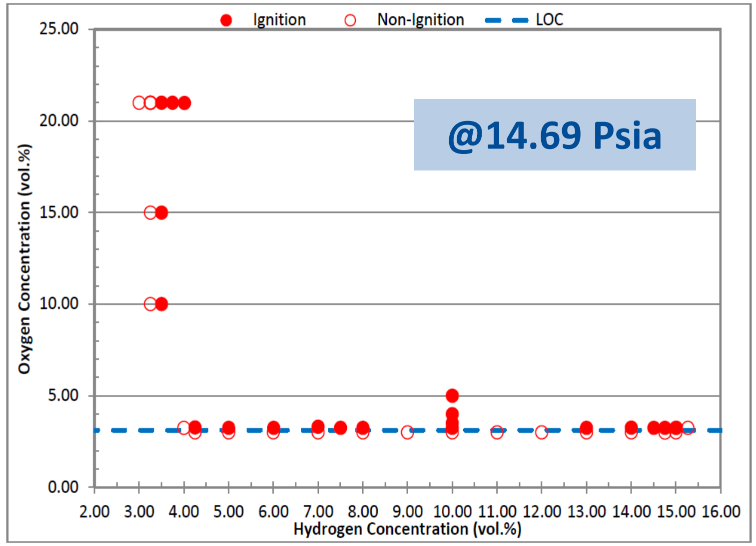
- We cannot do this in LBNF Horn systems because higher powers produces more $^{41}Ar$, which is radioactive.

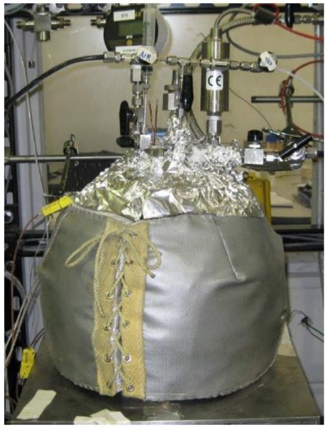
- Hence, we need a system to control $H_2$ and $^{41}Ar$.

# Hydrogen Flammability

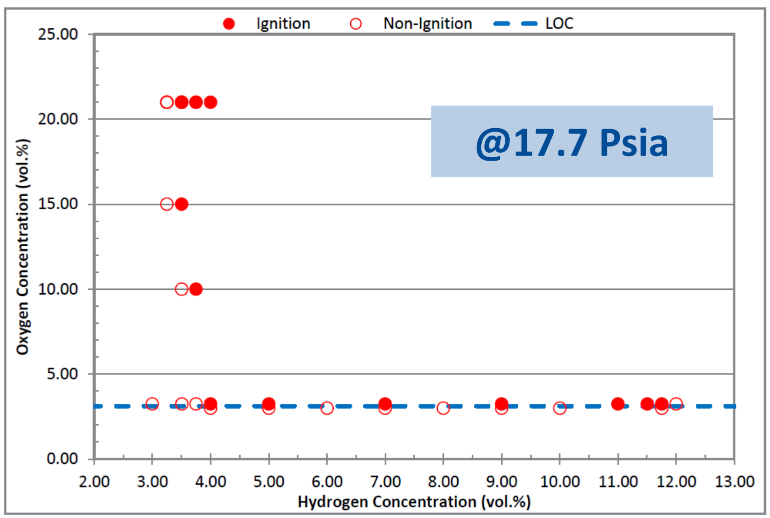
- Flammability of $H_2$ in Argon was tested by Fauske LLC at different pressures at 90 $^0$F



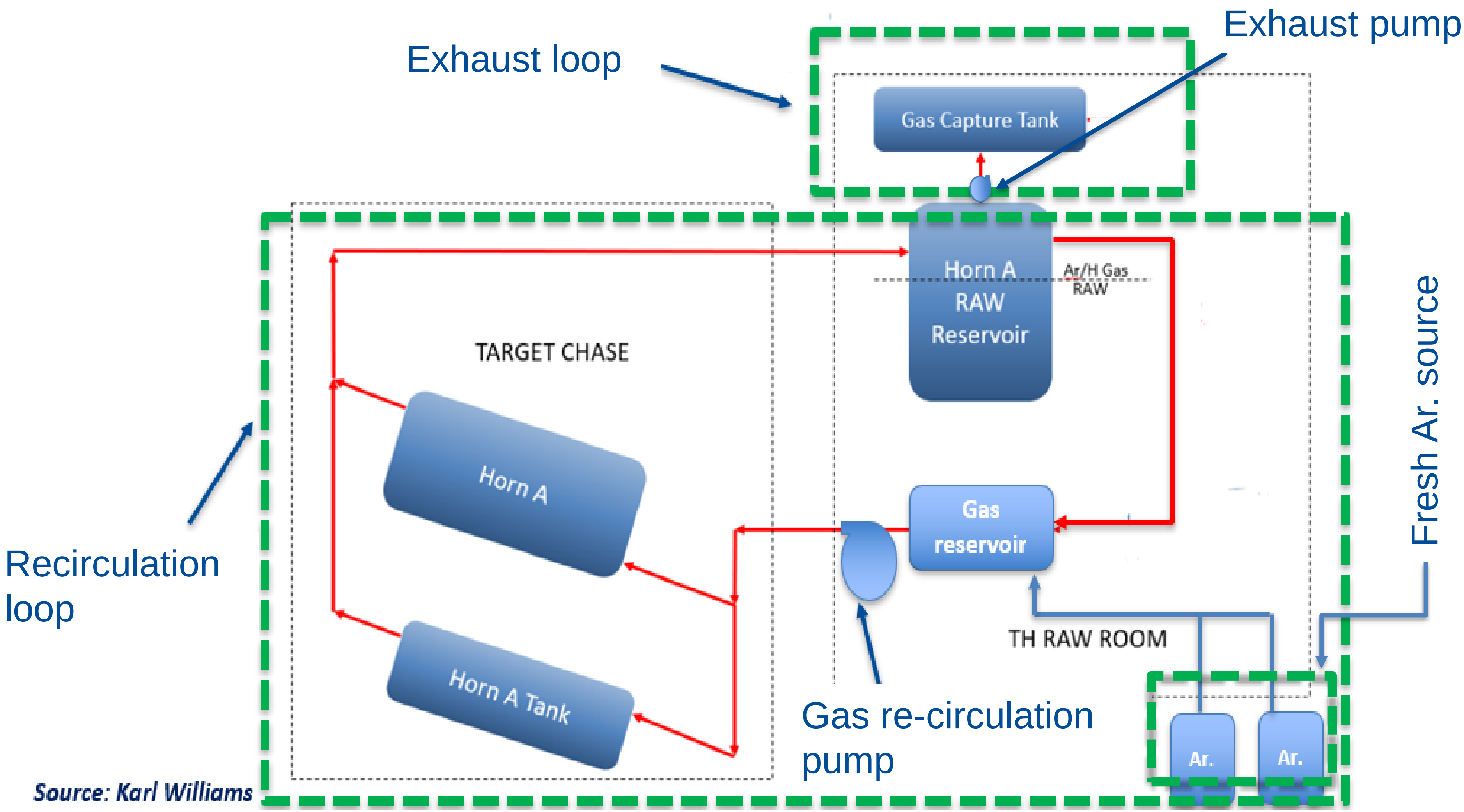
5-L spherical vessel. Experiment done per ASTM E918 standard




- The LFL is 3.13% of $H_2$ in a background of Ar.
- As per NFPA 69, LFL is the lowest concentration of a combustible substance in an oxidizing medium that will propagate a flame.
- Full report: Dune-doc-19993.

# System Design

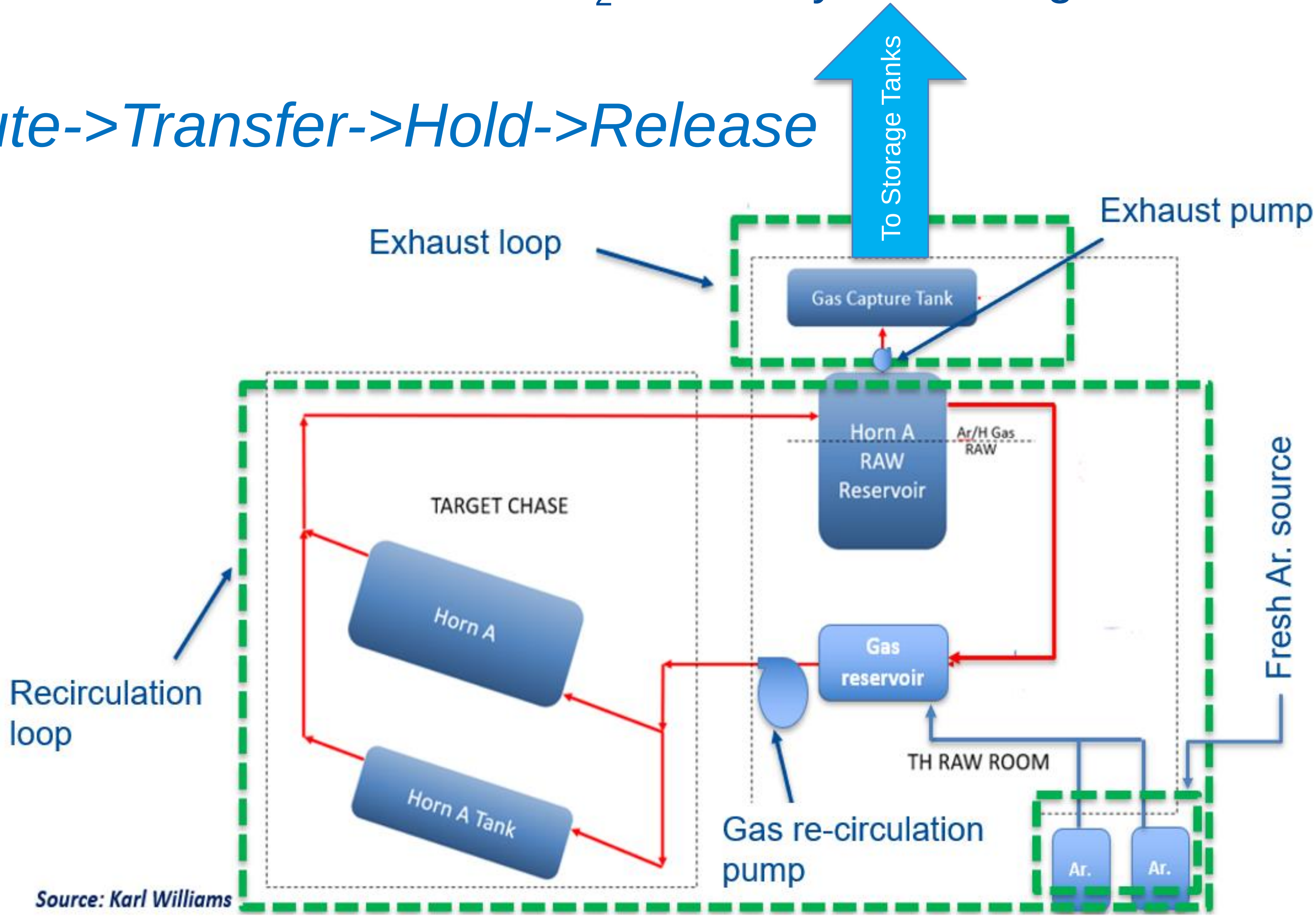
- General idea behind the $H_2$ control system design:



