

OWNER

Sampling System Design and Thermowell Evaluation

Calculation



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TORUS

[REDACTED] [REDACTED], [REDACTED] County, [REDACTED]

ISSUE SUMMARY AND APPROVAL

This page records each issue of ME-A-CAL-004. The preparer, reviewer and approver sign for each revision.

Rev.	Date	Issue purpose	Description
A	2026-09-29	Issued for Review	First issue

Contributors

Rev.	Discipline	Prepared by	Reviewed by	Approved by
A	Measurement			

CONTENTS

1.	OBJECTIVE.....	1
2.	METHODOLOGY	1
3.	DESIGN INPUTS.....	1
4.	ASSUMPTIONS.....	2
5.	REFERENCES	3
6.	CALCULATION.....	3
	6.1. SAMPLE PROBE LOCATION	3
	6.2. THERMOWELL GEOMETRY.....	4
	6.3. WAKE FREQUENCY, METER TUBE WELLS AT C5.....	4
	6.4. RESULTS FOR ALL WELLS	5
	6.5. SAMPLE TRANSPORT LAG	6
	6.6. RESTRICTION ORIFICE RO-141A.....	6
	6.7. DEW POINT AND REGULATOR HEATING	7
	6.8. COMPOSITE SAMPLER	8
7.	RESULTS AND CONCLUSIONS	8

FIGURES AND TABLES

Figure 6-1. Thermowell Frequency Ratio at the Worst Case	5
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Table 3-1: Design Inputs.....2

Table 6-1: Sample Probe Location 3

Table 6-2: Thermowell Geometry and Natural Frequency.....4

Table 6-3: Wake Frequency and Stress Results.....5

Table 6-4: Sample Transport Lag, 19.9 ft Route.....6

Table 6-5: Cooling across the Probe Regulator.....7

Table 6-6: Composite Sampler Setting by Monthly Rate 8

APPENDICES

APPENDIX A. SKID AND ANALYZER SHELTER DRAWINGS.....9



1. OBJECTIVE

This calculation locates the custody sample probe SP-141, checks it and every station thermowell (TW-101, TW-111, TW-112, TW-121, TW-122, TW-135, TW-156 and TW-173) against vortex-induced vibration and stress per ASME PTC 19.3 TW-2016, calculates the sample transport lag to analyzer shelter B-101, establishes the heating needed to keep the sample above its hydrocarbon dew point, checks restriction orifice RO-141A at the shelter wall, and sizes the composite sampler SMP-146.

2. METHODOLOGY

Probe location. SP-141 was located against the requirements of API MPMS Chapter 14.1 and GPA 2166 for a representative custody sample, on the station piping as laid out in the piping general arrangement.

Wake frequency. The first natural frequency of each well was calculated as a tapered hollow cantilever by finite elements, clamped at the flange face. The distributed mass includes the steel, the added mass of the surrounding gas and the sensor sheath. A mounting compliance factor of 0.85 was then applied. The vortex shedding frequency uses the tip diameter and a Strouhal number of 0.22 for tip Reynolds numbers above 5×10^5 . Because the Scruton number of every well in gas is below 2.5, PTC 19.3 requires the shedding frequency to stay below 0.4 of the installed natural frequency, which avoids in-line resonance. Steady drag and oscillating lift stresses at the root were screened against the allowable stress and the fatigue endurance limit. Each well was evaluated at its worst case, the operating case with the highest ρV^2 .

The finite-element frequencies were checked independently by the Rayleigh energy method with the static deflection shape obtained by direct integration. The two methods agree within 0.8 % for every well, and every pass or fail verdict is the same.

Transport lag and heating. The lag is the standard volume of gas in transit divided by the total sample flow. The Joule-Thomson cooling across the probe regulator was calculated by isenthalpic expansion, and the dew point by GERG-2008 phase equilibrium.

Restriction orifice. RO-141A was checked with the compressible orifice equation. The expansion factor and the critical flow use the isentropic exponent $\kappa = \rho c^2 / p$ of the real gas, not the ratio of real-gas specific heats, which at pipeline pressure overstates it.

3. DESIGN INPUTS

Table 3-1 lists the inputs.

Table 3-1: Design Inputs

Input	Value	Source
Operating cases C1 to C7	Flow, pressure, temperature, composition	GEN-DB-001, Section 6
Meter conditions and run pressure drop (2.36 psi at C5)	Per case	MEA-CAL-001
Heater coil loss in service	10 psi at 120 MMSCFD	GEN-DB-001, Section 6
Control valve outlet temperature, heater on	45 °F	Assumption 1
NPS 12 bore	11.374 in (Sch 80)	Assumption 3
Thermowell material	316 stainless steel, E = 28.3×10^6 psi, 0.289 lb/in ³	ASME BPVC Section II Part D
Damping ratio	0.0005	ASME PTC 19.3 TW-2016
Allowable stress; fatigue endurance limit; root stress factor	20,000 psi; 21,000 psi; 2.2	ASME II-D; PTC 19.3 TW-2016
SP-141 location and tubing route	Plot (104, 116); 10.3 ft to the B-101 west wall	Piping general arrangement, Volume 4
Hydrocarbon dew point limit	15 °F cricondentherm	GEN-DB-001, Section 5.2 (HOLD H-13)
Minimum ambient temperature	-5 °F	GEN-DB-001, Section 3
Analyzer sample flows	GC 0.10, water 1.00, H ₂ S 0.50, O ₂ 0.50, speed loop 1.50 SLPM	Typical, HOLD H-15
RO-141A	1/32 in bore, discharge coefficient 0.80	PRO-CAL-007

