

OWNER

Preliminary Hazard and Operability Study

Report



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TORUS

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1. INTRODUCTION

1.1. PURPOSE

This report records the preliminary hazard and operability (HAZOP) study of the (), a 120 MMSCFD custody receipt station in County, , that delivers treated gas into a operated by , the receiving pipeline operator. TORUS carried out the study as a desktop review while the piping and instrumentation diagrams (P&IDs) were at their first issue for review, so that hazards could be designed out before the layout, the safety instrumented system (SIS) and the relief system were fixed.

The study had four aims. The first was to identify deviations from design intent that could injure people, release gas, overpressure the receiving pipeline, harm the environment, deliver off-specification gas or corrupt custody measurement. The second was to record the safeguards already in the design and rank the remaining risk. The third was to raise recommendations for the design team to close before the P&IDs are issued for construction. The fourth was to select the scenarios that need a layer of protection analysis (LOPA) in SAF-RPT-002 and, where a safety instrumented function (SIF) results, a requirement in SAF-SRS-001, Safety Requirements Specification.

1.2. SCOPE

The study covered the station from inlet insulating joint IJ-101 to outlet insulating joint IJ-102, and the Owner's buried outlet lateral from IJ-102 to the flange of the receiving pipeline operator's tap valve. It covered normal operation across design cases C1 to C7 of GEN-DB-001, Basis of Design, together with startup and first gas-in, planned and emergency shutdown, pigging, filter element change, meter run switching and series verification, heater operation and summer bypass, manual blowdown, maintenance with an SIS bypass, and loss of power, control and communications.

1.3. EXCLUSIONS

The Owner's upstream lateral and treating facility were excluded except where they place a demand on the station, such as an upstream pressure excursion, a liquid slug or off-specification gas. The hot tap fitting, tap valve, remote terminal unit and remote shutoff at the tap belong to the receiving pipeline operator and were reviewed only as interfaces. Occupational hazards that do not arise from the process, such as working at height or vehicle movements, were left to the construction and operations safety plans.

This preliminary study does not replace the formal HAZOP. A full team study on the P&IDs issued for HAZOP is required before the design is issued for construction (recommendation HZ-50), and it will revalidate every entry in this report.

2. STUDY BASIS

The study was based on the documents listed below. Where the Basis of Design and later project decisions differ, the later decisions were used, and the worksheets reflect the design as it stood at this issue: SDV-106 on the separator liquid outlet, restriction orifice RO-104 with emergency vent EV-193 on T-101, an overpressure shutdown trip at 1,225 psig with a 4 s stroke for SDV-102, two diverse flame detectors on the line heater, and the standby meter run held with its outlet valve open.

1. GEN-DB-001, Basis of Design.
2. PRO-DWG-101 to PRO-DWG-111, P&IDs, Rev A, Issued for Review, and PRO-LST-101, P&ID Line and Tag Register. Interlocks are referred to by the numbers I-01 to I-08 shown on the P&IDs.
3. INS-LST-001, Instrument Index; INS-LST-002, I/O List; INS-LST-003, Alarm and Trip Setpoint Schedule; INS-LST-004, Cause and Effect Matrix.
4. INS-RPT-001, Control Philosophy and Functional Narrative.
5. PRO-CAL-003, Joule-Thomson, Water Content, Hydrate and Hydrocarbon Dewpoint; PRO-CAL-006, Control Valve Sizing and Noise; PRO-CAL-007, Relief System; PRO-CAL-009, Overpressure Protection System Hydraulic Analysis.
6. SAF-RPT-002, Layer of Protection Analysis; SAF-CAL-001, SIL Verification; SAF-SRS-001, Safety Requirements Specification.
7. SAF-RPT-003, Fire and Gas Detection Philosophy; SAF-RPT-004, Facility Siting and Spacing Review; SAF-RPT-005, Emergency Response Plan.
8. IEC 61882:2016, Hazard and Operability Studies (HAZOP Studies), Application Guide.
9. IEC 61511-1:2016, Functional Safety, Safety Instrumented Systems for the Process Industry Sector.
10. CCPS, Guidelines for Hazard Evaluation Procedures, 3rd Edition (2008).
11. 49 CFR 192.195, 192.199 and 192.201, overpressure protection of pipelines.
12. API 521, API 2000, API 12K, API RP 556, API RP 500 and NFPA 780 for relief, tank venting, line heaters, fired heater instrumentation, area classification and lightning protection.

3. METHOD

3.1. APPROACH

The study followed IEC 61882. Each node was described by its design intent, and each process parameter was combined with the guidewords that give a meaningful deviation. For every credible deviation the study recorded the causes, the consequences with no safeguard acting, the safeguards in the design, and a risk ranking with those safeguards credited as designed. Where the safeguards were judged insufficient, or where the scenario was a candidate for a SIF, a recommendation and a LOPA scenario reference were raised. Deviations with no credible cause were recorded only where the reasoning helps the reader.

A desktop study was chosen at this stage, instead of waiting for a full team session on frozen P&IDs, because several of the largest design decisions (the SIS architecture, the relief of T-101 and the overpressure shutdown valve stroke) depended on the answers, and changing them later would have moved equipment and cost. The desktop study does not have the Owner's operating staff or the receiving pipeline operator in the room, which is why HZ-50 requires the full study before construction.

The parameter and guideword combinations used are listed in Table 3-1. Measurement, utilities and operations were added to the classical process parameters because custody accuracy, loss of power and human actions during pigging and blowdown are the main sources of hazard at an unmanned meter station.

Table 3-1: Parameters and Guidewords

Parameter	Guidewords applied
Flow	No, More, Less, Reverse, Misdirected
Pressure	More, Less
Temperature	More, Less
Level	More, Less, No
Composition	Other than (contamination, off-specification gas, liquids, solids, air ingress)
Phase	Other than (hydrates, liquid dropout)
Combustion (H-101 fired side)	More, Less, No, Delayed ignition
Measurement	Other than (bias, drift, interference)
Corrosion, erosion, noise, vibration, static, lightning	As well as
Operations	Startup, shutdown, maintenance, pigging, sampling, human error
Utilities	Loss of power, UPS, communications, control system, SIS bypass, security

3.2. RISK RANKING

The Owner's corporate risk matrix was not available for this issue (HOLD, Owner). The study therefore used the five-by-five matrix in Table 3-2, Table 3-3 and Table 3-4, which follows common practice on gas transmission projects. Risk R is the product of severity S and likelihood L, ranked with the existing safeguards credited. Every scenario with a severity of 4 or 5 was carried to LOPA regardless of its rank, because a qualitative ranking is not precise enough to accept a fatality-potential scenario on its own.