# System Design

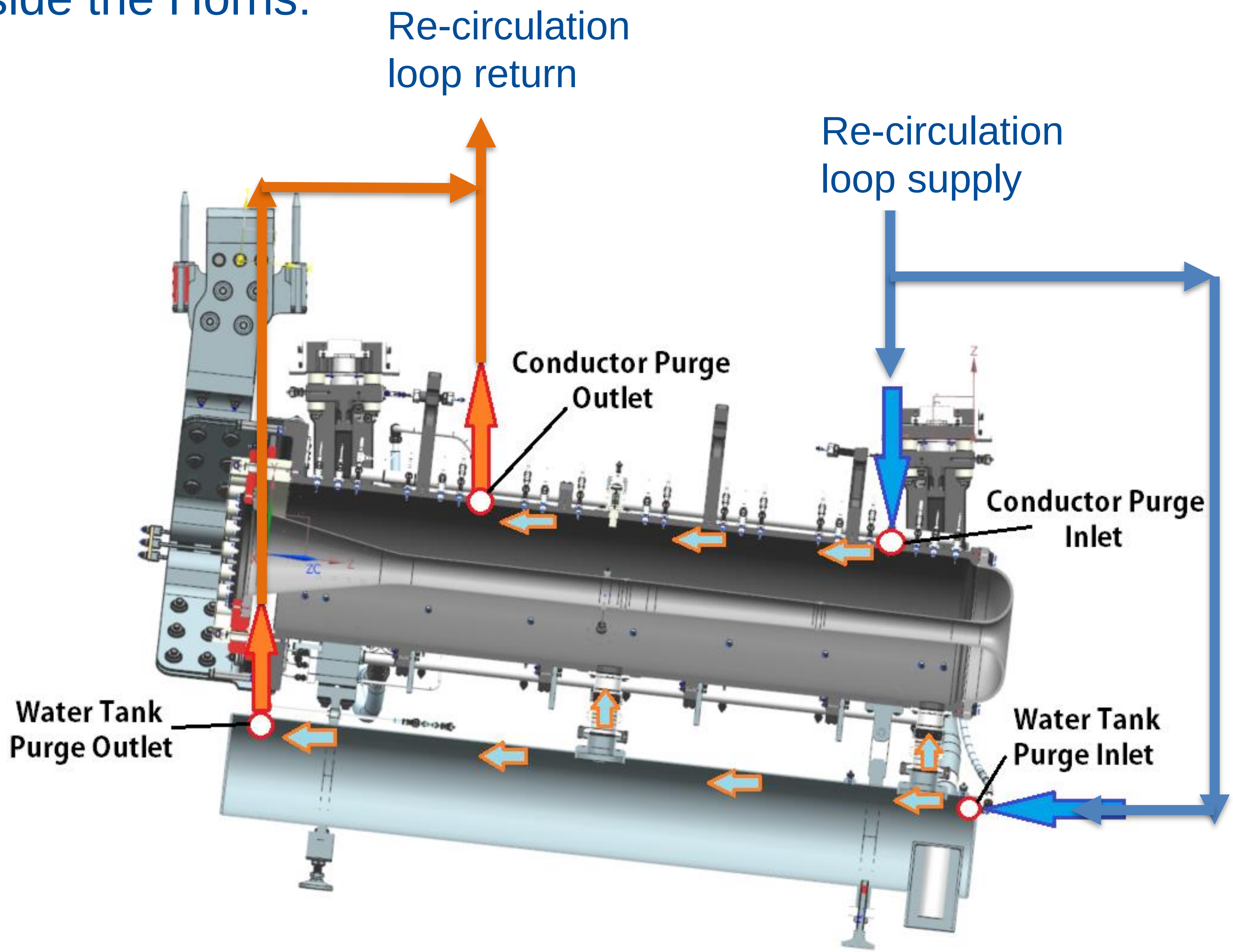
- General idea behind the $H_2$ control system design:

*Dilute->Transfer->Hold->Release*



# System Design

- Inside the Horns:



# System Design: Requirements at 2.4 MW beam power

- Required Argon flow rates to dilute $H_2$ :

*Source: Kamran Vaziri, Dune-doc-19315*

| RAW system | Hydrogen gas production rate at 2.4 MW beam power | | | | | $H_2O$ lost | Argon gas | Horn Argon | | $^{41}Ar$* |
|---|---|---|---|---|---|---|---|---|---|---|
| | (gal/sec) | (gal/hr) | (gal/day) | (gal/wk) | (gal/yr) | (gal/yr) | (sccm ) | (Sccm) | | (Ci/year) |
| Cooling Panels | 3.83E-04 | 1.38 | 33.12 | 231.83 | 6773.98 | 5.44 | 8706 | 0.03 | | 1.06E-05 |
| Horn_A | 4.01E-04 | 1.44 | 34.63 | 242.42 | 7083.50 | 5.69 | 9128 | **9128** | **Exposed** | 7658 |
| Horn_B | 1.79E-04 | 0.64 | 15.45 | 108.17 | 3160.66 | 2.54 | 4155 | **4155** | **to beam** | 1182 |
| Horn_C | 3.92E-05 | 0.14 | 3.38 | 23.68 | 692.03 | 0.56 | 973 | **973** | **spray** | 322 |
| T_blocks | 7.05E-05 | 0.25 | 6.09 | 42.64 | 1245.91 | 1.00 | 1601 | 0.03 | | 1.06E-05 |
| Modules | 2.55E-06 | 0.01 | 0.22 | 1.54 | 45.05 | 0.04 | 58 | 0.03 | | 1.06E-05 |
| Target Helium HX | 5.24E-11 | 1.89E-07 | 4.53E-06 | 3.17E-05 | 9.26E-04 | 7.44E-07 | 0.0012 | 0.03 | | 1.06E-05 |
| **Totals** | **1.08E-03** | **3.87** | **92.9** | **650** | **19001** | 15 | 24621 | **14256** | | 9162 |
| Hadron Absorber | 7.61E-05 | 2.74E-01 | 6.57E+00 | 4.60E+01 | 1.34E+03 | 1.08E+00 | 1728 | 0.03 | | 1.10E-06 |

**Hydrogen gas production rate at 2.4 MW at STP**

| **System** | **$H_2$ prod, Gal/Hr.** | **$H_2$ prod, cc/min.** | **Flush rate, cc/min[1]** | **Mass flow rate, g/sec** |
|---|---|---|---|---|
| ~~**Target Shield Pile RAW**~~ | ~~**1.38**~~ | ~~**87.06**~~ | ~~**8706**~~ | ~~**0.24**~~ |
| **Horn A RAW** | **1.44** | **90.85** | **9085** | **0.25** |
| **Horn B RAW** | **0.64** | **40.38** | **4038** | **0.11** |
| **Horn C RAW** | **0.14** | **8.83** | **883** | **0.02** |
| **Total flush rate from RAW systems-->[2]** | | | **14006** | **0.38** |

**Notes:**

**1). Flush rate to keep $H_2$ below 1%. With this, we have a SF of ~3.**

**2). Total flush rate if no re-combination is used.**

# System Design: Requirements at 2.4 MW beam power

- Horn external pressure requirement (Target Hall Bunker)=16.16 Psia.
- Horn internal pressure shall be between 16.16 Psia and 18.16 Psia.
- These requirements are in: https://fermipoint.fnal.gov/project/LBNF/Near%20Site/Beamline/Shared%20Documents/Forms/AllItems.aspx
- The flush rates in the previous slide are also present in the above parameters sheet.

**LBNF Beamline Design Parameters Spreadsheet**

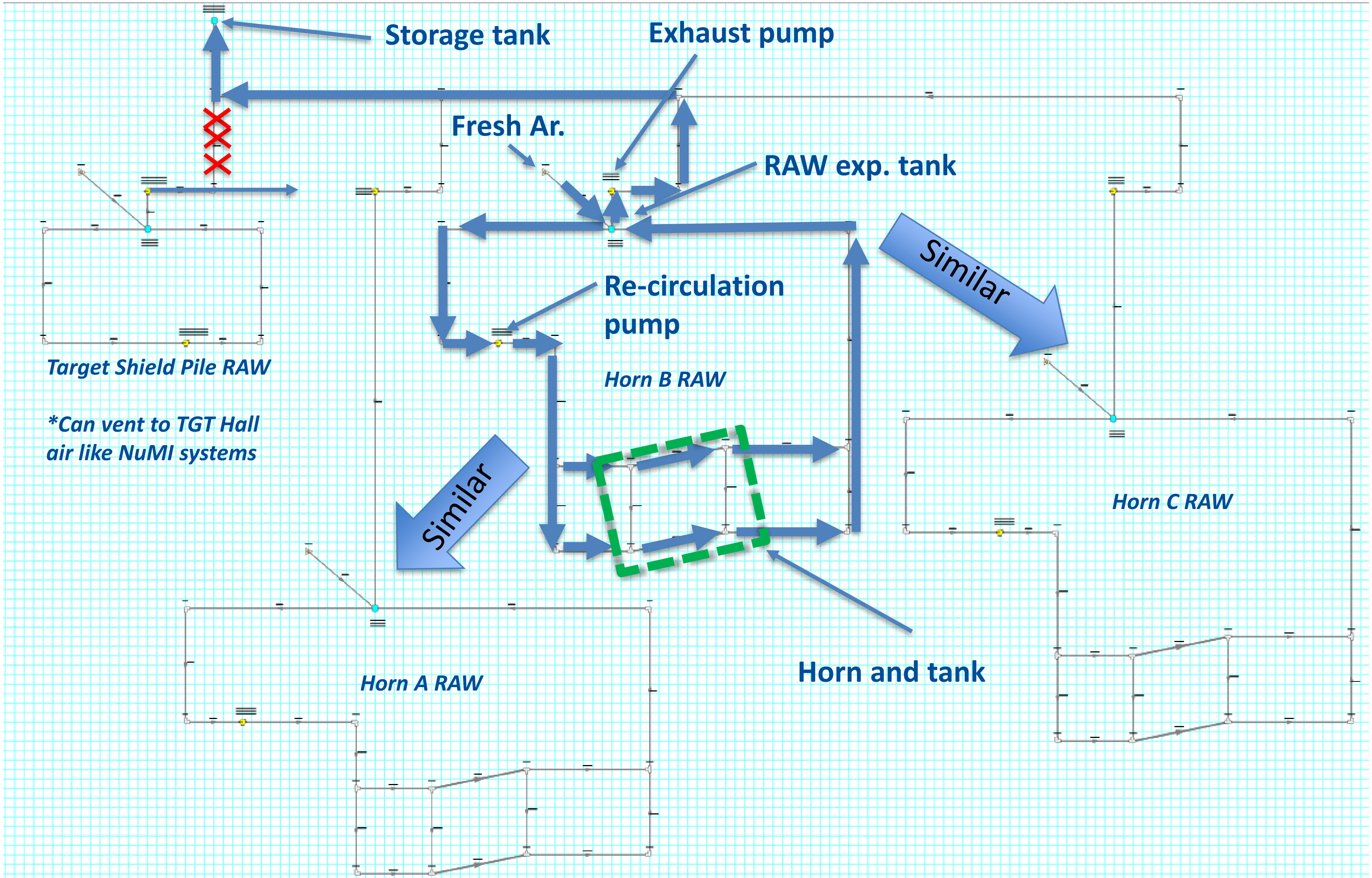
*Horns [Cory Crowley-FNAL]*

*This spreadsheet summarizes the design parameters for the LBNF Neutrino Beam Horns*