4. ASSUMPTIONS

1. The heater holds the control valve outlet at 45 °F when in service. This affects only the conditions at TW-135, TW-156 and TW-173. *Verification required by the process heater calculation.*
2. Loss from the control valve outlet to IJ-102 is 5 psi at 120 MMSCFD, used only for thermowell velocity.
3. NPS 12 lines are taken with the Sch 80 bore, which gives the highest velocity. A thinner wall lowers velocity and increases margin.
4. The mounting compliance factor is 0.85 for a flanged well in a weldolet nozzle. *Verification required: the vendor shall apply the PTC 19.3 TW-2016 compliance equations with the actual nozzle (HOLD H-15).*
5. Probe, regulator, filter and valve internal volume is 50 cm³.

6. Hexanes plus are represented as n-hexane. *Verification required with the extended analysis (HOLD H-12).*

5. REFERENCES

1. API MPMS Chapter 14.1 (2016), Collecting and Handling of Natural Gas Samples for Custody Transfer.
2. GPA 2166-17, Obtaining Natural Gas Samples for Analysis by Gas Chromatography.
3. ASME PTC 19.3 TW-2016, Thermowells.
4. ASME BPVC Section II Part D (2023).
5. ISO 5167-2:2022 and ANSI/ISA-75.01.01, compressible orifice flow.
6. GEN-DB-001, Basis of Design; MEA-CAL-001, Ultrasonic Meter Sizing.
7. PRO-CAL-007, Pressure Relief Devices and Tank Venting; SAF-RPT-003, Fire and Gas Detection.
8. MEA-DWG-002, Meter Skid General Arrangement, and MEA-DWG-003, Analyzer Shelter (Appendix A).

6. CALCULATION

6.1. SAMPLE PROBE LOCATION

SP-141 is on top of 12"-G-1020 at plot (104, 116), where the line runs north from the meter outlet header toward the line heater. Table 6-1 compares the location with the requirements. The point is downstream of both meter runs, so every delivered molecule passes it, and it is 15.0 ft (15.8 pipe diameters) downstream of the last header tee, well beyond the 5 diameters API 14.1 asks for.

Table 6-1: Sample Probe Location

Requirement (API 14.1, GPA 2166)	Design
Representative of the custody stream, downstream of the meters	On the meter outlet line, downstream of both runs, upstream of H-101
Top of a horizontal pipe, away from liquids	12 o'clock on a straight run
At least 5 diameters from any disturbance	15.8 diameters downstream of the run 2 header tee; next elbow 32 ft further
Tip in the center third of the pipe	4.50 in into the 11.374 in bore (center third 3.79 to 7.58 in)
Short route to the analyzers	10.3 ft to the B-101 west wall

6.2. THERMOWELL GEOMETRY

All thermowells are flanged 1-1/2 in Class 600, one-piece 316 stainless steel, tapered from a 1.25 in root to a 0.875 in tip with a 0.26 in bore, with the flange face 5.0 in above the pipe. SP-141 has a straight 1.00 in stem with a 0.50 in bore on a 2 in Class 600 flange. Table 6-2 gives the dimensions and natural frequencies. The insertion places each sensing tip at about one third of the bore.

Table 6-2: Thermowell Geometry and Natural Frequency

Tag	Line	Insertion (in)	Unsupported length (in)	FE frequency (Hz)	Installed frequency (Hz)
TW-101	12"-G-1001	3.75	9.44	443	376
TW-111, 112, 121, 122	Meter tubes	3.25	8.84	504	429
TW-135	12"-G-1033	3.75	9.44	443	376
TW-156	12"-G-1022	3.75	9.44	443	376
TW-173	12"-G-1041	3.75	9.44	443	376
SP-141	12"-G-1020	4.50	10.19	282	239

6.3. WAKE FREQUENCY, METER TUBE WELLS AT C5

The governing well is TW-111 at C5, with gas at 3.544 lb/ft³ and 38.4 ft/s. With the unsupported length of 5.00 + 0.594 + 3.25 = 8.84 in, the finite-element frequency is 504 Hz, so the installed frequency is:

$$f_{n,c} = H_c f_n = 0.85 \times 504 = 429 \text{ Hz}$$

The tip Reynolds number is 1.2×10^6 , so the Strouhal number is 0.22:

ASME PTC 19.3 TW-2016, shedding frequency

$$f_s = \frac{N_s V}{B} = \frac{0.22 \times 38.4}{0.875/12} = 116 \text{ Hz}$$

ASME PTC 19.3 TW-2016, Scruton number

$$N_{Sc} = \frac{\pi^2}{2} \zeta \frac{\rho_m}{\rho} \left[1 - \left(\frac{d}{B} \right)^2 \right] = \frac{\pi^2}{2} (0.0005) \frac{499.4}{3.544} \left[1 - \left(\frac{0.26}{0.875} \right)^2 \right] = 0.32$$

The Scruton number is below 2.5, so the limit is 0.4:

$$\frac{f_s}{f_{n,c}} = \frac{116}{429} = 0.271 < 0.4$$

The well passes with a velocity limit of 57 ft/s, 1.5 times the highest operating velocity.