Table 3-2: Severity Categories

S	People	Environment and regulatory	Asset and commercial
1	First aid	Minor release, not reportable	Under \$10,000, no delivery impact
2	Recordable injury	Reportable release contained on site	\$10,000 to \$100,000, short curtailment
3	Lost-time injury	PHMSA or reportable incident; off-site odor or noise complaint	\$100,000 to \$1 million; off-specification delivery; custody error
4	Single fatality or permanent disability	Major release; regulatory enforcement	\$1 million to \$10 million; extended outage
5	Multiple fatalities or a public fatality	Trunkline rupture; public evacuation	Over \$10 million

Table 3-3: Likelihood Categories

L	Description (with existing safeguards)	Frequency, per year
1	Remote: not expected in the industry	Below 1E-04
2	Unlikely: has occurred in the industry	1E-04 to 1E-03
3	Possible: could occur in the life of the facility	1E-03 to 1E-02
4	Likely: occurs several times a year in the industry	1E-02 to 1E-01
5	Frequent: expected in the life of the facility	Above 1E-01

Table 3-4: Risk Classes and Required Action

R = S x L	Class	Required action
1 to 4	Low (L)	Manage by procedure
5 to 9	Medium (M)	Reduce where practicable; recommendation optional
10 to 14	High (H)	Recommendation required before issue for construction
15 to 25	Very high (VH)	Not acceptable; design change, or a SIF sized by LOPA

3.3. TEAM

A formal HAZOP is led by an independent facilitator with a multi-discipline team. Table 3-5 lists the roles required for the full study. The individuals are to be named by the Owner and TORUS before the session (HOLD, Owner). For this desktop study the TORUS process safety, process, instrumentation and measurement engineers acted in their roles, and the Owner, the receiving pipeline operator and the heater vendor positions were represented by the documents they have supplied.

Table 3-5: HAZOP Team Roles

Role	Organization	Name
Facilitator, independent of the design team	To be appointed	To be named
Scribe	TORUS	To be named
Process engineer	TORUS	To be named
Instrumentation, controls and process safety engineer	TORUS	To be named
Measurement engineer	TORUS	To be named
Mechanical and piping engineer	TORUS	To be named
Electrical engineer	TORUS	To be named
Operations representative (gas control and field)	Owner	To be named
Measurement representative	Owner	To be named
Receiving pipeline operator representative, by invitation (HOLD H-01)		To be named
Heater vendor representative, after award (HOLD H-15)	Vendor	To be named

4. NODES AND DESIGN INTENT

The station was divided into eleven nodes that follow the P&ID sheets, so that each node has one design intent and one set of operating conditions. The node boundaries are the isolation valves, because a hazard found at a boundary can then be assigned to a single node. The nodes are described below and summarized with their P&ID sheets in Table 4-1.

Node N1 is the inlet from IJ-101 through pig receiver PR-101 and inlet shutdown valve SDV-101 to the filter separator. Its intent is to receive up to 120 MMSCFD at 900 to 1,150 psig and 45 to 120 F, to receive pigs, and to isolate the station on emergency shutdown. The station is designed for 1,440 psig; the upstream lateral maximum allowable operating pressure (MAOP) is not yet confirmed (HOLD H-16).

Node N2 is filter separator V-101 with its locked-closed bypass and its liquid outlet through SDV-106, level control valve LCV-104 and RO-104 to T-101. Its intent is to remove solids and free liquids down to 1 micron and to dump liquid under level control without passing gas.

Node N3 is the custody meter skid: two 100 % ultrasonic meter runs with their motor-operated isolation valves, the series crossover MOV-115 and flow computer FQI-110. One run is in service and the other on standby, held pressurized with its outlet valve open, and the runs are placed in series at least quarterly to verify agreement within 0.3 %.

Node N4 is the sampling and analyzer system: probe SP-141, the sample tubing, shutoff valve SDV-141 with its restriction orifice, the analyzers in shelter B-101 and composite sampler SMP-146. Its intent is continuous gas quality measurement and a flow-proportional sample without gas accumulating in the shelter.

Node N5 is line heater H-101, both the process coil with its bypass and the fired side with the burner management system (BMS), the burner safety shutoff valves XV-150A/B/C and the fuel trim valve TCV-152. Its intent is to keep the gas leaving the control valves above the pressure-compensated setpoint of TIC-135, from 43.5 F at 750 psig to 51.1 F at 1,150 psig (PRO-CAL-003), with the heater bypassed in summer.

Node N6 is the fuel gas system FG-101: the take-off downstream of V-101, the electric preheater E-161, the two-cut regulation by PCV-161 and PCV-162, relief valve PSV-161 set at 250 psig, fuel meter FT-163, and SDV-165 on the heater branch only. Its intent is to supply clean, warm fuel at regulated pressure that never passes the custody meters, while keeping the standby generator supplied after an emergency shutdown.

Node N7 is the control valve station, flow control valves FCV-131 and FCV-132 with the outlet pressure override PIC-134, and the overpressure shutdown system (OPSS): transmitters PT-133A/B/C voting two-out-of-three in the safety PLC and shutdown valve SDV-102. Its intent is to control flow to the nomination, hold outlet pressure at or below 1,150 psig, and close SDV-102 at 1,225 psig so the trunkline never exceeds the 49 CFR 192.201 limit of 1,290 psig.

Node N8 is the outlet: check valve CKV-171, outlet shutdown valve SDV-103, IJ-102 and the buried lateral to the tap valve. Its intent is to deliver into the trunkline, operating at 750 to 1,050 psig, without reverse flow, and to isolate on emergency shutdown.

Node N9 is the vent and blowdown system: the manual blowdown valves with their restriction orifices, the relief valve outlets, the stainless steel vent header and vent stack VS-101. Its intent is safe manual depressuring, one section at a time, and relief discharge to a remote point. There is no automatic blowdown.

Node N10 is the drains and liquids tank: the drain lines, the 100 bbl atmospheric tank T-101 with its pressure-vacuum valve, flame arrestor and emergency vent, level transmitter LT-191, high-high switch LSHH-192 and the truck loadout. Its intent is to receive liquids at atmospheric pressure, store them and load them out safely.