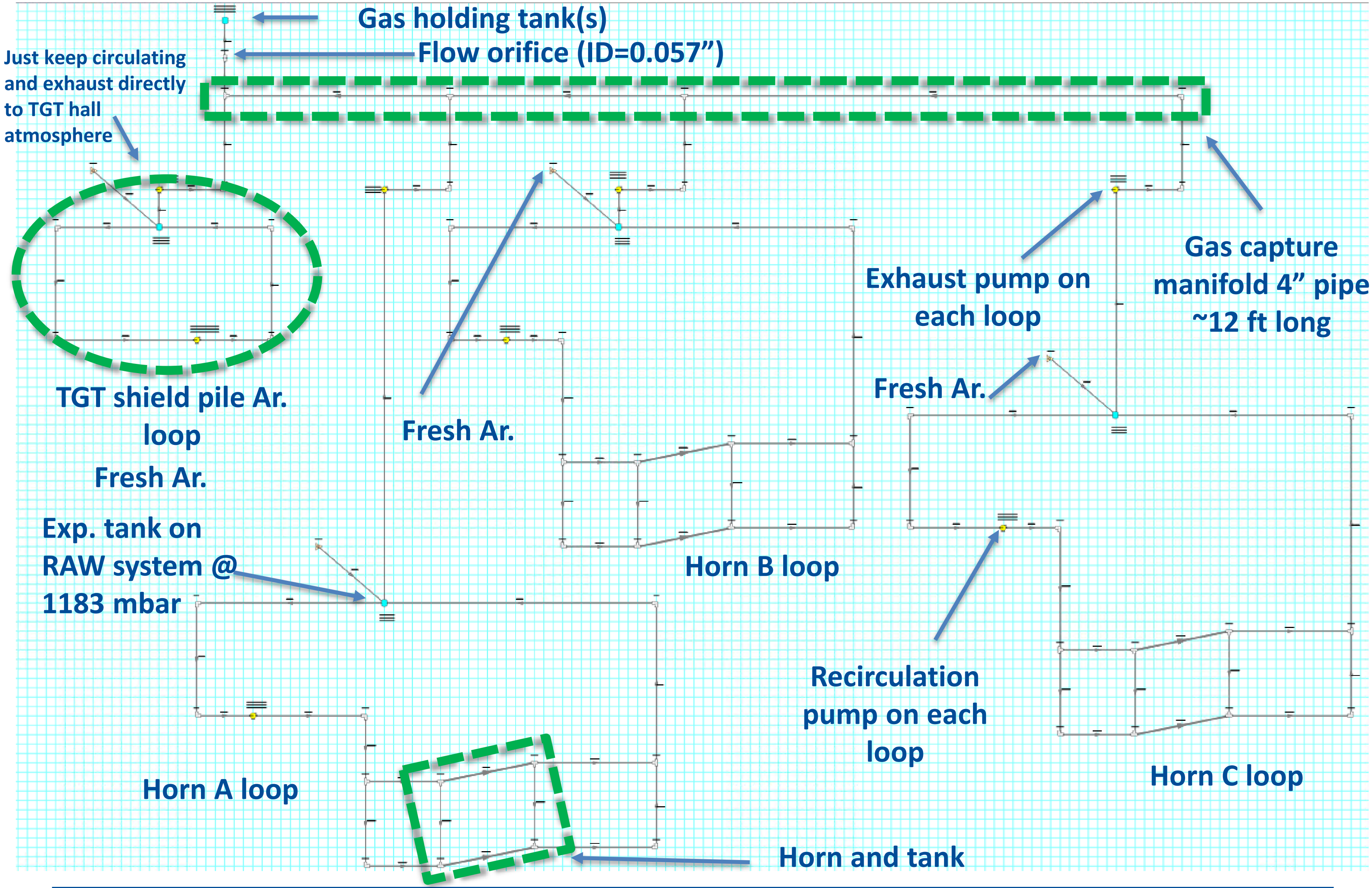
| # | Parameter/Specification | Horn A | Horn A Module | Horn B | Horn B Module | Horn C | Horn C Module | Units |
|---|---|---|---|---|---|---|---|---|
| 7 | Maximum Beam Power (MW) | 1.2 | 2.4 | 1.2 | 2.4 | 1.2 | 2.4 | |
| 37 | Instrumentation Line Weight | /A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | lbs |
| 38 | Half Component Weight | 1750 | Line Weight Transferred to Device | 5000 | Line Weight Transferred to Device | 3750 | Line Weight Transferred to Device | lbs |
| 39 | U.S. Utility Line Weight | 1,040 | Line Weight Transferred to Device | 1040 | Line Weight Transferred to Device | 1040 | Line Weight Transferred to Device | lbs |
| 40 | U.S. Instrumentation Line Weight | 0 | Line Weight Transferred to Device | 0 | Line Weight Transferred to Device | 0 | Line Weight Transferred to Device | lbs |
| 41 | D.S. Utility Line Weight | 300 | Line Weight Transferred to Device | 500 | Line Weight Transferred to Device | 500 | Line Weight Transferred to Device | lbs |
| 42 | D.S. Instrumentation Line Weight | 570 | Line Weight Transferred to Device | 570 | Line Weight Transferred to Device | 570 | Line Weight Transferred to Device | lbs |
| 43 | Module Vertical Drive System Weight | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | lbs |
| 44 | Stripline Offset Force Required | 2,012 | | 2107 | | 2162 | | lbs-force |
| 45 | Module Wall Span | 71 | | 132.5 | | 83 | | inch |
| 46 | Stripline Offset | 13 | | 30.875 | | 22 | | inch |
| 47 | U.S. Supply Line Weight @ 10' Average Length | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | lbs |
| 48 | D.S. Supply Line Weight @ 10' Average Length | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | lbs |
| 49 | D.S. Ejector System Weight @ 10' Average Length (Single Ejector) | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | N/A | Line Weight Transferred to Device | lbs |
| 50 | Total U.S. Vertical Drive System Force Required | | | 7127 | | 8539 | | lbs-force |
| 51 | Total D.S. Vertical Drive System Force Required | | | 9558 | | 6201 | | lbs-force |
| 52 | Cooling | | | | | | | |
| 53 | Helium Supply Temperature (Nominal, Range) (Celcius) | N/A | N/A | N/A | N/A | N/A | N/A | C |
| 54 | Helium Return Temperature (Nominal, Range) (Celcius) | N/A | N/A | N/A | N/A | N/A | N/A | C |
| 55 | Nitrogen Supply Temperature (Nominal, Range) | 75F, +5F / -30F | | | | | | F |
| 56 | RAW Supply Temperature (Nominal, Range) | 70F, +5F / -10F | | | | | | F |
| 57 | SLB Nitrogen Flow | | | | | | | |
| 58 | Flow Rate, CFM @ 2.4MW | 3,000 | | 3,000 | | 3,000 | | CFM |
| 59 | Supply Pressure (PSI) | 1.1 | | | | | | Atm |
| 60 | Maximum Required Flow Rates | | | | | | | |
| 61 | Inner Conductor Line - BRU (1.5" OD Tube W/Swage Connection @ Horn) | 8 | N/A | 25 | N/A | 15 | N/A | GPM |
| 62 | Inner Conductor Line - BRL (1.5" OD Tube W/Swage Connection @ Horn) | 8 | N/A | 25 | N/A | 15 | N/A | GPM |
| 63 | Inner Conductor Line - BLL (1.5" OD Tube W/Swage Connection @ Horn) | 8 | N/A | 25 | N/A | 15 | N/A | GPM |

Radiation Safety | Magnet Production | Magnet Power Supplies | Primary Water Systems | Beam Instrumentation | Primary Vacuum | Magnet Installation | Beam Windows | Targetry | Horns

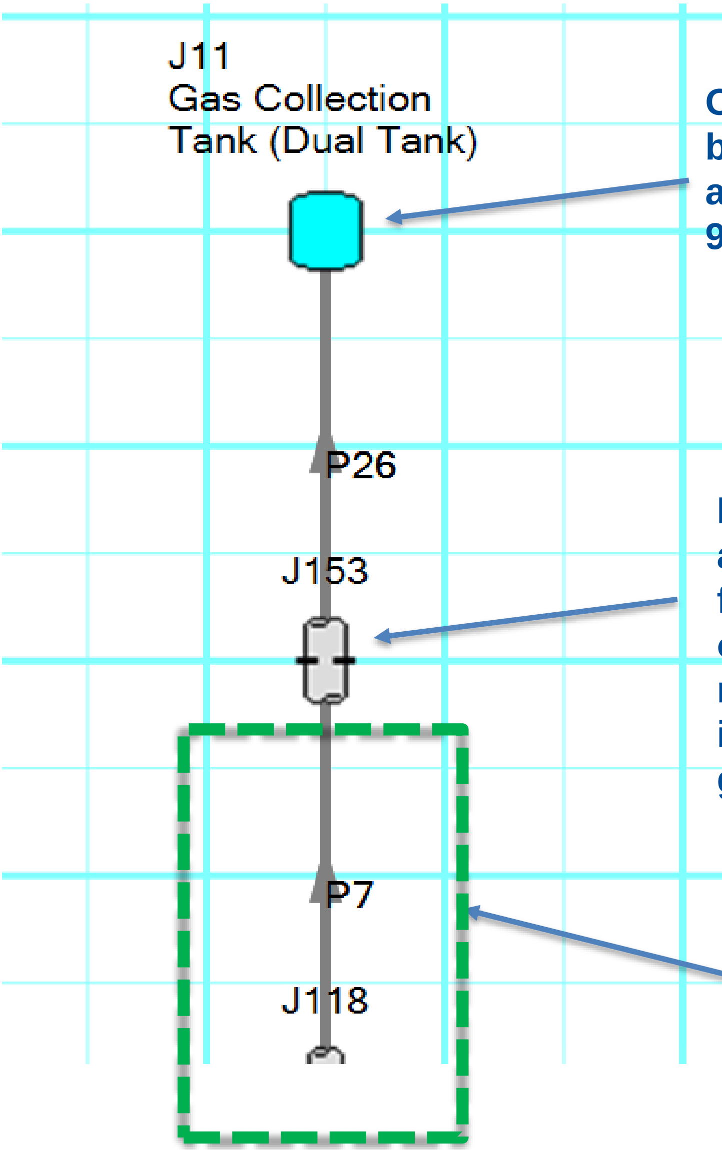
# System design: AFT Arrow Compressible Fluid flow



# System design: AFT Arrow Compressible Fluid flow model



# System design




Operate this tank between 70 mbar and 780 mbar @ 90 F

Between 70 mbar and 780 mbar, the flow through the orifice is "choked," meaning mass flow is constant ~0.38 g/s

When tank reaches 780 mbar, the highest pressure in piping upstream is ~17.89 Psia

@ 780 mbar

| Jct | Results Diagram | Name | Mass Flow (gram/sec) | Overall Power (hp) | P Static Disc. (psia) | P Static Suction (psia) |
|---|---|---|---|---|---|---|
| 49 | Show | TGT Shield Panel Recirc. Pump | 0.24000 | 3.528E-05 | 15.71 | 15.69 |
| 72 | Show | Horn A Exh. Pump | 0.24000 | 8.602E-04 | 17.89 | 17.15 |
| 82 | Show | Horn B Exh. Pump | 0.11000 | 3.941E-04 | 17.88 | 17.16 |
| 92 | Show | Horn C Exh. Pump | 0.02000 | 7.108E-05 | 17.88 | 17.16 |
| 99 | Show | Horn A Recirc. Pump | 0.24000 | 6.439E-05 | 17.19 | 17.14 |
| 106 | Show | Horn B Recirc. Pump | 0.24000 | 8.090E-05 | 17.20 | 17.14 |
| 112 | Show | Horn C Recirc. Pump | 0.24000 | 8.087E-05 | 17.20 | 17.14 |