6.4. RESULTS FOR ALL WELLS

Figure 6-1 shows the frequency ratio of every well against the limit, including the two lighter stems TORUS evaluated and rejected. Table 6-3 gives the values.

Figure 6-1. Thermowell Frequency Ratio at the Worst Case

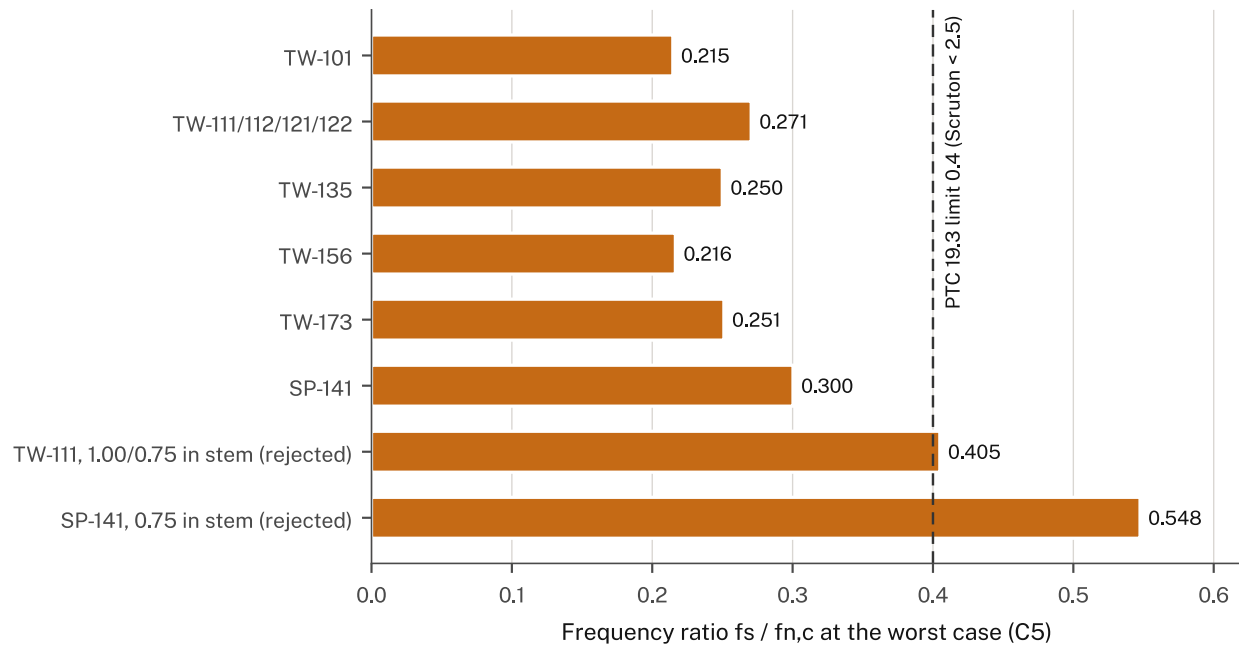


Table 6-3: Wake Frequency and Stress Results

Tag	Case	Velocity (ft/s)	Shedding (Hz)	Ratio	Velocity limit (ft/s)	Dynamic stress (psi)	Result
TW-101	C5	26.8	81	0.215	50	90	Pass
TW-111, 112, 121, 122	C5	38.4	116	0.271	57	155	Pass
TW-135	C5	31.2	94	0.250	50	107	Pass
TW-156	C5	27.0	81	0.216	50	91	Pass
TW-173	C5	31.3	95	0.251	50	107	Pass
SP-141	C5	27.2	72	0.300	36	265	Pass
TW-111 with 1.00/0.75 in stem	C5	38.4	135	0.405	38	284	Fail
SP-141 with 0.75 in stem	C5	27.2	96	0.548	20	613	Fail

Note 1: Dynamic stress is the lift stress at the root including the stress factor of 2.2 and the off-resonance magnification, against the 21,000 psi endurance limit. Steady drag bending plus pressure is below 1,100 psi for every well, against 1.5 times the 20,000 psi allowable.

The common catalog well with a 1.00 in root and 0.75 in tip fails in the meter tube, where the gas is fastest, and a 0.75 in probe stem fails in 12"-G-1020. The heavy-duty taper was selected for all station wells so that one design serves every location with at least 1.5 times velocity margin, rather than accepting a well that sits on the limit. Velocity collars were not considered, because PTC 19.3 discourages them and they depend on a tight fit that cannot be verified after installation.

6.5. SAMPLE TRANSPORT LAG

The route from SP-141 to the conditioning panel is 3.0 ft for the probe head and heated regulator, 10.3 ft of tubing to the B-101 west wall, and 4.0 ft through SDV-141 and RO-141A to the panel: 17.3 ft, or 19.9 ft with a 15 % routing allowance. At the 25 psig transport pressure:

$$V = \frac{\pi}{4} (0.305)^2 (19.9 \times 12) (16.387) = 286 \text{ cm}^3$$

$$\text{Lag} = \frac{(286 + 50) \times 2.67}{3,600 \text{ scc/min}} \times 60 = 15 \text{ s}$$

where 2.67 is the ratio of standard to actual volume at 25 psig and 60 °F. Table 6-4 compares transport options. Carrying the sample at line pressure would take 6.8 minutes and is rejected; reducing pressure at the probe is the reason the probe carries a regulator. The 1.5 SLPM speed loop keeps the line swept when an analyzer is isolated; without it the lag would be 26 s.