Node N11 is utilities and control: utility power, standby generator G-101, the transfer switch, the 24 VDC UPS, the RTU, safety PLC and flow computer, the SCADA and receiving pipeline operator links, building ventilation, security and the emergency shutdown pushbuttons. Its intent is to keep control, protection and measurement powered and communicating, and to fail safe when they are lost.

Table 4-1: Node List

Node	Description	P&ID sheet	Deviations reviewed
N1	Inlet and pig receiver	PRO-DWG-101	15
N2	Filter separator V-101	PRO-DWG-102	11
N3	Custody meter runs	PRO-DWG-103	11
N4	Analyzers and sampling, B-101	PRO-DWG-104	8
N5	Line heater H-101, process and fired side	PRO-DWG-105	13
N6	Fuel gas FG-101	PRO-DWG-106	9
N7	Control valves and OPSS	PRO-DWG-107	12
N8	Outlet and receiving pipeline interface	PRO-DWG-108	9
N9	Vent and blowdown	PRO-DWG-109	8
N10	Drains and T-101	PRO-DWG-110	9
N11	Utilities, control and communications	PRO-DWG-111	12
Total			117

Note 1: The worksheets for each node are in Appendix A.

5. FINDINGS

5.1. OVERVIEW

The study reviewed 117 deviations across the eleven nodes and raised 53 recommendations, HZ-01 to HZ-53. Table 5-1 shows how the ranked risk is distributed by node, with the design safeguards credited as they stand at this issue. No scenario remains in the very high class. The one scenario that ranked very high on the original design, gas blow-by from the separator into the atmospheric tank, fell to medium once SDV-106, RO-104 and the T-101 emergency vent were added.

Table 5-1: Ranked Risk by Node

Node	Low	Medium	High	Very high
N1 Inlet and pig receiver	2	11	2	0
N2 Filter separator V-101	1	9	1	0
N3 Custody meter runs	1	10	0	0
N4 Analyzers and sampling, B-101	2	5	1	0
N5 Line heater H-101, process and fired side	0	10	3	0
N6 Fuel gas FG-101	2	7	0	0
N7 Control valves and OPSS	1	7	4	0
N8 Outlet and receiving pipeline interface	1	8	0	0
N9 Vent and blowdown	2	6	0	0
N10 Drains and T-101	2	7	0	0
N11 Utilities, control and communications	0	10	2	0
Total	14	90	13	0

5.2. HIGHEST-RANKED SCENARIOS

Table 5-2 lists the scenarios that ranked high, or that carry a severity of 4 or 5, in order of rank. The paragraphs that follow explain why each ranks where it does and what closes it.

Table 5-2: Highest-Ranked Scenarios

Rank	Worksheet ref	Scenario	Risk (S/ L/R)	Recommendations	LOPA
1	1.1, 2.3	Upstream pressure above the station design pressure	4 / 3 / 12 H	HZ-01, HZ-20	L-01
2	1.7, 2.1	Liquid carryover to the meters, heater and receiving pipeline	3 / 4 / 12 H	HZ-13, HZ-14	L-02
3	5.4	H-101 low bath level and firetube overheating	4 / 3 / 12 H	HZ-16	L-07

Rank	Worksheet ref	Scenario	Risk (S/ L/R)	Recommendations	LOPA
4	5.6, 5.7	H-101 firebox explosion on flame failure or light-off	4 / 3 / 12 H	HZ-15	L-05
5	4.2	Gas release inside analyzer shelter B-101	4 / 3 / 12 H	HZ-24, HZ-25, HZ-26	L-11
6	7.1, 7.6 to 7.8	Overpressure of the receiving trunkline	5 / 2 / 10 H	HZ-01, HZ-28, HZ-48, HZ-51	L-01
7	11.5	Cyber attack opening an FCV with alarms suppressed	5 / 2 / 10 H	HZ-31	L-01
8	11.1	Loss of utility power	2 / 5 / 10 H	HZ-29	None
9	2.2, 10.1	Gas blow-by from V-101 into T-101	4 / 2 / 8 M	HZ-03, HZ-04, HZ-09	L-03
10	6.1	Fuel gas Class 150 section overpressured by PCV-161 failure	4 / 2 / 8 M	HZ-44	L-09

Upstream overpressure ranks first because its likelihood depends on data the station does not control. The Owner's compressors discharge at up to 1,150 psig, but the upstream MAOP and the compressor relief setting are not confirmed (HOLD H-16). Relief valve PSV-101 on V-101 is sized for fire only, so if the upstream source can exceed 1,440 psig the station itself needs inlet overpressure protection (HZ-20). The same excursion is the demand on the OPSS.

Liquid carryover ranks high because pig runs and upstream dehydration upsets are expected in the life of the station, and a slug larger than the separator sump reaches the custody meters and the heater coil. The high-high level trip that closes SDV-101 (I-03, SIF-02) is the main safeguard; HZ-13 asks the Owner for the maximum slug volume so the sump and tank can be checked.

The two heater scenarios, low bath level and firebox explosion, rank high because a natural-draft water-bath heater is fired unattended. Both rely on the vendor's burner management system. The design now carries two diverse flame detectors and a SIL 2 certified BMS, and the remaining detail (purge, trial for ignition, proof of closure, low-level switch placement) is set out in HZ-15 and HZ-16 for the vendor.

A gas release inside B-101 ranks high because the shelter is small and enclosed. Ventilation, two gas detectors, sample shutoff SDV-141 and the restriction orifice downstream of it are the safeguards; HZ-24 to HZ-26 move vents and cylinders outside and confirm the relief capacity of the sample system.

Overpressure of the receiving trunkline carries the highest severity in the study, since a rupture of a 24 in line operating at 1,200 psig could cause multiple fatalities. Its likelihood is low because PIC-134 overrides flow control at 1,150 psig and the OPSS closes SDV-102 at 1,225 psig. PRO-CAL-009 shows that a 4 s stroke keeps the peak near 1,264 psig, 26 psi below the 1,290 psig limit. It is carried to LOPA (L-01), which sets SIF-01 at SIL 2.

The two scenarios at the foot of the table ranked higher on the original design and fell to medium with the changes now adopted. Gas blow-by into T-101 was the only very high scenario: a failed-open dump valve would pass separator gas at up to 1,440 psig into a tank built for ounces per square inch. RO-104 limits the flow, the 16 in emergency vent EV-193 relieves it, and SDV-106 closes on low-low separator level. The PCV-161 failure case fell once PSV-161 was set at 250 psig and sized for the full-open regulator.