@ 70 mbar

| Jct | Results Diagram | Name | Mass Flow (gram/sec) | Overall Power (hp) | P Static Disc. (psia) | P Static Suction (psia) |
|---|---|---|---|---|---|---|
| 49 | Show | TGT Shield Panel Recirc. Pump | 0.24000 | 3.528E-05 | 15.71 | 15.69 |
| 72 | Show | Horn A Exh. Pump | 0.24000 | 8.602E-04 | 17.89 | 17.15 |
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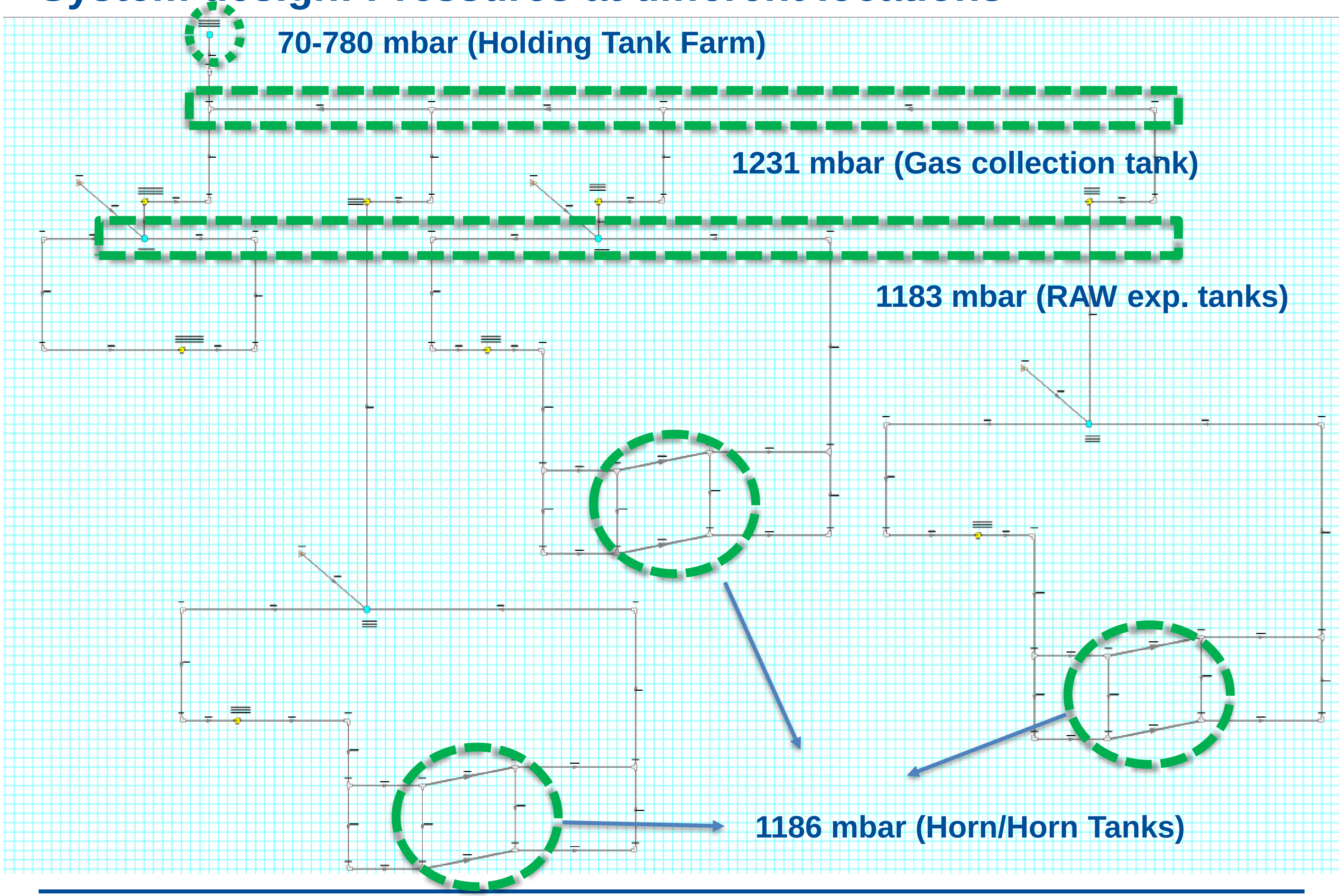
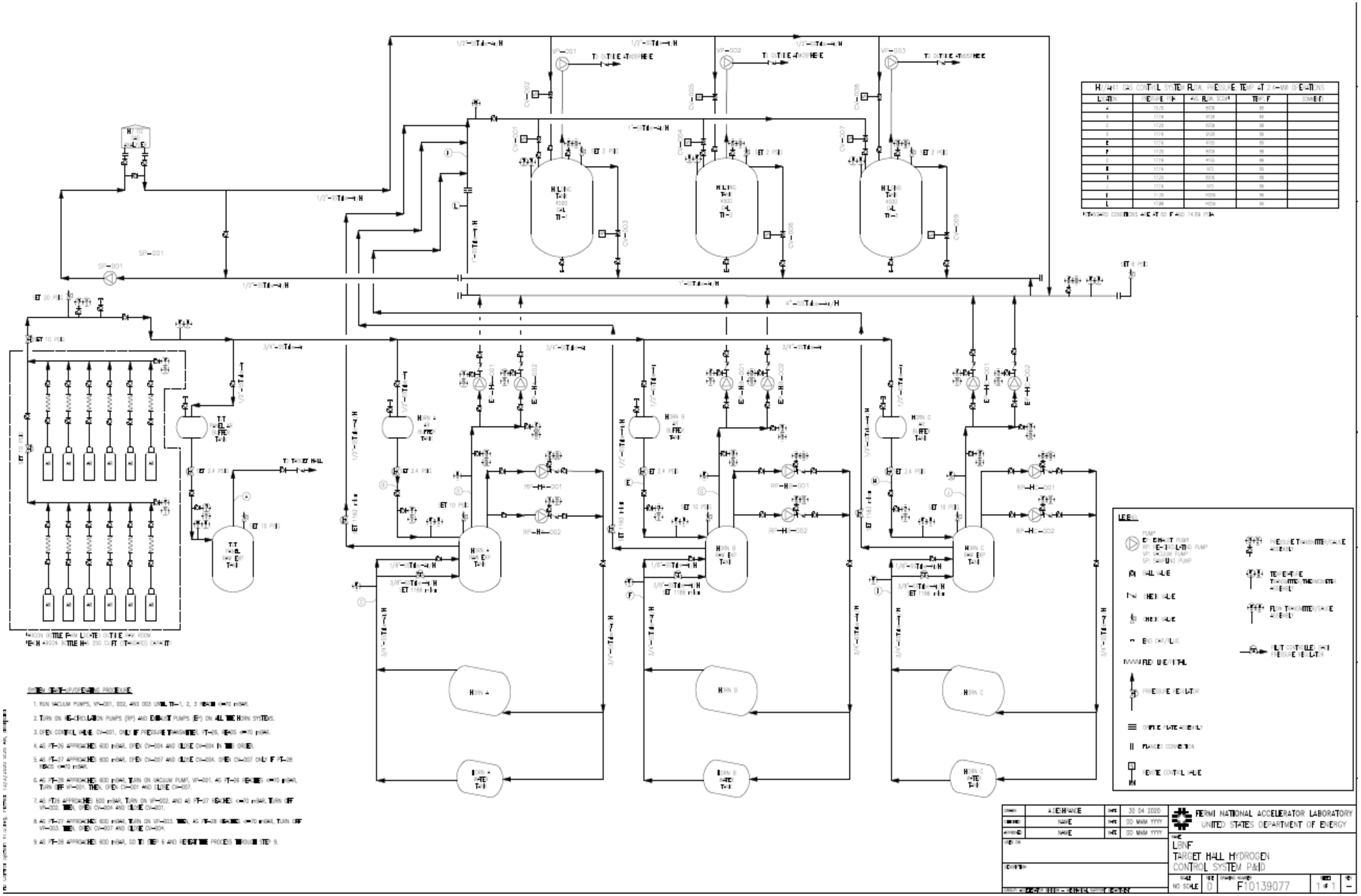
| 112 | Show | Horn C Recirc. Pump | 0.24000 | 8.087E-05 | 17.20 | 17.14 |

Max pressure in both conditions is 1185 mbar ~ 17.89 Psia

# System design: Pressures at different locations

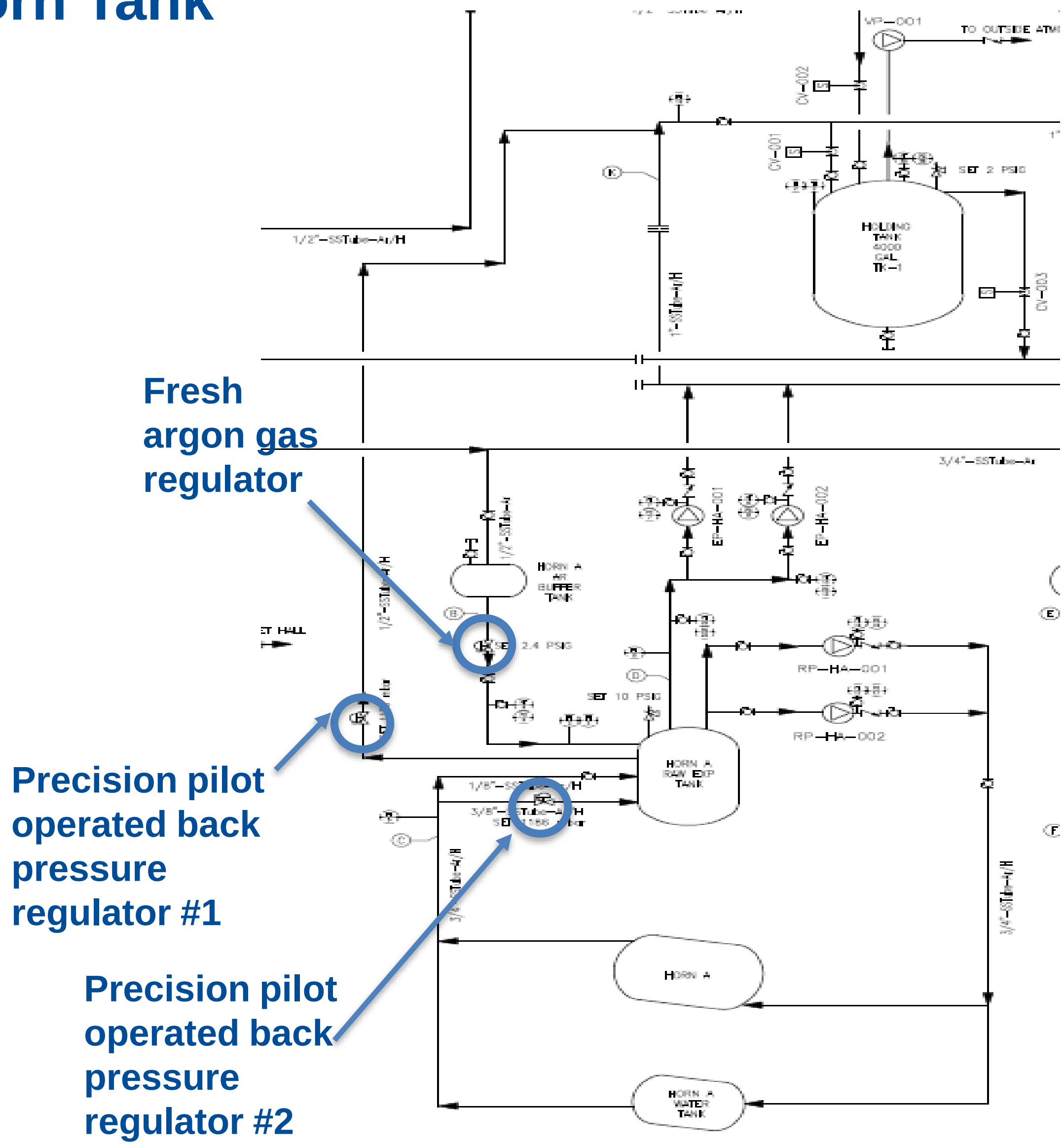


# System design: Preliminary P&ID



# System design: Pressure compensation between RAW expansion tank and Horn Tank

- Three regulators sized to maintain pressures in the Horn and the RAW expansion tank.
- A very low-pressure regulator for argon supply.
- Two pilot operated back-pressure regulators for Ar/ $H_2$ mixture loop



# System design: Pressure compensation between RAW expansion tank and Horn Tank

| Sizing of back pressure regulator between Horn Tank and Horn RAW Expansion Tank | | | |
|---|---|---|---|
| **Parameter** | **Value** | **Units** | **Comments** |
| Percentage of Argon | 99 | % | |
| Percentage of Hydrogen | 1 | % | |
| Specific gravity, Argon | 1.38 | | |
| Specific gravity, Hydrogen | 0.069 | | |
| Specific gravity of mixture | 1.36689 | | |
| Specific heat of Argon, Cp | 0.52 | kJ kg^-1 K^-1 | |
| Specific heat of Hydrogen, Cp | 14.32 | kJ kg^-1 K^-1 | |
| Specific heat of mixture, Cp | 0.658 | kJ kg^-1 K^-1 | |
| Specific heat of Argon, Cv | 0.312 | kJ kg^-1 K^-1 | |
| Specific heat of Hydrogen, Cv | 10.16 | kJ kg^-1 K^-1 | |
| Specific heat of mixture, Cv | 0.41048 | kJ kg^-1 K^-1 | |
| Ratio of specific heats of mixture | 1.60 | | |
| Gas upstream temperature | 545 | R | |
| Upstream pressure, P1 | 17.2 | Psia | Horn Tank pressure. |
| Downstream pressure, P2 | 17.15 | Psia | RAW expansion tank pressure. |
| Differential pressure, ΔP | 0.05 | Psia | |
| Pressure drop ratio, x | 0.003 | | |
| Ratio of specific heats factor, Fk | 1.145 | | |
| Pressure drop ratio required to produce critical flow, xt | 0.496 | | |
| Expansion factor, Y | 1.00 | | |
| Compressibility factor, Z | 0.99 | | |
| Units conversion factor, N7 | 1360 | | |
| Pipe geometry factor, Fp | 1 | | |
| Required volumetric flow | 9000 | Sccm | |
| Valve flow coefficient, Cv | 0.411 | | |

| Sizing of back pressure regulator between Horn RAW expansion tank and vacuum loop | | | |
|---|---|---|---|
| **Parameter** | **Value** | **Units** | **Comments** |
| Percentage of Argon | 99 | % | |
| Percentage of Hydrogen | 1 | % | |
| Specific gravity, Argon | 1.38 | | |
| Specific gravity, Hydrogen | 0.069 | | |
| Specific gravity of mixture | 1.36689 | | |
| Specific heat of Argon, Cp | 0.52 | kJ kg^-1 K^-1 | |
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| Specific heat of Hydrogen, Cv | 10.16 | kJ kg^-1 K^-1 | |
| Specific heat of mixture, Cv | 0.41048 | kJ kg^-1 K^-1 | |
| Ratio of specific heats of mixture | 1.60 | | |
| Gas upstream temperature | 545 | R | |
| Upstream pressure, P1 | 17.2 | Psia | Horn Tank pressure. |
| Downstream pressure, P2 | 1 | Psia | Vacuum loop pressure. |
| Differential pressure, ΔP | 16.2 | Psia | |
| Pressure drop ratio, x | 0.942 | | |
| Ratio of specific heats factor, Fk | 1.145 | | |
| Pressure drop ratio required to produce critical flow, xt | 0.496 | | |
| Expansion factor, Y | 0.45 | | |
| Compressibility factor, Z | 0.99 | | |
| Units conversion factor, N7 | 1360 | | |
| Pipe geometry factor, Fp | 1 | | |
| Required volumetric flow | 9000 | Sccm | |
| Valve flow coefficient, Cv | 0.051 | | |

| Sizing of low pressure regulator between Argon source and Horn RAW expansion tank | | | |
|---|---|---|---|
| **Parameter** | **Value** | **Units** | **Comments** |
| Percentage of Argon | 100 | % | |
| Percentage of Hydrogen | 0 | % | |
| Specific gravity, Argon | 1.38 | | |
| Specific gravity, Hydrogen | 0.069 | | |
| Specific gravity of mixture | 1.38 | | |
| Specific heat of Argon, Cp | 0.52 | kJ kg^-1 K^-1 | |
| Specific heat of Hydrogen, Cp | 14.32 | kJ kg^-1 K^-1 | |
| Specific heat of mixture, Cp | 0.52 | kJ kg^-1 K^-1 | |
| Specific heat of Argon, Cv | 0.312 | kJ kg^-1 K^-1 | |
| Specific heat of Hydrogen, Cv | 10.16 | kJ kg^-1 K^-1 | |
| Specific heat of mixture, Cv | 0.312 | kJ kg^-1 K^-1 | |
| Ratio of specific heats of mixture | 1.67 | | |
| Gas upstream temperature | 545 | R | |
| Upstream pressure, P1 | 20 | Psia | Argon gas bottle farm regulator downstream pressure. |
| Downstream pressure, P2 | 17.15 | Psia | RAW expansion tank pressure. |
| Differential pressure, ΔP | 2.85 | Psia | |
| Pressure drop ratio, x | 0.143 | | |
| Ratio of specific heats factor, Fk | 1.190 | | |
| Pressure drop ratio required to produce critical flow, xt | 0.487 | | |
| Expansion factor, Y | 0.92 | | |
| Compressibility factor, Z | 0.99 | | |
| Units conversion factor, N7 | 1360 | | |
| Pipe geometry factor, Fp | 1 | | |
| Required volumetric flow | 9000 | Sccm | |
| Valve flow coefficient, Cv | 0.055 | | |

$$C_v = \frac{q}{N_7 F_p P_1 Y \sqrt{\frac{x}{G_g T_1 Z}}}$$

$$Y = 1 - \frac{x}{3F_k x_T}$$

where,

$F_k = k/1.4$, the ratio of specific heats factor

$k$ = Ratio of specific heats

$x = \Delta P/P_1$, the pressure drop ratio

$x_T$ = The pressure drop ratio factor for valves installed without attached fittings. More definitively, $x_T$ is the pressure drop ratio required to produce critical, or maximum, flow through the valve when $F_k = 1.0$