Table 6-4: Sample Transport Lag, 19.9 ft Route

Transport pressure	Tubing	Standard volume in transit (scc)	Velocity (ft/s)	Lag (s)
15 psig	3/8 in x 0.035	666	2.11	11
25 psig	3/8 in x 0.035	896	1.57	15
50 psig	3/8 in x 0.035	1,476	0.95	25
887 psig (line)	3/8 in x 0.035	24,309	0.06	405

The lag is short compared with the chromatograph cycle of 5 minutes and the hourly composition update.

6.6. RESTRICTION ORIFICE RO-141A

SDV-141 and RO-141A at the B-101 wall close the sample line on station ESD and limit the gas that can enter the shelter if a tube breaks inside. At 25 psig and 60 °F the gas density is 2.088 kg/m³ and the isentropic exponent $\kappa = 1.281$. The design sample flow of 3.60 SLPM (0.047 g/s) passes the 1/32 in bore with:

ISO 5167-2, compressible orifice flow

$$\Delta P = \frac{1}{2\rho} \left(\frac{\dot{m}}{C_d YA} \right)^2 = 0.49 \text{ psi}$$

The downstream pressure of 24.5 psig stays above the 15 psig set point of the panel regulator PCV-141E, so the orifice does not starve the analyzers, and it does not change the lag, because the transport volume is upstream of it. With a full break downstream the orifice chokes at 15.1 SLPM (32 scf/h), which the shelter ventilation dilutes (PRO-CAL-007 and SAF-RPT-003). After SDV-141 reopens, the line needs 10 volumes of purge, 2.5 minutes, before analyzer data are valid; the flow computer holds the last good composition for that period.

6.7. DEW POINT AND REGULATOR HEATING

The design gas has a calculated cricondenthem of 14.6 °F, consistent with the 15 °F tariff limit; the rich upset gas reaches 42.5 °F. Because the heavy ends are not yet characterized, the sample system is designed on the 15 °F tariff limit plus a 20 °F margin: every wetted sample part stays at or above 35 °F.

An unheated probe regulator would cool the sample to -48.6 °F at C1, as Table 6-5 shows. The expansion from 1,135 psig passes through 200 to 800 psig, where the dew point is 10 to 15 °F, so heavy components would condense in the regulator and the sample would read lean. The gas must enter the pressure cut at 103 °F or higher (106 °F for the rich envelope). A heated regulator set at 140 °F is therefore specified, T3 temperature class or better. The gas heating duty is under 5 W; the heater rating is set by enclosure losses, typically 50 to 100 W.

Table 6-5: Cooling across the Probe Regulator

Case	Line pressure (psig)	Line temperature (°F)	Outlet, unheated (°F)	Inlet needed for 35 °F outlet (°F)
C1	1,135	44.2	-48.6	103
C2	1,041	69.6	-4.0	99
C3	1,000	60.0	-14.0	96
C4	1,085	119.4	59.4	Not needed
C5	885	59.2	-5.6	90
C7 (rich)	1,085	59.2	-33.0	106

Both sample lines will be heat traced to 120 °F on two separate circuits, so the line-pressure composite line and the analyzer line can be maintained and alarmed independently. At -5 °F with a 20 mph wind and 1/2 in of insulation, the loss is 5.7 W/ft for the 3/8 in analyzer line and 4.9 W/ft for the 1/4 in composite line. With a 1.5 safety factor the cable must deliver 8.5 and 7.4 W/ft at 120 °F, which a self-regulating cable of about 15 W/ft nominal at 50 °F provides. The line-pressure composite line must be traced because at -5 °F it would cool below the dew point between about 400 and 800 psig and lose heavy ends before reaching the cylinder. Hydrates are not a concern after the pressure cut: at 25 psig the water dew point of gas at the tariff limit of 7 lb/MMscf is far below 35 °F.

6.8. COMPOSITE SAMPLER

SMP-146 is a flow-proportional pump sampler that takes fixed 0.5 cm³ bites at line pressure into a 500 cm³ constant-pressure floating-piston cylinder, per API 14.1 and GPA 2166. The fill is limited to 80 %, or 800 bites. A month at 120 MMSCFD is 3,720 MMscf, so the interval must be at least 4.65 MMscf per bite. A bite at C5 is 36 scc.

A fixed interval of 5.0 MMscf would collect only 62 bites in a turndown month, too few for a representative composite. The interval will therefore be reset at the start of each period to the forecast volume divided by 700 bites, within 0.4 to 5.0 MMscf per bite. Table 6-6 shows that this keeps the fill near 70 % at every rate. The flow computer stops the sampler and alarms if the cylinder reaches 80 %.