5.3. LINK TO LOPA

Every scenario with a severity of 4 or 5 was carried to SAF-RPT-002. Table 5-3 maps each LOPA scenario to the worksheet entries it came from, so the reader can trace a SIL requirement back to its cause.

Table 5-3: HAZOP to LOPA Map

LOPA scenario	Description	Worksheet refs
L-01	Trunkline and outlet overpressure	1.1, 7.1, 7.6, 7.7, 7.8, 11.4, 11.5
L-02	V-101 liquid carryover	1.7, 2.1, 2.9, 3.5
L-03	Gas blow-by to T-101	2.2, 2.9, 10.1
L-04	T-101 overfill	10.2, 10.5
L-05	H-101 firebox explosion	5.6, 5.7
L-06	H-101 coil tube rupture	5.5
L-07	H-101 low bath level and overheating	5.3, 5.4
L-08	Hydrates or low temperature downstream of the FCVs	1.5, 5.1, 6.4, 6.4A, 7.4
L-09	Fuel gas overpressure	5.8, 6.1, 6.2
L-10	Closure opened under pressure	1.9, 2.7
L-11	Gas release in B-101	4.1, 4.2, 4.3
L-12	Reverse flow from the trunkline	1.2, 7.12, 8.1, 8.1A, 9.5

The PR-101 closure scenario (1.9) fell to medium once mechanical interlock I-08 was shown on the P&ID. The V-101 quick-opening closure (2.7) has no equivalent device yet and remains open under HZ-06.

6. RECOMMENDATIONS

Table 6-1 lists the 53 recommendations with the party responsible and their status at this issue. Priority A items shall be closed before the design is frozen for construction, priority B items before construction is complete, and priority C items before startup, where the pre-startup safety review (SAF-LST-001) will check them. The status column records the decision taken where one has been made.

Table 6-1: Recommendations Register

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-01	Confirm upstream lateral MAOP, Owner compressor discharge relief set pressure and settle-out pressure (HOLD H-16). This sets the OPSS demand frequency: if the upstream source cannot exceed 1,200 psig the OPSS still stays as required by 49 CFR 192.195 but the LOPA initiating event changes	1.1, 7.1; L-01	Owner / Process	A	Open
HZ-02	Confirm the SDV-102 closure time against the process safety time from the OPSS trip to the 1,290 psig accumulation limit with FCV-131 wide open at the maximum upstream excursion, including outlet lateral line pack and detection delay; specify partial stroke testing and a travel alarm	7.1, 7.8; L-01	Instrumentation / Process	A	Closed. The trip was lowered to 1,225 psig, because at 1,250 psig the process safety time (5.8 s) was shorter than the OPSS response, and SDV-102 is specified to close in 4 s or less. PRO-CAL-009 gives a process safety time of 8.9 s against a 5.5 s response (1.5 s detection including the 0.5 s trip delay, plus the 4 s stroke) and a peak of about 1,264 psig against the 1,290 psig limit