# System design: Pressure compensation between RAW expansion tank and Horn Tank

## Back pressure regulator (pilot control)

EQUILIBAR
PRECISION PRESSURE CONTROL


| BASE PART # | MAX. PRESSURE RATING[1] | FLOW COEFF. (CV) | | INLET / OUTLET PORT SIZE | REFERENCE PORT SIZE | PORT THREADS | | DIM A | DIM B |
|---|---|---|---|---|---|---|---|---|---|
| | PSIG (BAR) | MIN | MAX | | | STANDARD | OPTIONAL | INCH (MM) | |
| Stainless Steel 316/316L, Hastelloy C276, Titanium, Monel and Zirconium Models | | | | | | | | | |
| GSD2/GS2 | 750 (51) | | | | | | | 3.00 (76) | 1.34 (34) |
| GSDM2 | 1000 (68) | | 1.20 | 1/4" | | | | 3.25 (83) | 1.34 (34) |
| GSDH2 | 2500 (172) | | | | | | B, C, O, R, S, T | 3.30 (84) | 1.60 (41) |
| GSD3/GS3 | 400 (28) | | | | | | | 3.50 (89) | 1.40 (36) |
| GSDM3 | 800 (55) | 1E-03 | 1.80 | 3/8" | | | | 3.75 (95) | 1.54 (39) |
| GSDH3 | 1400 (97) | | | | | | | 3.85 (98) | 1.78 (45) |
| GSD4/GS4 | 350 (24) | | | | | | | 4.50 (114) | 1.73 (44) |
| GSDM4 | 750 (52) | | 3.20 | 1/2" | 1/8" | N (NPT) | | 5.00 (127) | 1.85 (47) |
| GSDH4 | 1400 (97) | | | | | | | 5.00 (127) | 1.98 (50) |
| GSD6/GS6 | 300 (21) | | | | | | | 6.00 (152) | 2.01 (51) |
| GSDM6 | 800 (55) | | 5.50 | 3/4" | | | B, C, F, G, O, R, S, T | 6.25 (159) | 2.44 (62) |
| GSDH6 | 1600 (110) | 1E-02 | | | | | | 6.40 (163) | 2.90 (74) |
| GSD8/GS8 | 150 (10) | | | | | | | 7.00 (178) | 2.50 (64) |
| GSDM8 | 500 (34) | | 8.50 | 1" | | | | 7.25 (184) | 2.76 (70) |
| GSDH8 | 2100 (145) | | | | | | | 7.80 (198) | 3.33 (85) |

## Argon supply low-pressure regulator



# Model 3700 Series

## Low Pressure Line Regulator

**Design Features/Components**
- Zinc body
- Rubber diaphragm
- 2-1/2" delivery pressure gauge - 3701
- 3-1/2" delivery pressure gauge - 3702/3703
- Porous metal filter protects seat from contamination
- 1/4" NPTM inlet/outlet connection with loose hose barb
- Pressure adjusting screw protected by "security cap"

**Materials of Construction**

| | |
|---|---|
| Gauges: | Chrome plated brass |
| Body: | Cast zinc |
| Bonnet: | Die cast zinc |
| Diaphragm: | Natural rubber |
| Seat: | Natural rubber |
| Seals: | Natural rubber |

**Description**

A general purpose line regulator designed for low inlet pressure and low delivery pressure applications with non-corrosive gases.

**Applications**
- Control of constant fuel burner flame.
- Inert gas blanketing at low pressures.

**Specifications**

| | |
|---|---|
| Maximum Inlet Pressure: | 250 psig (1,725 kPa) |
| Maximum Flow Rate: (At 200 psig, $N_2$) | Model 3701A: Less than 35 SLPM<br>Model 3702: 260 SCFH (123 SLPM)<br>Model 3703: 350 SCFH (165 SLPM) |
| Flow Capacity (Cv): | 0.8 ✓ |
| Operating Temperature: | -40°F to 150°F (-40°C to 65°C) |
| Porting (Regulator Body): | 1/4" NPT Female |
| Porting Configuration: | 1 High, 1 Low |
| Shipping Weight: | 7 lbs |

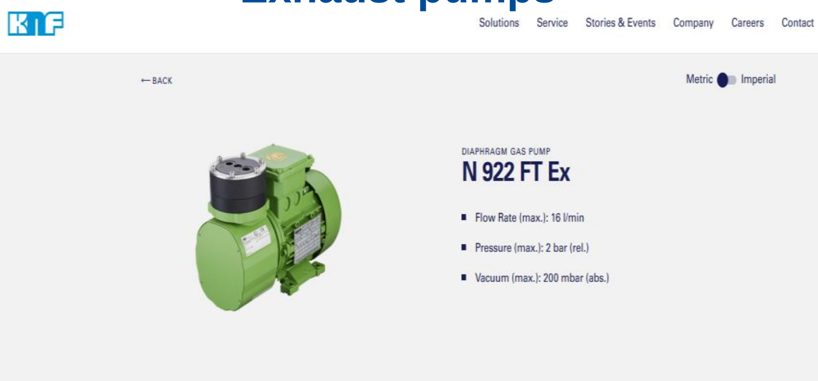
**Ordering Information**

| Part Number** | Delivery Pressure Range | Delivery Pressure Gauge |
|---|---|---|
| SEQ3701A | 2-25" water column | 0-35" water column |
| SEQ3702 ✓ | 0.5-5.0 psig | 0-10 psig* |
| SEQ3703 | 5-10 psig | 0-10 psig* |

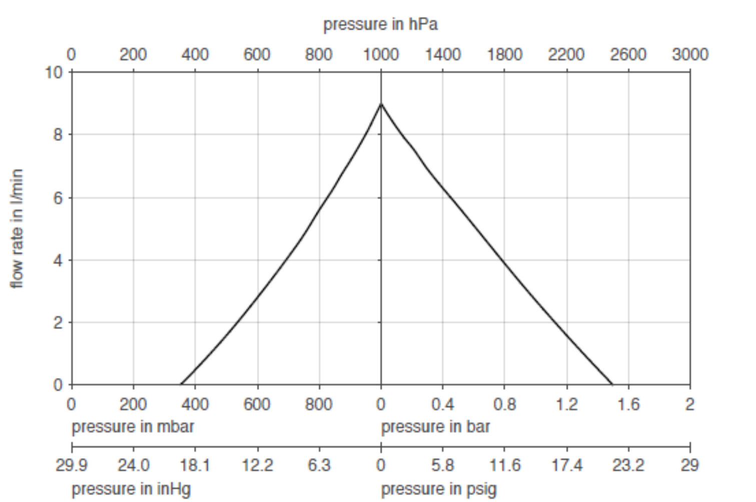
Regulators

# System design: Pumps

## All recirculation loop and Horn A Exhaust pumps



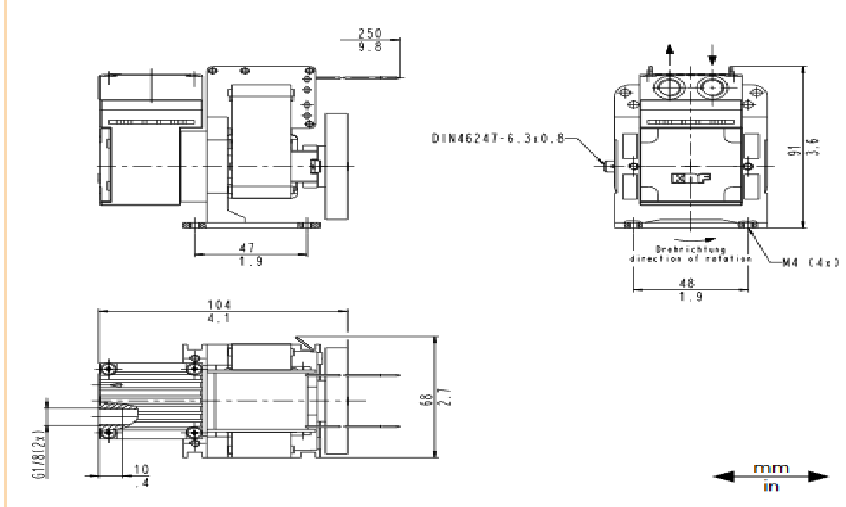

### N 922 FTE 8L



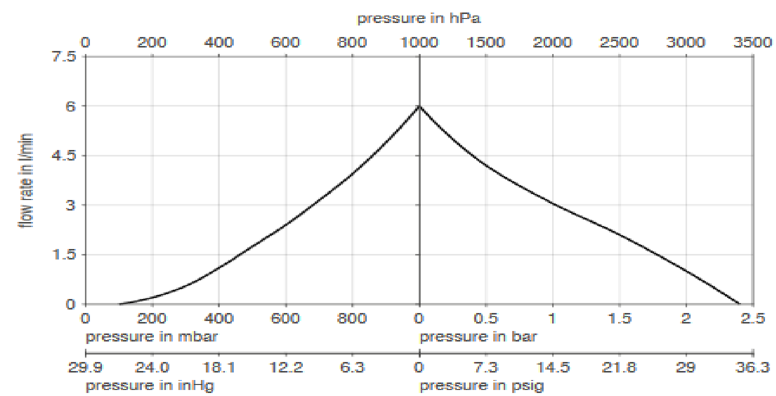

Flow rate determined at 20°C, 1013 mbar abs.
(Pressure 0 to 1013 mbar abs. in accordance with ISO 21360-1/2)