Table 6-6: Composite Sampler Setting by Monthly Rate

Flow (MMSCFD)	Month volume (MMscf)	Interval (MMscf per bite)	Bites	Collected (cm ³)	Fill (%)
120	3,720	5.00	744	372	74
90	2,790	3.99	700	350	70
60	1,860	2.66	700	350	70
30	930	1.33	700	350	70
10	310	0.44	700	350	70

7. RESULTS AND CONCLUSIONS

1. SP-141 is on top of 12"-G-1020 at plot (104, 116), 15.8 diameters downstream of the last header tee, with its tip 4.5 in into the bore.
2. Every thermowell passes with the 1.25 in root and 0.875 in tip taper and a 5.0 in standoff; the highest frequency ratio is 0.271 in the meter tubes. SP-141 passes with a 1.00 in stem at 0.300. The 1.00/0.75 in taper and the 0.75 in probe stem shall not be supplied. Vendors shall submit a full PTC 19.3 TW-2016 calculation with their final dimensions and nozzle stiffness.
3. The sample transport lag is 15 s at 25 psig in 3/8 in tubing.
4. RO-141A costs 0.49 psi at the design flow and limits a break inside B-101 to 32 scf/h.
5. The probe regulator shall be heated (set 140 °F); both sample lines shall be traced to 120 °F on two circuits.
6. SMP-146 uses a 500 cm³ cylinder with a 0.5 cm³ bite, the interval set each month from the forecast volume, and two cylinders (one in service, one in transit).

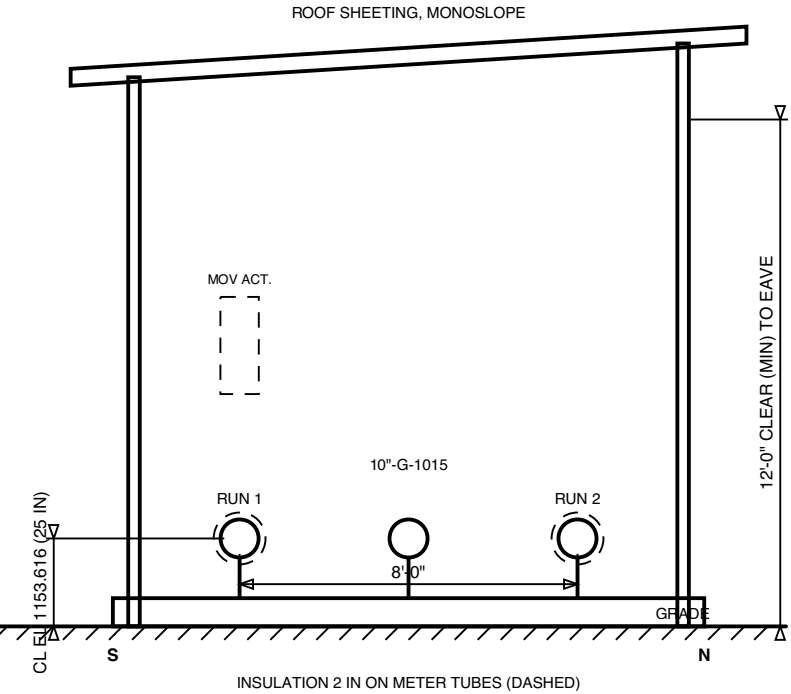
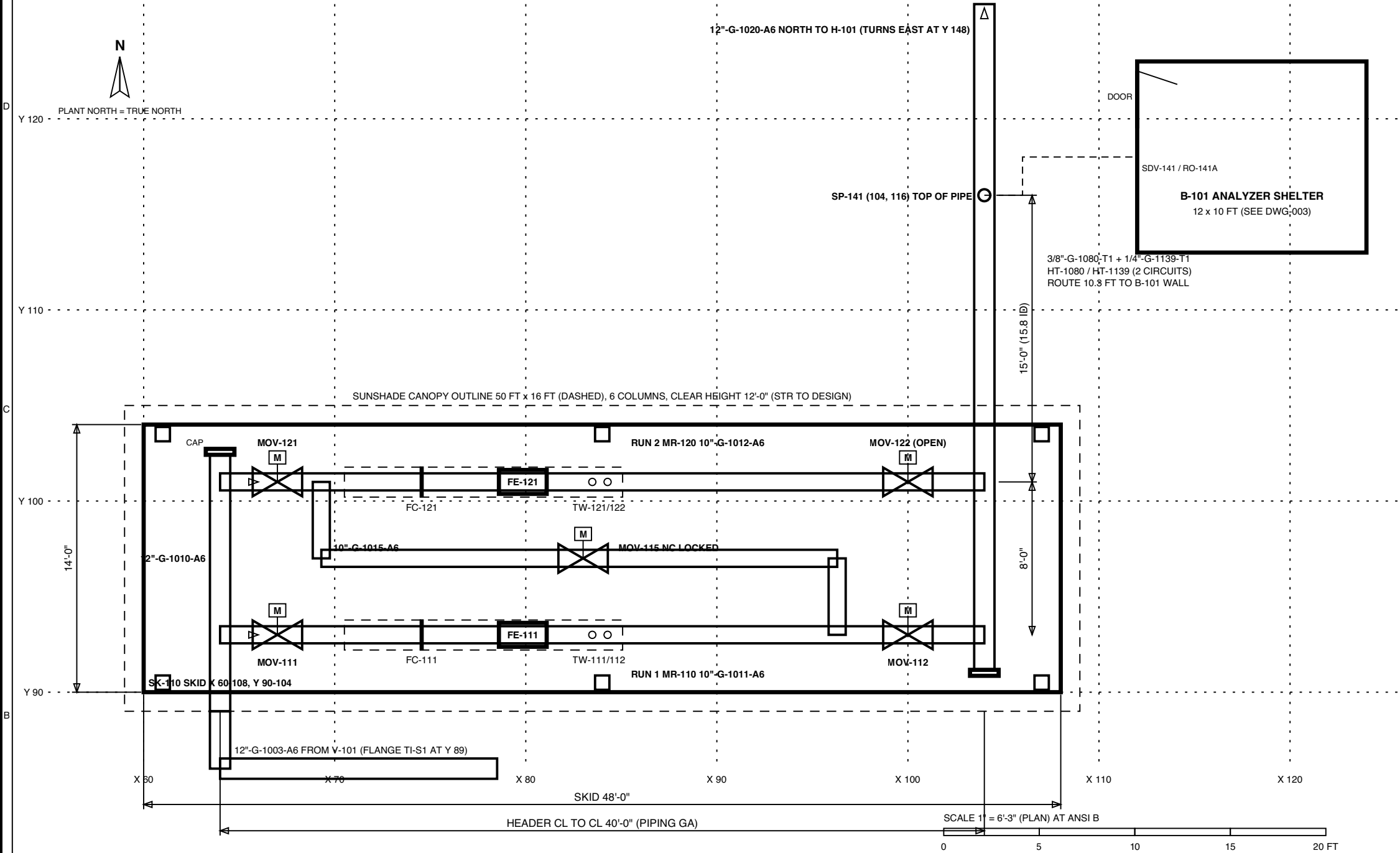
The next step is to rerun the dew point and regulator heating with the extended gas analysis (HOLD H-12), and to check the vendors' thermowell calculations against these results (HOLD H-15).