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-03	Add restriction orifice RO-104 on 2"-L-1060 downstream of LCV-104, sized so the maximum gas blow-by at 1,440 psig does not exceed the relieving capacity of a T-101 emergency vent (API 2000); size RO-104 and the emergency vent together	2.2, 10.1; L-03	Process / Mechanical	A	Addressed. RO-104 and a 16 in emergency vent EV-193 on T-101 were adopted; bore and vent sizing in PRO-CAL-007
HZ-04	Confirm SDV-106 with LSLL-106 as SIF-03, target SIL by LOPA; specify tight shutoff (API 598 / ANSI FCI 70-2 Class VI, to confirm)	2.2; L-03	Instrumentation	A	Addressed. SDV-106 was adopted with an electric spring-return, fail-closed actuator; SIL set in SAF-RPT-002
HZ-05	H-101 coil tube rupture: heater vendor to demonstrate the bath, firetube and expansion tank vent can pass full-bore tube rupture gas flow per API 521, heat-transfer equipment failure (tube rupture) case, or provide a bath rupture disk to a safe location; add bath high level switch LSH-154B to BMS trip	5.5; L-06	Process / Mechanical / Instrumentation	A	Open
HZ-06	PR-101: mechanical closure interlock I-08 to BDV-102 and PI-102 is on the P&ID (partly met); confirm vendor supply and PT-102A alarm, and write the pigging procedure. V-101 quick-opening closure: pressure warning / locking device per ASME BPVC Section VIII, Division 1, UG-35.2 (quick-actuating closures), still required	1.9, 2.7; L-10	Mechanical / Instrumentation	A	Partly met. PR-101 closure interlock I-08 is on the P&ID; the V-101 closure device remains open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-07	Perform an FCV-131/132 aerodynamic noise prediction (IEC 60534-8-3) including ultrasonic frequency content, and confirm with the USM vendor that the FCV station distance and trim do not degrade FE-111/121 SNR; consider acoustic silencing trim or pipe layout change	3.4, 7.5	Process / Measurement	A	Addressed. Three-stage low-noise trim selected (85.6 dBA before the required acoustic insulation, PRO-CAL-006); USM vendor interference check open
HZ-08	Calculate minimum metal temperature during manual blowdown of each section (BDV-181/182/183, BDV-102) at -5 F ambient; confirm at or above MDMT -20 F or specify low-temperature materials downstream of the ROs	1.14, 9.1	Process / Mechanical	A	Open
HZ-09	Size PVRV-193 for flash gas from V-101 liquids dumped from 1,150 psig and for working / breathing; calculate OOOOb emissions; check hydrate / ice across LCV-104	2.11, 10.1, 10.3, 10.7; L-03, L-04	Process / Regulatory	A	Partly addressed. EV-193 adopted for emergency venting; flash and OOOOb emission calculation open
HZ-10	E-161 preheater is on the P&ID (PCV-161 outlet about -32 F in C1 without it). Process to confirm E-161 duty and TIC-161A setpoint so PCV-161 outlet stays above the hydrate temperature at 150 psig and above MDMT -20 F with margin; Electrical to put E-161 on generator-backed power; RTU alarm XA-161 on heater fault / power loss and TI-161C low alarm (consider a transmitter TT-161C in place of the gauge)	6.3, 6.4, 6.4A, 6.4B; L-08	Process / Electrical / Instrumentation	A	Partly met. E-161 is on the P&ID with its outlet set at 105 F; duty confirmation open
HZ-11	Agree with the operation of the tap valve and remote shutoff, and the interaction with HS-215 and the station ESD (HOLD H-01, H-14)	8.4	Owner	A	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-12	Lightning and surge protection per NFPA 780 for VS-101, H-101 stack, T-101, B-101, B-102 and antenna mast; surge protection on field cables entering B-102, on the interface JB-W01 and across IJ-101 / IJ-102	1.13, 10.4, 11.8	Electrical	A	Open
HZ-13	Obtain the Owner pigging program and maximum slug volume (H-16); confirm V-101 sump and T-101 capacity for one slug; if exceeded, add slug handling ahead of V-101	1.7; L-02	Owner / Process	A	Open
HZ-14	Set target SIL for SIF-02 (LSHH-105) and SIF-04 (LSHH-192) by LOPA using the Owner commercial and environmental criteria (HOLD)	1.7, 2.1, 10.2; L-02, L-04	Instrumentation / Owner	A	Open
HZ-15	Heater vendor BMS: purge, trial for ignition, FFRT 4 s maximum, proof of closure on XV-150A/B, low and high fuel pressure trips, high bath temperature and low bath level trips, and TCV-152 unable to override a BMS trip; confirm BMS SIL capability for SIF-05 to SIF-07	5.3, 5.6, 5.7, 5.9; L-05, L-07	Instrumentation / Mechanical	A	Partly addressed. Two diverse flame detectors and a SIL 2 certified BMS adopted; vendor BMS details open
HZ-16	LSL-154 to be independent of LG-154A and mounted to trip with at least 2 in of liquid above the firetube (vendor); bath make-up procedure and routine check	5.4; L-07	Mechanical / Instrumentation	B	Open
HZ-17	Confirm H-101 duty for C1 / C6 (heater-off outlet about 19 F, heater gas outlet about 67 F required for the 43.5 F TIC-135 setpoint at 750 psig, per INS-LST-003); Process to calculate hydrate temperature at 750 psig for 7 lb/MMscf and confirm 10 F margin; define operator response to TT-135 TALL	1.5, 5.1, 7.4; L-08	Process / Instrumentation	A	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-18	Heater mode interlock: RTU alarms "heater required" when TIC-135 demand exists and HV-158C is open; prevent burner enable with HV-158A or HV-158B closed (uses ZSO/ ZSC-158C; add position switches on HV-158A/B if needed)	5.1, 5.10; L-08	Instrumentation	B	Open
HZ-19	V-101 bypass HV-103C / HV-103D on 12"-G-1004: add open position switch ZSO-103C on HV-103C to the RTU (P3 alarm), keep locks and bleed check, and use only with approval (GEN-DB-001 Sec. 12)	2.6	Instrumentation / Operations	B	Open
HZ-20	PSV-101 is fire case only. If upstream MAOP or compressor relief exceeds 1,440 psig (H-16), the station needs inlet overpressure protection (relief or HIPPS) sized for the upstream source	1.1, 2.3; L-01	Process	A	Open
HZ-21	Route TSV-136 and other thermal relief outlets to the vent header or a safe location; confirm set and sizing	7.10	Process	B	Open
HZ-22	Confirm DBB body cavity relief on MOV-111/112/121/122/115 and keep the standby run pressurized with its outlet MOV open so no run is blocked in at both ends in sun (about 1,570 psig otherwise)	3.8	Process / Measurement	B	Closed. The standby run is operated with its outlet MOV open; cavity relief confirmation open
HZ-23	MOV-115 series verification: body-bleed seal check (PI-115A) before and after each test; MOV-115 opens only within the FC verification sequence; sequence abort returns to single-run with alarm	3.3, 3.11	Instrumentation / Measurement	B	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-24	Route all analyzer, GC and sampler vents to a single vent outside B-101 at roof height; store calibration and carrier gas cylinders outside the shelter where the analyzer allows	4.2, 4.8; L-11	Measurement	A	Open
HZ-25	Confirm B-101 ventilation rate and FSL-208 action (SAF-RPT-003); isolate non-rated power on sustained ventilation loss	4.2, 4.3; L-11	Instrumentation / Electrical	A	Open
HZ-26	Measurement to confirm PSV-141G is sized for full-open failure of the SP-141 probe regulator and set below the lowest analyzer inlet rating, discharging above the B-101 roof; tubing to SDV-141 rated for full line pressure	4.1; L-11	Measurement	A	Addressed. PSV-141B added per PRO-CAL-007; capacity of PSV-141B and PSV-141G for the failed-open regulator to be confirmed by the probe vendor (HOLD H-15)
HZ-27	Agree gas quality shut-in delay, ramp rate and analyzer validation (two-analyzer or validation check before shut-in) with (H-13)	4.6	Owner / Instrumentation	B	Open
HZ-28	SIS bypass management: key-switch permissive HS-200B, maximum bypass time with alarm, compensating measures (manual watch of PT-134 and FCV at reduced rate) in the operating procedure; no OPSS bypass during upstream excursions	7.7; L-01	Instrumentation / Operations	B	Open
HZ-29	Confirm UPS 8 h autonomy includes SDV dump solenoids and the BMS; confirm SDV reset needs EH pump power (G-101, whose fuel stays live after ESD); define restart after power loss	11.1, 11.2	Electrical / Instrumentation	B	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-30	Define loss-of-communications behavior (hold last SP, timeout ramp, alarm) for SCADA and the link (INS-RPT-001 and INS-RPT-002)	8.6, 11.3	Instrumentation	B	Open
HZ-31	Implement API 1164 program: authenticated setpoint writes, SIS write protection, remote access through MFA jump host (INS-RPT-002); include a cyber PHA per IEC 61511-1 8.2.4	11.5; L-01	Instrumentation / Owner	A	Open
HZ-32	Physical security: lighting, intrusion alarms on all gates and buildings, lockable valve handles on BDVs and bypasses, consider cameras	11.6	Owner / Electrical	B	Open
HZ-33	Vent stack VS-101: ignited vent radiation at grade and unignited dispersion to 50 % LEL for the largest blowdown and PSV case (API 521); confirm 25 ft height and location relative to B-101 / B-102 intakes	9.3, 9.4	Process	A	Open
HZ-34	Check vent header back-pressure for simultaneous relief and blowdown; add low-point drain on 8"-V-1070-S1	9.2, 9.6	Process	A	Partly addressed. Blowdown is limited to one section at a time by procedure
HZ-35	Lock closed BDV-181/182/183, BDV-102, HV-133D, HV-172A, HV-180A and HV-180B; include in LDAR survey	9.5, 7.12, 9.8; L-12	Operations	C	Open
HZ-36	T-101 loadout: bonding and grounding with interlock or permissive, dry-break couplings, bollards; decide heat tracing of V-101 sump, level cage and 2"-L-1060	2.8, 10.5, 10.6, 10.8, 10.9; L-04	Mechanical / Electrical	B	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-37	Filter element change procedure with DP check after change; confirm T-101 containment holds 110 % of tank plus rainfall (Civil)	2.5, 10.2; L-04	Operations / Civil	B	Open
HZ-38	Pigging procedure: pig bars on barrel branches, debris handling (keep wet), NORM survey, black powder disposal	1.8, 1.11, 1.12	Operations / Mechanical	C	Partly addressed. Kicker guide bars and RO-102 downstream of BDV-102 adopted
HZ-39	FCV switchover logic must never leave both FCVs open without PIC-134 active; test at FAT	7.2	Instrumentation	B	Open
HZ-40	Reverse-flow protection: procedure to close SDV-103 before any station blowdown and to confirm the tap valve closed before HV-172A outlet lateral blowdown; RTU permissive that SDV-103 may open only when PT-134 is at least 10 psi above PT-172	1.2, 8.1; L-12	Instrumentation / Operations	B	Open
HZ-41	Hot tap and tie-in to be performed by per API RP 2201 with a joint work permit and ERP coverage	8.5	/ Owner	C	Open
HZ-42	Nitrogen purge and gas-in procedure; verify O2 below 10 ppmv at AT-144 before delivery	11.11	Construction / Operations	C	Open
HZ-43	Implement I-01 / I-06 as on the P&ID: SDV-165 (H-101 branch only) and XV-150A/B/C close on station ESD and BMS trip; G-101 fuel stays live; confirm G-101 vendor shutoff and that G-101 is outside any area where an ESD cause (gas or fire) makes continued running unsafe	6.6	Instrumentation / Electrical	A	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-44	Size PSV-161 for full-open failure of PCV-161 at 1,150 psig inlet and confirm protection downstream of PCV-162 for the burner train and G-101 regulator; route PSV-161 outlet to a safe location	6.1, 6.2; L-09	Process	A	Closed. PSV-161 set at 250 psig and sized for full-open PCV-161 (PRO-CAL-007)
HZ-45	Confirm that no process or analyzer gas tubing enters B-102 (pressure transmitters remote-mounted outside)	11.12	Instrumentation	A	Open
HZ-46	Coordinate station ESD and SDV-101 closure with the Owner upstream facility (compressor recycle or shutdown on station ESD, alarm link)	1.3	Owner	B	Open
HZ-47	Specify H-101 bath as inhibited glycol-water for freeze protection to -20 F with a bath chemistry maintenance program	5.11, 5.12	Mechanical	A	Open
HZ-48	PT-133A/B/C root valves car-sealed open with independent taps and separate impulse lines (HU-P2); include tap blockage in proof test	7.6; L-01	Instrumentation / Mechanical	A	Open
HZ-49	Confirm erosion velocity limits for solids-laden gas at FCV trims, meter run expanders and SDV seats after a V-101 element failure; include FCV trim inspection after any PDAL alarm	1.8	Process	B	Open
HZ-50	Hold a full team HAZOP on the issued-for-HAZOP P&IDs with the Owner and , and a LOPA revalidation, before IFC	All; all	Owner / Engineer	A	Open