## Horn B exhaust loop pumps

### N 86 K_E



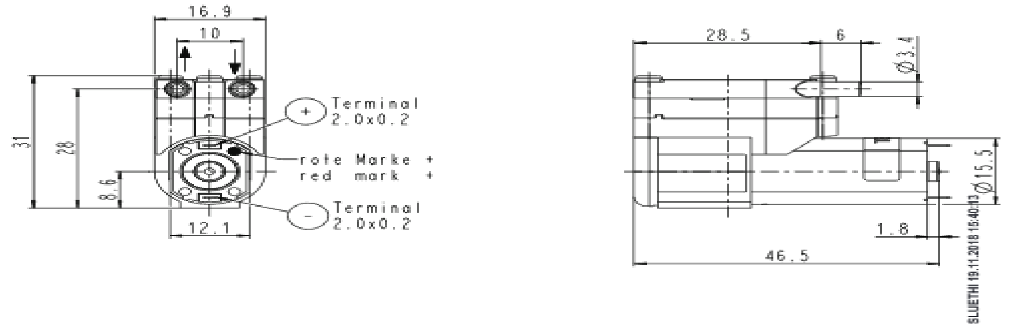

### N 86 KNE



# System design: Pumps

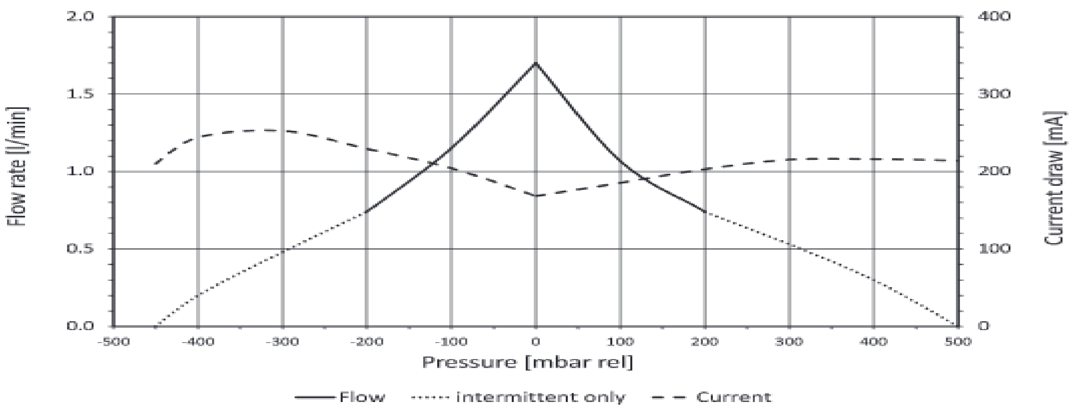
## Horn C exhaust loop pumps

**NMS020KPDC-S**



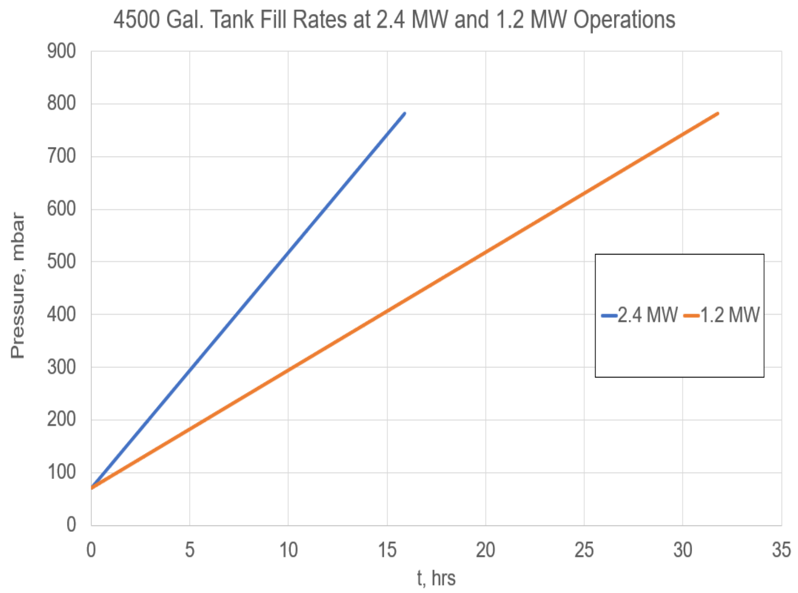

Dimensions in mm

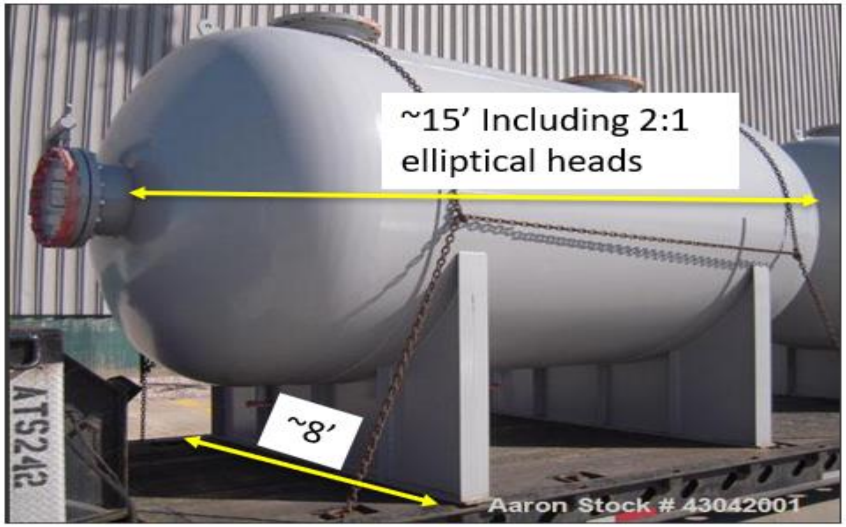
**NMS020KPDC-S 6V FLOW CURVE**



# System design: Tank fill rate

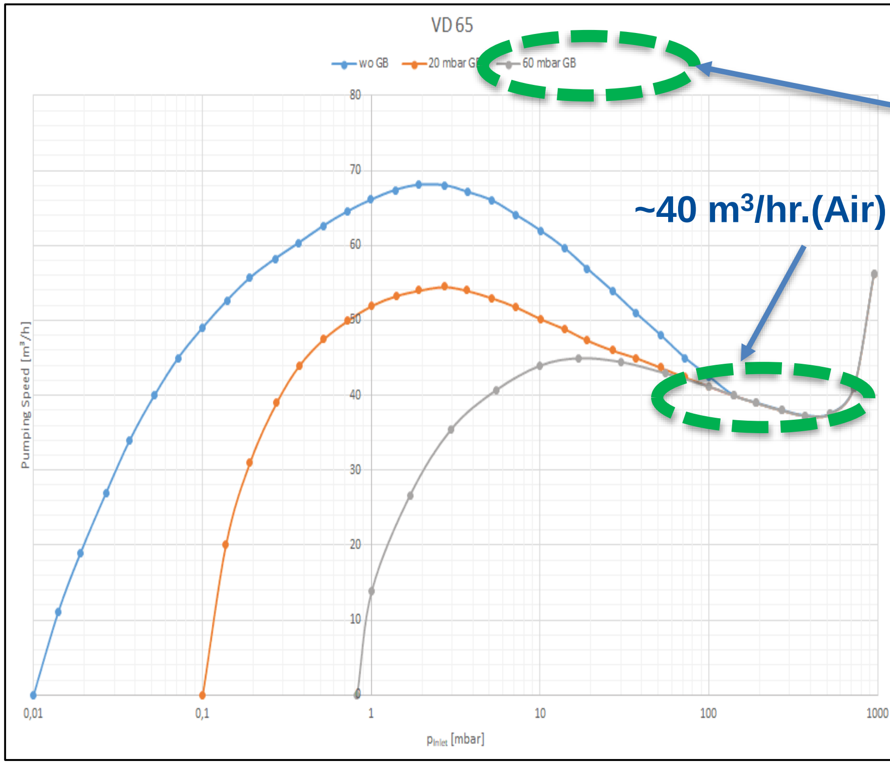
- A 4500 Gal. tank takes approximately 16 hours to operate between 70 mbar and 780 mbar pressure (2.4 MW line).
- The tank is an ASME code tank capable of operating at full vacuum, 0 Psia.
- The tank is approximately 8500 lb. when its empty.



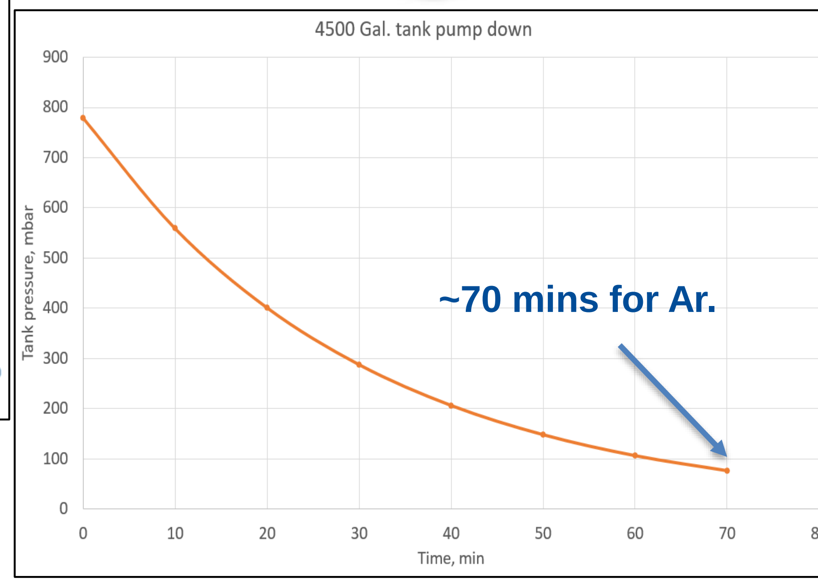



# System design: Purge time from 780 mbar to 70 mbar

- A 4500 Gal. tank will operate between above pressures for ~16 hours.