APPENDIX A. SKID AND ANALYZER SHELTER DRAWINGS



PLAN - METER SKID SK-110 AND ANALYZER SHELTER B-101 (PLOT COORDINATES, FT)

SECTION A-A (LOOKING EAST AT X = 80)



MOV LINE-UP BY MODE (MEA-RPT-001)

MODE	111	112	121	122	115
RUN 1 DUTY	O	O	C	O	C
RUN 2 DUTY	C	O	O	O	C
PARALLEL (>80 FT/S)	O	O	O	O	C
SERIES 1 -> 2	O	C	C	O	O
RUN 1 MAINT.	C/B	C/B	O	O	C

O OPEN, C CLOSED, C/B CLOSED AND BLED (DEPRESSURED). STANDBY RUN OUTLET MOV KEPT OPEN.

- COORDINATES ARE PLOT COORDINATES (FT), GEN-DB-001 SECTION 10.1. SKID PIPING PER PIPING GA (VOLUME 4).
- CALIBRATED METER TUBE ASSEMBLY PER MEA-DWG-001 AND MEA-CAL-001 (X 70.51 TO 85.07).
- RUN CL EL 1153.616; FINISHED GRADE PER CIV-CAL-001.
- SERIES MODE AT C2 RATE (90 MMSCFD) OR LOWER: ADDED LOSS 1.97 PSI AT 90 MMSCFD, 4.07 PSI AT 120 MMSCFD.
- SP-141 AT PLOT (104, 116): 12 O'CLOCK ON 1020, 15.8 ID DOWNSTREAM OF RUN 2 TEE; TIP 4.5 IN.
- STANDBY RUN OUTLET MOV ALWAYS OPEN (BLOCKED-IN RUN IN SUN REACHES ABOUT 1,570 PSIG); A RUN IS BLOCKED IN AT BOTH ENDS ONLY WHEN DEPRESSURED.
- CANOPY BY STR/CIV; FULL SHADE OF METER TUBES, 12 FT CLEAR. MOV DATA PER MEC-LST-003 (HOLD H-15).

NOTES / REFERENCES

- SEE DRAWING NOTES ON SHEET.
 - PLAN SCALE BASED ON ANSI B PRINT (16 UNITS PER FT).
- REF: MEA-DWG-001
REF: MEA-DWG-003
REF: MEA-RPT-001
REF: MEA-CAL-001/004

REVISIONS

REV	DATE	DESCRIPTION	BY	CHK	APP
A	2026-09-29	ISSUED FOR REVIEW (IFR)			