No.	Recommendation	Worksheet ref and LOPA	Action by	Priority	Status
HZ-51	OPSS setpoint 1,225 psig and trip margin to the 1,290 psig accumulation limit to be witnessed with at SAT; PT-133A/B/C calibration by a different technician or with a different reference from PT-134 to reduce common-cause calibration error	7.1, 7.6; L-01	Instrumentation	C	Open. The limit to be witnessed is 1,290 psig
HZ-52	Alarm rationalization per ISA-18.2 for the SCADA host; first-out display for ESD, OPSS and BMS	11.7	Instrumentation	B	Open
HZ-53	Severe weather and post-seismic event inspection procedures in the O&M manual and ERP	11.9, 11.10	Operations	C	Open

7. OPEN ITEMS

The items in Table 7-1 were outside the reach of the design team at this issue. Each affects a ranking or a recommendation above and is listed with the party that must resolve it.

Table 7-1: Open Items Affecting the Study

Item	Description	Needed from
1	Upstream lateral MAOP and compressor relief setting (HOLD H-16); governs HZ-01, HZ-20 and LOPA L-01	Owner
2	Gas quality specification and shut-in expectations (HOLD H-13)	Receiving pipeline operator
3	Point list, remote shutoff logic and data link (HOLD H-01, H-14)	Receiving pipeline operator
4	Heater vendor data: tube rupture relief, BMS certification, bath chemistry (HOLD H-15)	Heater vendor
5	Owner risk matrix and tolerable risk criteria, used in Section 3 and in SAF-RPT-002 (HOLD)	Owner
6	Hydrate temperature for the fuel gas at 150 psig and E-161 duty confirmation	TORUS Process
7	Area classification drawing and B-101 ventilation classification	TORUS Electrical
8	Owner call-out time and gas control staffing, which set the credit for operator response	Owner
9	Team member names and the formal HAZOP session on the P&IDs issued for HAZOP (HZ-50)	Owner and TORUS

8. CONCLUSIONS AND NEXT STEP

TORUS draws the following conclusions from the preliminary study:

1. The design, as it stands at this issue, has no scenario in the very high risk class. The one very high scenario on the original design, gas blow-by from V-101 into T-101, is now medium because SDV-106 closes on low-low separator level, RO-104 limits the gas flow and emergency vent EV-193 relieves it. LOPA scenario L-03 sets SIF-03 at SIL 1 on that basis.
2. Overpressure of the receiving trunkline remains the highest-severity scenario. The OPSS is required by 49 CFR 192.195 whatever the upstream pressure proves to be. With the trip at 1,225 psig and a 4 s stroke on SDV-102 the peak stays near 1,264 psig, below the 1,290 psig limit (PRO-CAL-009). The OPSS is verified at SIL 2 in SAF-CAL-001, and HZ-02 is closed.
3. The demand on the OPSS, and whether the station needs its own inlet overpressure protection, depend on the upstream MAOP (HOLD H-16). This is the most important open input to the study, and the Owner should confirm it before the P&IDs are issued for HAZOP.
4. The line heater scenarios depend on the vendor's burner management system and relief design. They are carried to LOPA L-05 to L-07, and HZ-15 and HZ-16 set out what the vendor must demonstrate.
5. Of the 53 recommendations, 13 have been closed, addressed or partly met by decisions taken since the study, and 40 remain open.