Leybold VARODRY VD65

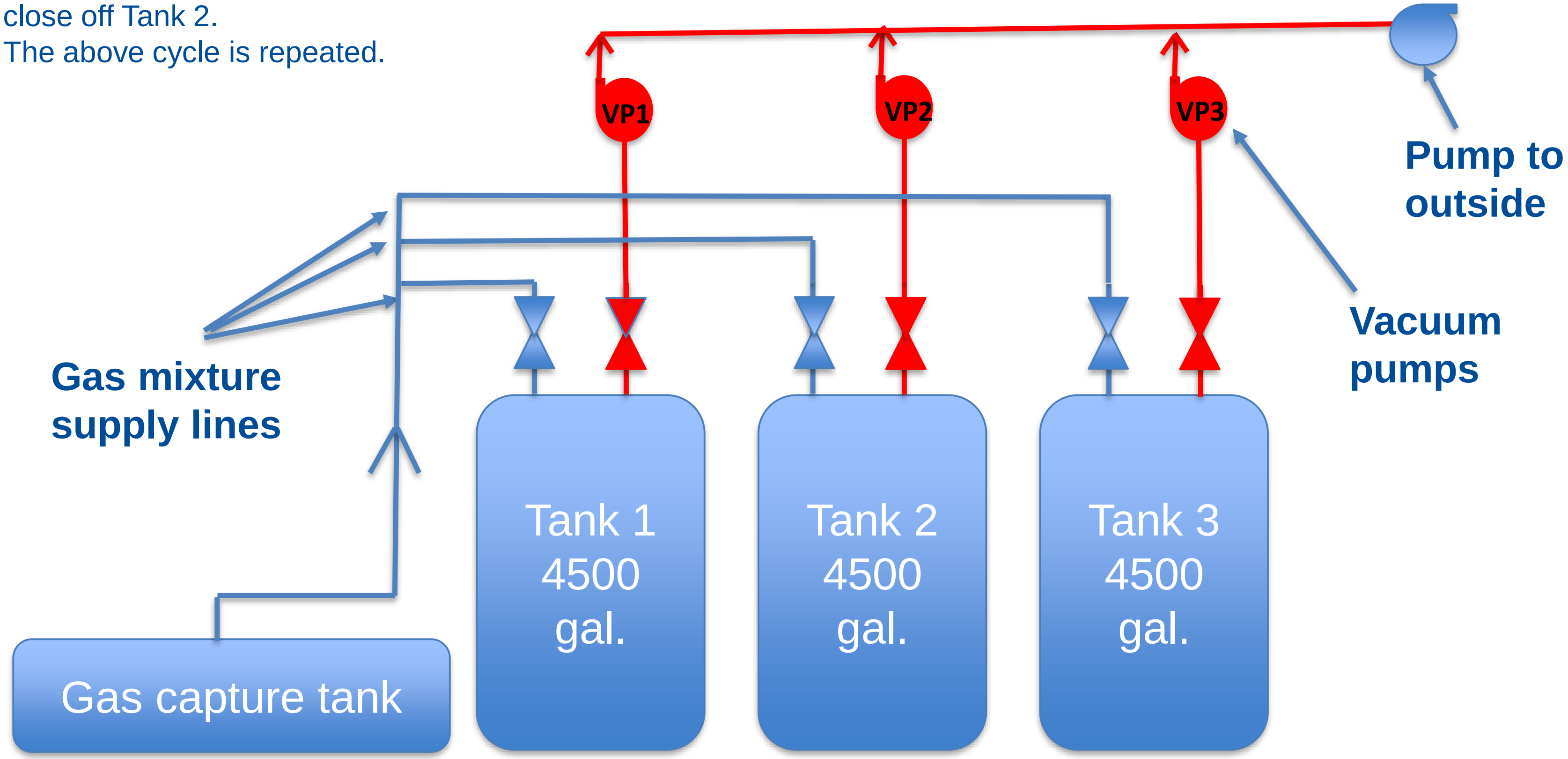



$$S = \frac{V}{t_1} \ln \frac{p_0}{p_1}$$

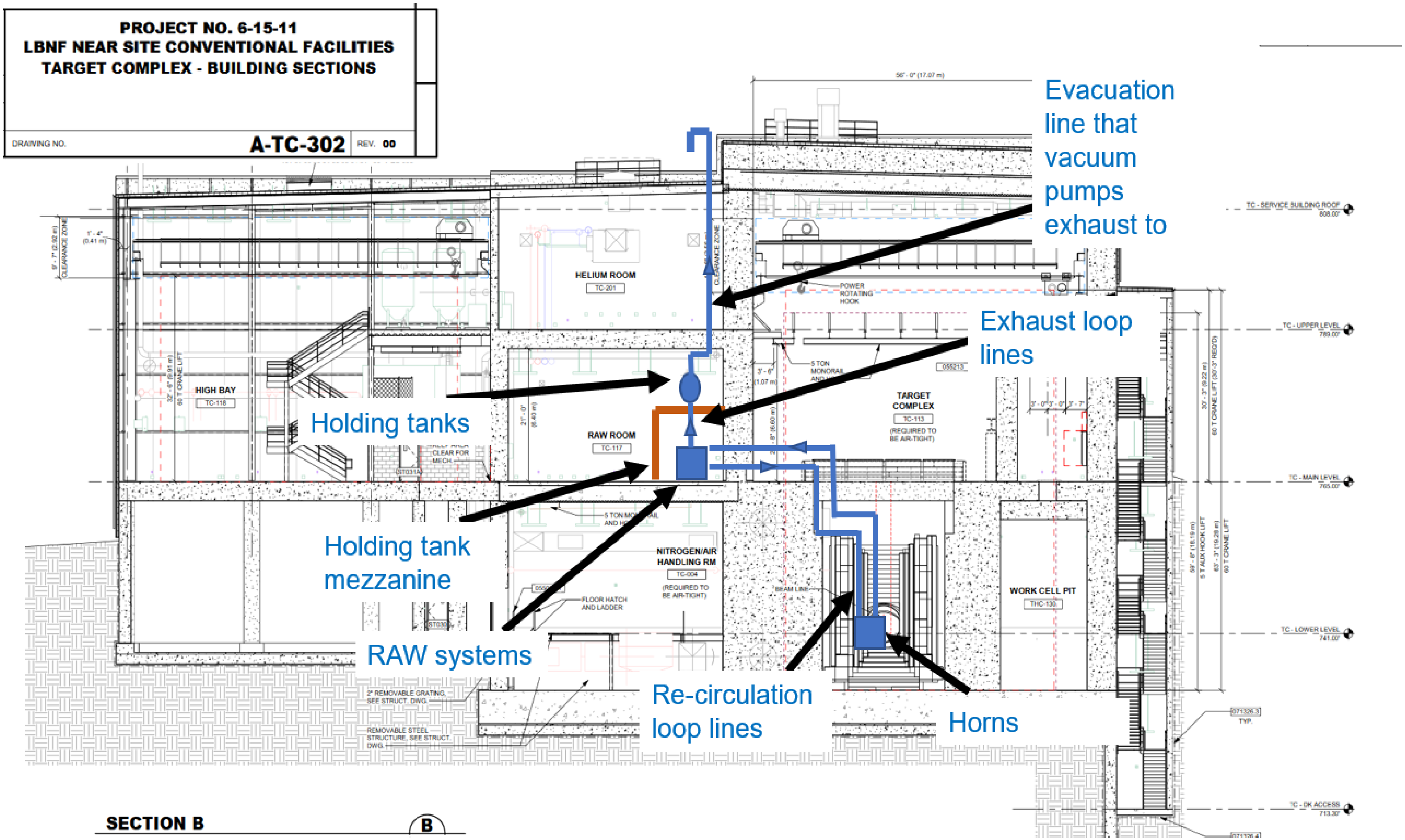
- One 4500 Gal. tank will blow-down from 780 mbar to 70 mbar in ~70 min.

# System design: 3-Tank Operation at 2.4 MW

- The system operation will be designed to be automatic, that is, not like the NuMI feed/bleed system where the process is carried out by trained personnel.
- Step-1→ Fill Tank 1 for 10 hours.
- Step-2→ Start filling Tank 2. Close Tank 1. Fill Tank 2 for 10 hours.
- Step-3→ Start filling Tank 3. Close Tank 2. Fill Tank 3 for 10 hours.
- Step-4→While Tank 3 is filling, evacuate Tank 1. Start filling Tank 1, close Tank 3.
- Step-5→Fill Tank 1 for 10-hours. While Tank 1 is filling, evacuate Tank 2. After Tank 2 is evacuated, start filling Tank 2, close off Tank 1.
- Step-6→ Fill Tank 2 for 10 hours. At the end of 10 hours, start evacuating Tank 3. After this is done, start filling Tank 3 and close off Tank 2.
- The above cycle is repeated.



# System design: General layout




*DUNE-doc-20744, drawings volume 1 and 2*

# System design: Standards

| Component/System | Standards |
|---|---|
| $H_2$/$^{41}$Ar gas piping system | • FESHM 5031.1—Piping Systems<br>• ASME B31.3 Normal Fluid Systems<br>• FESHM 6020.3—Storage and Use of Flammable gases |
| Holding tanks | • FESHM 5033—Vacuum Vessels Chapter<br>• ASME Section VIII BPVC (Code Stamped Vessel) |
| Mezzanine system | • FESHM 5100—Structural Safety<br>• IBC2015 |
| RAW cooling systems | • FESHM 5031.1—Piping Systems<br>• ASME B31.3 Normal Fluid Systems |

# System design: Safety and Parameter Summary

## FESHM 6020 System Risk Class 0

| Parameter | Total volume, m^3 | H2 volume, m^3 | Amount of H2 at 17.2 Psia, moles[2] | Mass of H2 at 17.2 Psia, Kg |
|---|---|---|---|---|
| Horn A gas volume[1] | 0.71 | 0.007 | 0.35 | 6.98E-04 |
| Horn B gas volume[1] | 6 | 0.060 | 2.93 | 5.90E-03 |
| Horn C gas volume[1] | 3.12 | 0.031 | 1.53 | 3.07E-03 |
| Target shield panel expansion tank volume | 0.56 | 0.006 | 0.27 | 5.51E-04 |
| Total volume of TK-1, 2, and 3 | 45.42 | 0.454 | 22.21 | 4.47E-02 |
| Total | | | | 5.26E-02 |
| Safety Factor[3] | | | | 10.94 |

**Notes:**

1. This includes the total gas volume in the Horn A, B, and C. Including the gas volume in the RAW system expansion tank.
2. This is the number of moles of H2, 1% of the total volume, at 17.20 Psia and 90 $^0$F.
3. Safety factor is determined by dividing 0.6 Kg with the available amount of H2 in the system.

## System Parameters

| Parameter | Value | Units | Comments |
|---|---|---|---|
| Recirculation loop pressure | 17.20 | Psia | This is absolute pressure |
| Exhaust loop pressure | 17.85 | Psia | This is absolute pressure |
| Vacuum loop pressure | 11.30 | Psia | This is absolute pressure |
| Horn A, B, and C recirculation mass flow rate | 0.24 | g /s | |
| Horn A exhaust mass flow rate | 0.24 | g /s | |
| Horn B exhaust mass flow rate | 0.11 | g /s | |
| Horn C exhaust mass flow rate | 0.02 | g /s | |
| All loops temperature | 90 | $^0$F | |
| Exhaust loop orifice diameter | 0.057 | In. | |
| H2 concentration | 1 | % v/v | |
| Ar40 concentration | 99 | %v/v | |
| Holding time in TK-1, 2, or 3 | 18 | hr. | Dune-doc-19315 [3] |
| Tank volume | 4500 | Gal. | |
| Fill time in TK-1,2, or 3 | 10 | hr. | |

# Conclusions

- The system is sized to keep the $H_2$ concentration at 1% by volume in the Horn RAW systems. The LFL of $H_2$ in Argon is 3.13%. This gives a factor of safety of ~3. At the same time, the Horns are maintained between 16.16 Psia and 18.18 Psia.

- The tanks provide enough decay time and prevent exposure of $^{41}$Ar to personnel.

Table 4. One complete cycle of fill, cool and purge for the three-tank system

| | |
|---|---|
| Fill #1 | 10 hrs |
| Close #1, change over to #2 | 0.5 hrs |
| Cool #1 | 18.5 hrs |
| Purge #1 | 1 hrs |
| Fill #2 | 10 hrs |
| Close #2, change over to #3 | 0.5 hrs |
| Cool #2 | 18.5 hrs |
| Purge #2 | 1 hrs |
| Fill #3 | 10 hrs |
| Close #3 change over to #1 | 0.5 hrs |
| Cool #3 | 18.5 hrs |
| Purge #3 | 1 hrs |

Table 6. One complete cycle of fill, cool and purge for the two-tank system at 2.4 MW.

| | |
|---|---|
| Fill #1 | 15.5 hrs |
| Close #1, change over to #2 | 0.5 hrs |
| Cool #1 | 14 hrs |
| Purge #1 | 1 hrs |
| Fill #2 | 15.5 hrs |
| Close #2, change over to #1 | 0.5 hrs |
| Cool #2 | 14 hrs |
| Purge #2 | 1 hrs |

# Conslusions

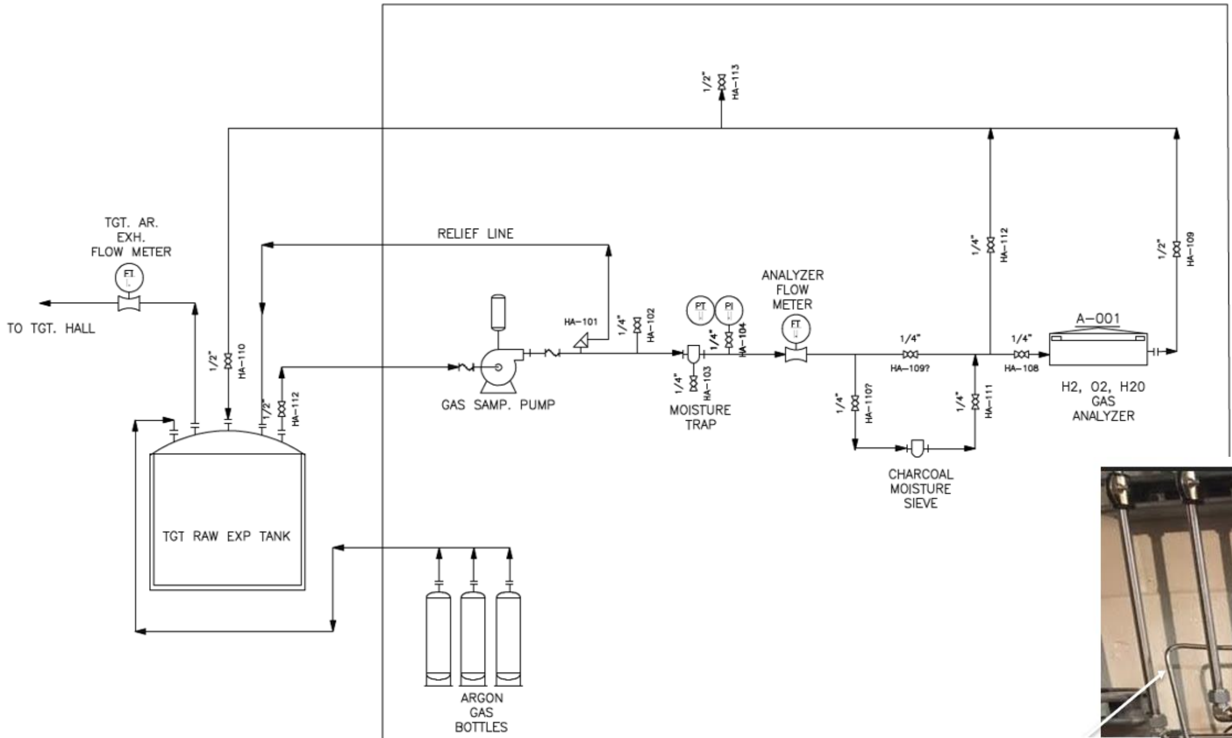
- All the instrumentation used will be rad-hard. Like the ones used on the RAW system.
- The $H_2$/$^{41}$Ar control system will be interlocked to several beam control systems.
- As per FESHM chapter 6020.3—Storage and Use of Flammable Gases, this system falls in Class 0 risk category as it has less than 0.6 Kg of Hydrogen.
- The pressure stabilizing system could be prototyped to understand its operational nuances.
- The moisture element is not modeled here. This can be tackled by installing charcoal absorbers in the exhaust loops.
- A detailed installation procedure for the mezzanine and the holding tank systems needs to be developed.