PRELIMINARY - ISSUED FOR REVIEW - NOT FOR CONSTRUCTION

ENGINEER OF RECORD SEAL

NOT SEALED
PRELIMINARY

PE NO. _____

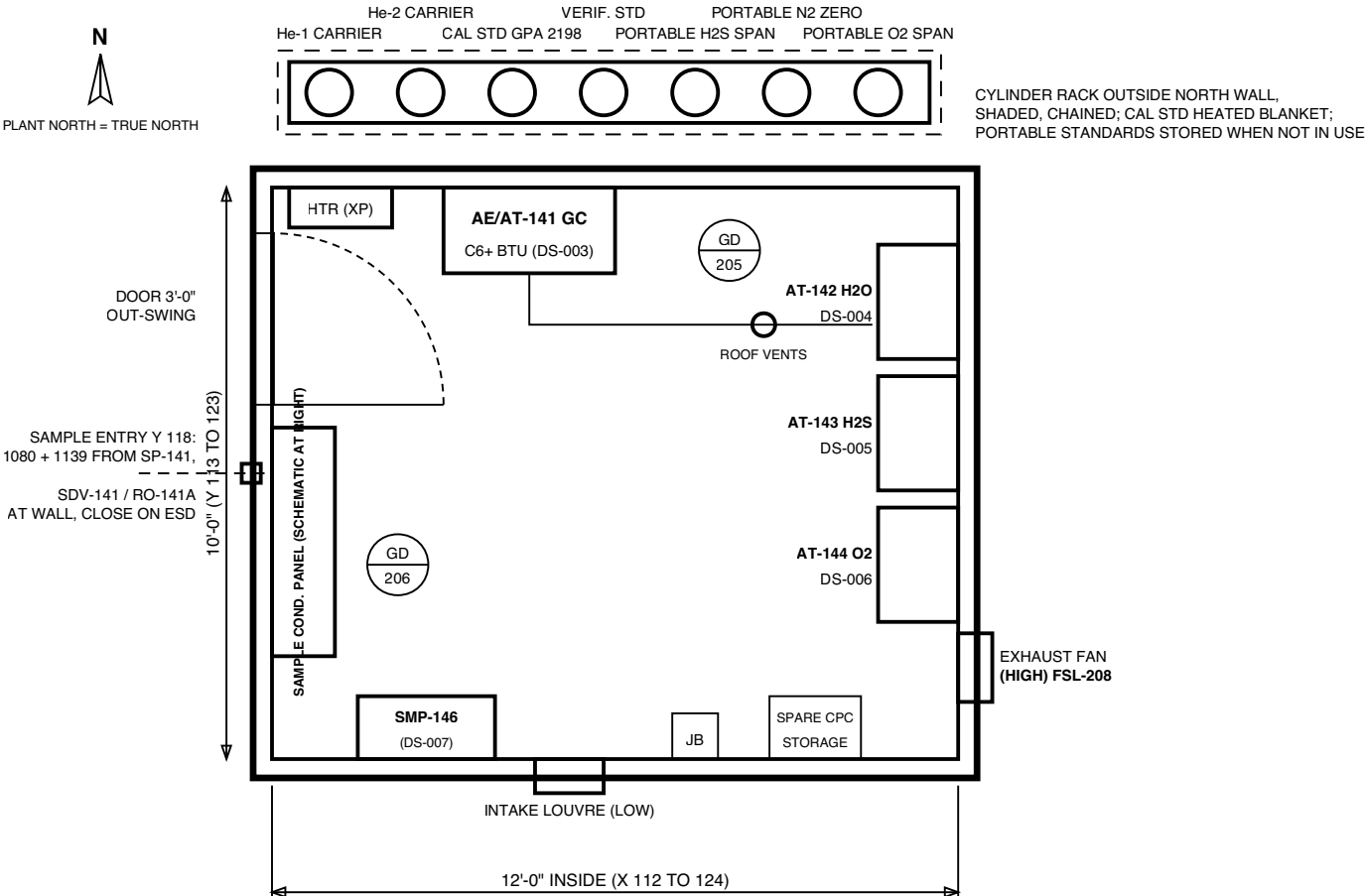
PROJECT

120 MMSCFD RECEIPT INTO _____
COUNTY, _____
DISCIPLINE: MEASUREMENT
SCALE: PLAN 1" = 6'-3"; SECTION NTS

METER SKID GENERAL ARRANGEMENT

SK-110 PLAN, SECTION A-A, MOV LINE-UP
DRAWN: _____ CHECKED: _____ APPROVED: _____
DWG NO. MEA-DWG-002
SHEET 1 OF 1 REV A

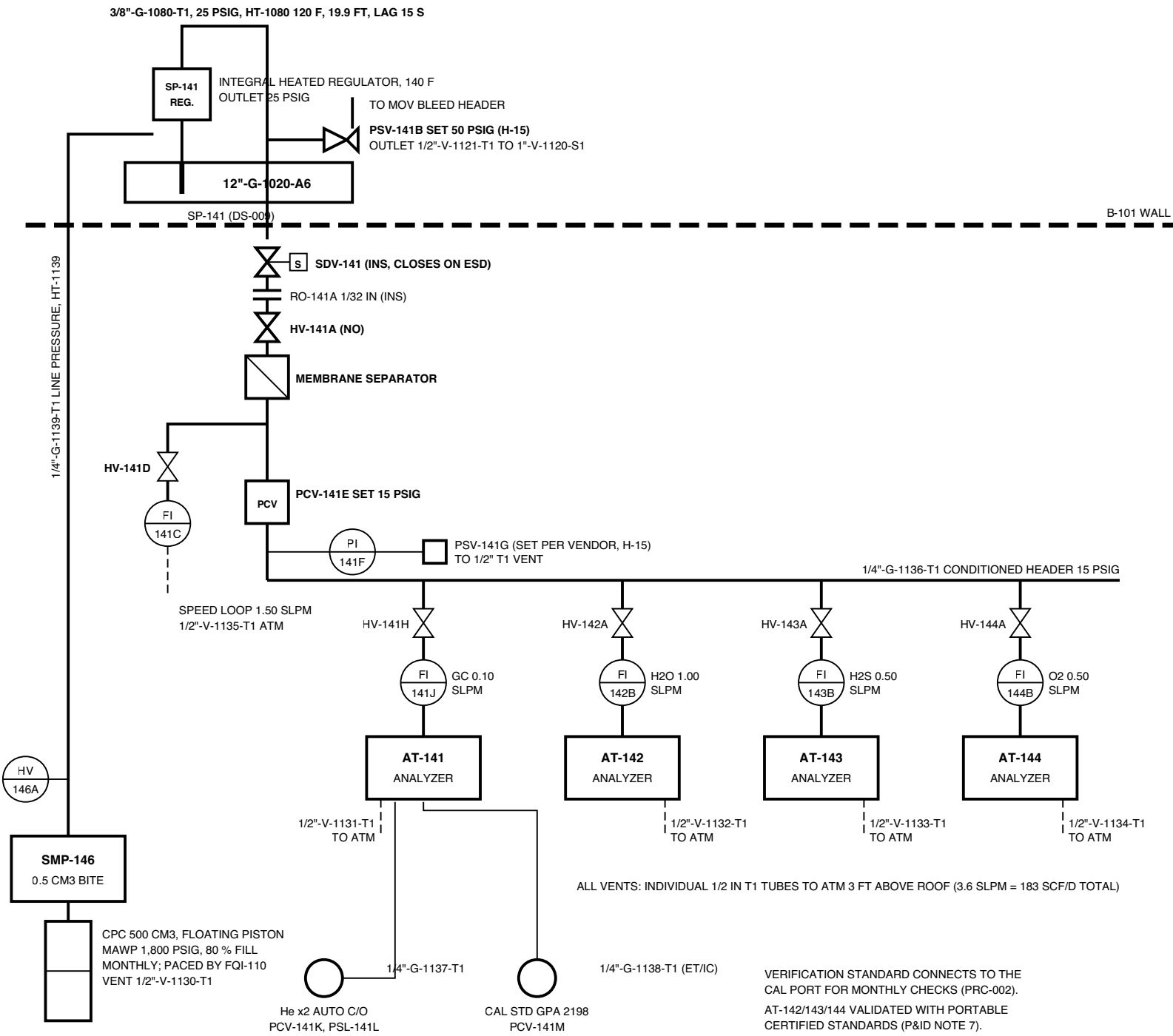
PLAN - ANALYZER SHELTER B-101 (12 FT x 10 FT, FIBERGLASS, HEATED, VENTILATED)



INTERIOR CLASS I DIV 2 GROUP D (BASIS 8.1); HEATED 50 F MIN; VENTILATION PER ELE/INS.
PLAN SCALE 1" = 3'-4" AT ANSI B (30 UNITS PER FT).

1. SAMPLE TRANSPORT 3/8 IN x 0.035 316 SS, 25 PSIG, 3.6 SLPM TOTAL, 19.9 FT ROUTE, LAG 15 S (CAL-004).
2. SP-141 INTEGRAL REGULATOR HEATED, SET 140 F; GAS INLET 103 F MIN AT C1 FOR 35 F OUTLET (UNHEATED -48.6 F).
3. ALL WETTED SAMPLE PARTS 35 F MIN (TARIFF HCDP 15 F + 20 F); HEAT TRACE HT-1080 / HT-1139 MAINTAIN 120 F.
4. SMP-146 BITE INTERVAL = FORECAST PERIOD VOLUME / 700 (5.0 MMSCF PER BITE AT 120 MMSCFD).