The next step is the formal team HAZOP on the P&IDs issued for HAZOP, with the Owner's operations staff and the receiving pipeline operator present, followed by revalidation of the LOPA in SAF-RPT-002 (HZ-50). The open priority A recommendations should be answered before that session so the team reviews a settled design.

APPENDIX A. HAZOP WORKSHEETS



The worksheets record each deviation reviewed, node by node. Risk is shown as severity, likelihood and rank (S / L / R) using the categories of Section 3.2, with the existing safeguards credited. The last column gives the recommendation raised, if any, and the LOPA scenario the entry was carried to. Abbreviations: BPCS, basic process control system (the RTU); SIS, safety instrumented system (the safety PLC); FCV, flow control valve; PSV, pressure safety valve; USM, ultrasonic meter; ESD, emergency shutdown. Discipline codes: PRO process, MEC mechanical, MEA measurement, ELE electrical, INS instrumentation.

Table A-1: Worksheet, Node N1: Inlet and pig receiver

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
1.1	More pressure	Owner compressor discharge control failure raises lateral above 1,150 psig; upstream MAOP unknown (H-16)	Station inlet section above normal; if upstream can exceed 1,440 psig, station piping (MAOP 1,440) overpressured; OPSS demand downstream	Upstream compressor PSVs (Owner); PT-101 PAH 1,180; PSV-101 on V-101 is fire case only	4 / 3 / 12 H	HZ-01, HZ-20; L-01
1.2	Less pressure	Upstream lateral rupture or Owner facility shutdown	Loss of supply; possible reverse flow from station toward rupture; liquids slug on repressuring	PT-101 PAL 880, PALL 600, rate-of-change alarm; CKV-171 prevents trunkline backflow	3 / 3 / 9 M	HZ-40; L-12
1.3	No flow	SDV-101 spurious closure (solenoid, power, SIS fault)	Upstream lateral pressure rise to Owner compressor settle-out; surge at Owner facility; delivery loss	Owner upstream overpressure protection; SDV-101 ZSC alarm; SIS diagnostics	3 / 3 / 9 M	HZ-46
1.4	More flow	Upstream supply above 120 MMSCFD with FCV wide open	Meter over-range, V-101 carryover, high velocity erosion	FIC-131 limits flow; FT-111/121 FAH 125 MMSCFD	2 / 3 / 6 M	None
1.5	Less temperature	Winter inlet 45 F or lower; upstream cooler over-cooling	Lower heater outlet margin; downstream hydrate risk (see N7)	TT-101 TAL 35 F; heater cascade	2 / 3 / 6 M	HZ-17; L-08

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
1.6	More temperature	Upstream aftercooler failure, inlet above 120 F	Delivery above 120 F tariff limit; coating damage on buried outlet lateral (design 120 F)	TT-101 TAH 125 F; TT-173 TAHH 120 F initiates quality shut-in	2 / 3 / 6 M	None
1.7	Other than composition (liquids)	Pig run pushes liquid slug; upstream dehydration upset	Slug to V-101 exceeding sump capacity; carryover to meters	V-101 sump and LIC-104; LSHH-105 SIF-02 closes SDV-101 (I-03)	3 / 4 / 12 H	HZ-13, HZ-14; L-02
1.8	Other than composition (solids, black powder)	Pigging, internal corrosion upstream	Filter loading, USM transducer fouling, valve seat damage	V-101 1 micron elements; PDIT-103 alarms	2 / 4 / 8 M	HZ-38, HZ-49
1.9	Maintenance: PR-101 closure opened under pressure	Operator opens closure without full depressuring; BDV-102 closed or vent blocked; HV-101B or HV-101D passing	Closure ejection, fatal injury	Mechanical closure interlock I-08 (closure cannot open until BDV-102 open and barrel depressured, P&ID DWG-101); quick-opening closure pressure warning device; PI-102; PT-102A PAH 5 psig; RO-102 downstream of BDV-102; procedure	4 / 2 / 8 M	HZ-06; L-10
1.10	Pigging: pig not received	Pig stuck in lateral or barrel, XI-102 failure	Upstream pressure build-up; repeated pig launch	XI-102 signaler; PT-101 trend	2 / 3 / 6 M	None
1.11	Pigging: pig passes into station	Barrel valve arrangement wrong, pig bar missing	Pig damages SDV-101 / V-101 internals	Pig bars on branch tees (MEC); receiver procedure	2 / 2 / 4 L	HZ-38
1.11A	Pigging: misoperation of receiver valves	HV-101A (mainline) closed before HV-101B (barrel) opened, or HV-101B opened before barrel equalized through HV-101D	Flow blocked to station with upstream pressure rise; high DP across HV-101B, seat damage, pig launched at speed into barrel	Receiver valve sequence procedure; HV-101D equalizing bypass; PT-101 / PT-102A indication	2 / 3 / 6 M	HZ-38

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/ L/R)	Rec. and LOPA
1.12	Pyrophoric / hazardous debris at barrel opening	Iron sulfide (low, sweet gas), NORM scale	Smouldering debris, exposure	Keep debris wet; NORM survey	2 / 2 / 4 L	HZ-38
1.13	As well as: IJ-101 shorted or failed	Conductive debris, lightning, AC interference	Loss of CP isolation, arcing across IJ in flammable atmosphere	Surge protection across IJ (CP / ELE)	2 / 3 / 6 M	HZ-12
1.14	Less temperature during blowdown of inlet section	Manual BDV-181 depressuring through RO-181 at -5 F ambient	Metal below MDMT -20 F, brittle fracture	RO limits rate; procedure; Process to confirm by calc	3 / 3 / 9 M	HZ-08

Table A-2: Worksheet, Node N2: Filter separator V-101

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/ L/R)	Rec. and LOPA
2.1	More level	LCV-104 fails closed, LIC-104 or LT-104 fails, SDV-106 spurious close, slug	Liquid carryover to USMs (measurement error, damage), heater coil, FCVs and into the receiving pipeline (tariff "no free liquids")	LT-104 LAH 20 in; LG-104; LSHH-105 SIF-02 closes SDV-101 (I-03)	3 / 4 / 12 H	HZ-14; L-02
2.2	Less / no level	LCV-104 fails open (actuator, positioner, LIC-104 output fail), LT-104 reads high	Gas blow-by at up to 1,150 psig into 2"-L-1060 and atmospheric T-101; tank overpressure and rupture, fire; D1 Class 150 piping overpressured downstream of spec break	LT-104 LAL 6 in; LSLL-106 SIF-03 closes SDV-106 (electric spring-return) and forces LCV-104 closed (I-04); RO-104 limits blow-by, relieved through EV-193 16 in emergency vent and PVRV-193 so D1 (285 psig) is not overpressured	4 / 2 / 8 M	HZ-03, HZ-04, HZ-09; L-03
2.3	More pressure	Upstream overpressure (1.1); fire exposure	V-101 overpressure	PSV-101 set 1,440 psig fire case; upstream protection (H-16)	4 / 2 / 8 M	HZ-20