# Conslusions

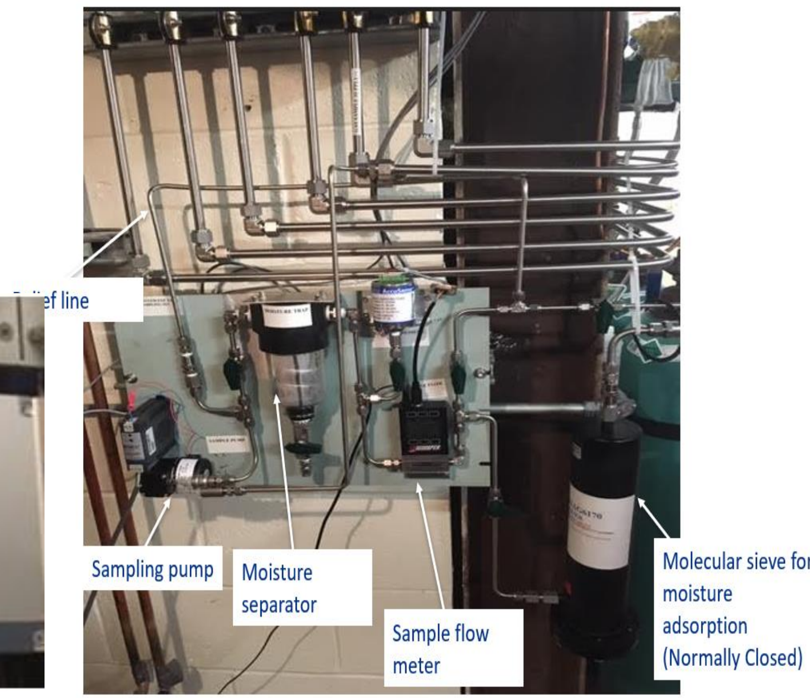
- A detailed ODH analysis will be done for the Target Hall RAW room and connected volumes.
- During operations, the fresh Argon bottle farm may be replaced by a bank of LAr dewars located outside the Target Hall Complex.

# Discussion and questions

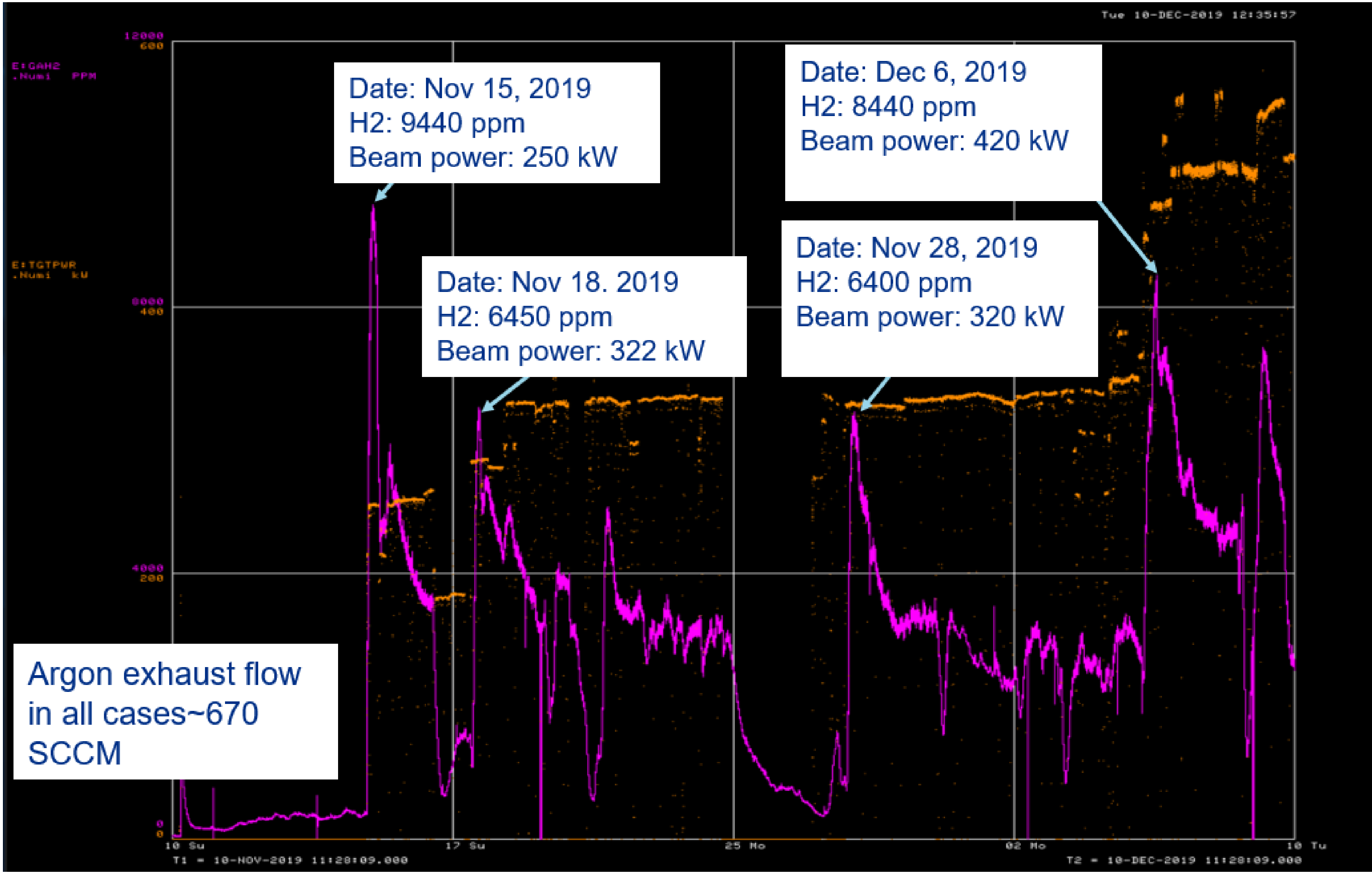
# Back-up: NuMI Gas Sampling



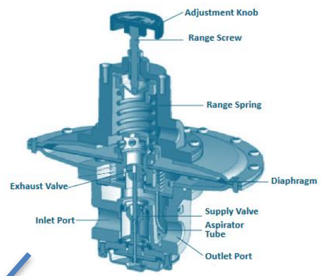




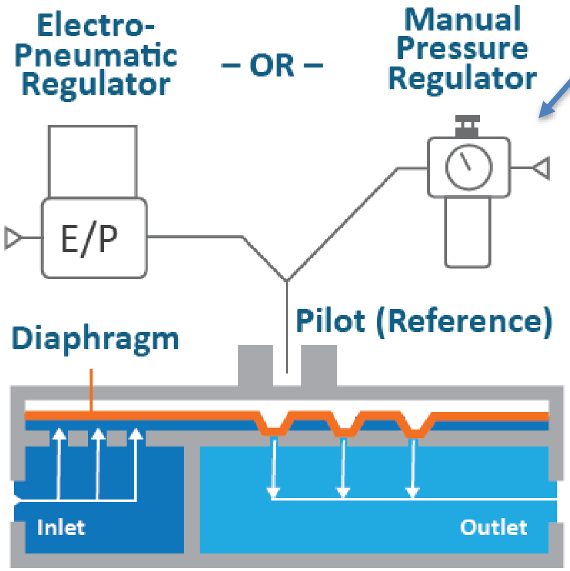
# Back-up: NuMI Gas Sampling

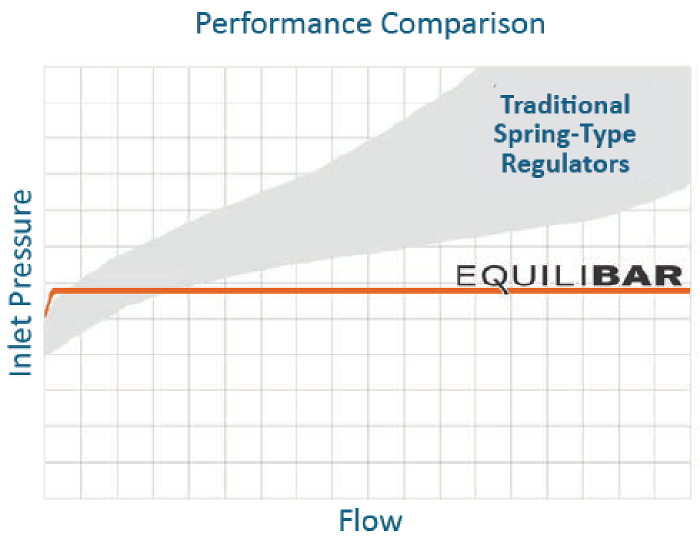


# Back-up: Pilot Operated Back Pressure Regulator



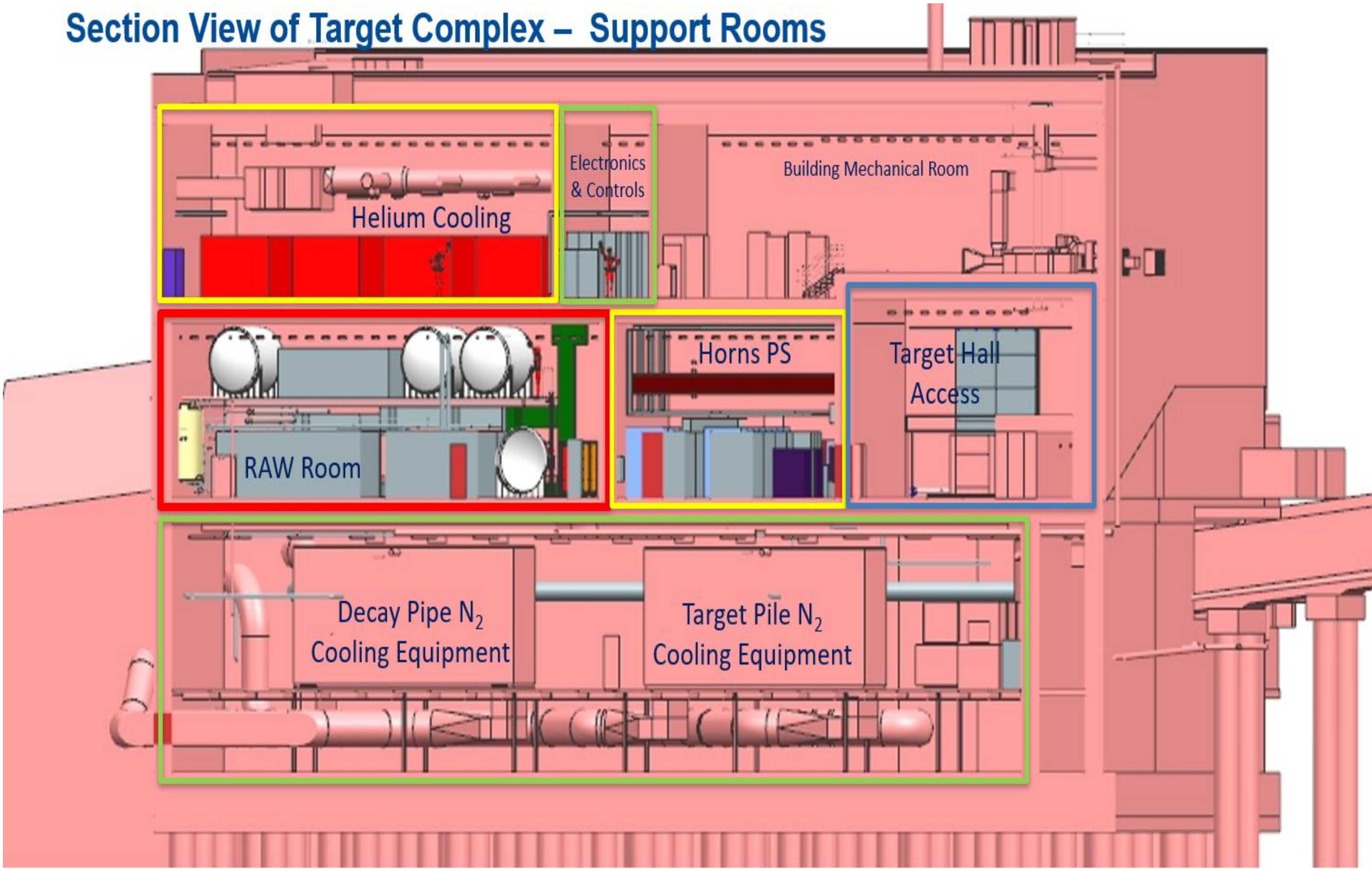

- Precision pressure regulator connected to compressed air system
- Set to a value to be maintained at the inlet of back pressure regulator




| WETTED MATERIALS | |
|---|---|
| Body Material | Stainless Steel 316/316L (standard)<br>Also available: Hastelloy C276, Titanium, Zirconium |
| O-Rings | Viton® (FKM) (standard)<br>Also available: Kalrez® (FFKM), PTFE, EPDM, Buna-N |
| Diaphragm | PTFE/Glass Laminate (standard)<br>Also available: Stainless Steel SS316/316L, Hastelloy C276, Virgin PTFE, FKM, Polyimide, Buna-N, PEEK, EPDM |

# Back-up: Mezzanine system



# Back-up: Mezzanine system