5. ANALYZER VENTS (LINES 1130-1135) ARE A CONTINUOUS EMISSION POINT (183 SCF/D); REG TO INVENTORY.
6. MINOR TAGS PER PRO-DWG-104; SDV-141 + RO-141A (1/32 IN) BY INS, CLOSED ON ESD; RO DP 0.49 PSI AT 3.6 SLPM.
7. EQUIPMENT DIMENSIONS TYPICAL, CONFIRM WITH VENDOR DATA (HOLD H-15).
8. PSV-141B (SET 50 PSIG) LIMITS THE PRESSURE AT RO-141A IF THE PROBE REGULATOR FAILS OPEN (PRO-CAL-007 7.7).

SAMPLE CONDITIONING SCHEMATIC (NTS, TAGS PER PRO-DWG-104)



GC CARRIER AND CALIBRATION GASES (RACK OUTSIDE NORTH WALL)

NOTES / REFERENCES

1. SEE DRAWING NOTES ON SHEET.
- REF: MEA-CAL-004
- REF: MEA-DS-003 TO DS-007, DS-009
- REF: MEA-DWG-002

REVISIONS

REV	DATE	DESCRIPTION	BY	CHK	APP
A	2026-09-29	ISSUED FOR REVIEW (IFR)			

PRELIMINARY - ISSUED FOR REVIEW - NOT FOR CONSTRUCTION

ENGINEER OF RECORD SEAL

NOT SEALED
PRELIMINARY

PE NO. _____

PROJECT

120 MMSCFD RECEIPT INTO _____

COUNTY, _____

DISCIPLINE: MEASUREMENT
SCALE: PLAN 1" = 3'-4"; SCHEMATIC NTS

ANALYZER SHELTER B-101

LAYOUT AND SAMPLE CONDITIONING SCHEMATIC

DRAWN: _____ CHECKED: _____ APPROVED: _____

DWG NO.

MEA-DWG-003

SHEET 1 OF 1 REV A