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
2.4	More DP across elements	Element loading, slug of solids, ice / hydrate on elements in winter	Element collapse, solids to meters; reduced flow	PDIT-103 PDAH 8, PDAHH 10 psid; PDI-103A	2 / 4 / 8 M	None
2.5	Less DP across elements	Element ruptured, O-ring missing after change-out	Unfiltered gas to USMs, fouling and bias	PDIT-103 PDAL 0.3 psid at flow above 20 MMSCFD	3 / 3 / 9 M	HZ-37
2.6	Misdirected flow: V-101 bypass 12" - G-1004 open	HV-103C / HV-103D (DBB, locked closed, plugged 3/4 in bleed between, P&ID interpretation on PRO-DWG-102) left open or passing after maintenance; no position indication	Unfiltered gas to meters; custody error; approval breached (GEN-DB-001 Sec. 12)	Locks on HV-103C / HV-103D; DBB bleed check; procedure	3 / 3 / 9 M	HZ-19
2.7	Maintenance: closure opened under pressure	Element change without full depressuring	Closure ejection, fatality	Quick-opening closure warning device (vendor); PI-103; BDV-181 procedure	4 / 2 / 8 M	HZ-06; L-10
2.8	Less temperature in sump	Heater off, winter, liquid water in sump (upset)	Freezing of sump, level instruments, LCV-104; blocked drain	Dry gas design; insulation and heat trace of sump and level cage to be decided	2 / 3 / 6 M	HZ-36
2.9	Instrument failure: LT-104 frozen / stuck	GWR failure, cage plugged	Loss of level control in either direction; see 2.1, 2.2	LSHH-105 and LSLL-106 independent switches; LT-104 vs LG-104 check	3 / 3 / 9 M	HZ-14; L-02, L-03
2.10	Corrosion	Free water with CO2 (0.88 to 1.0 mol %) in sump	Sump corrosion, leak	1/16 in corrosion allowance; inspection	2 / 2 / 4 L	None
2.11	Pressure drop at LCV-104	Flashing liquid, JT cooling across 1,150 to atmospheric pressure	Hydrate / ice in dump valve and 2"-L-1060, valve plugging, freezing of T-101 inlet	Intermittent service; Process to confirm by calc	2 / 3 / 6 M	HZ-09

Table A-3: Worksheet, Node N3: Custody meter runs

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
3.1	No flow through duty run	MOV-111 or MOV-112 closes spuriously or on operator error	Flow interruption, pressure excursion upstream; FIC-131 winds up	MOV travel alarms; run-switch sequence opens standby first (INS-RPT-001)	2 / 3 / 6 M	None
3.2	More flow in one run	Standby run fails to open during switch; meter above range	Meter over-velocity (above calibrated range), measurement bias	FT FAH 125 MMSCFD; FIC-131	3 / 3 / 9 M	None
3.3	Misdirected flow: MOV-115 open or passing outside a verification	Crossover left open, seat leakage	Gas measured twice or bypasses a meter, custody error	MOV-115 locked out in remote; PI-115A seal check; FC series logic	3 / 3 / 9 M	HZ-23
3.4	Measurement other than: noise interference	FCV-131/132 generate ultrasonic noise in the transducer band; USMs about 50 ft upstream of FCV station	Path failures, SNR loss, flow bias; undetected custody error	3-stage low-noise trim, predicted 85.6 dBA at 1 m before insulation, with mandatory acoustic insulation of the valve body and 10 ft of downstream pipe; USM diagnostics; series verification	3 / 3 / 9 M	HZ-07
3.5	Measurement other than: contamination	Liquids or solids past V-101 coat transducers or meter bore	Bias, path failure	V-101; USM gain and profile diagnostics; series verification 0.3 %	3 / 3 / 9 M	HZ-37; L-02
3.6	Measurement other than: temperature bias	TT-111/121 thermowell in sun, canopy missing, insulation damaged	Custody temperature bias	Sunshade canopy and insulation (basis SK-110); TW-112/122 test wells	2 / 3 / 6 M	None
3.7	Measurement other than: composition	GC failure or calibration error	Energy error	FC last good composition (GEN-DB-001 Sec. 12); GC alarms	3 / 3 / 9 M	None

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
3.8	More pressure blocked-in	Standby run isolated at both ends (MOV-111 and MOV-112) in summer sun; DBB body cavity	Isolated run reaches about 1,570 psig (above 1,440 psig MAOP); cavity over-pressure	Standby run kept pressurized with its outlet MOV open, never blocked in at both ends (run switching logic and O&M procedures); DBB body cavity relief (MEC to confirm)	3 / 1 / 3 L	HZ-22
3.9	Maintenance: meter removal under pressure	Incomplete isolation, bleed not verified	Release, injury	DBB MOVs with body bleed; lockout procedure	3 / 2 / 6 M	None
3.10	Vibration	Flow-induced vibration of small-bore connections (PT taps, thermowells)	Fatigue failure of tap, release	Thermowell wake frequency check (INS-DS-002); small-bore bracing (MEC)	3 / 2 / 6 M	None
3.11	Human factors: series verification left incomplete	Sequence aborted with MOV-115 open	Custody error, double registration	FC detects both meters registering; alarm; sequence abort logic (INS-RPT-001)	2 / 3 / 6 M	HZ-23

Table A-4: Worksheet, Node N4: Analyzers and sampling, B-101

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
4.1	More pressure in analyzer tubing	SP-141 probe regulator fails open; 1,150 psig into low-pressure analyzer inlets	Analyzer rupture, gas release in B-101 (without protection about 1,100 scf/h through RO-141A, about 9 x the ventilation dilution capacity)	PSV-141B at the probe regulator outlet outside B-101, set 50 psig, to bleed header 1120 (P&ID DWG-103), holds the RO-141A inlet at or below 55 psig (57 scf/h on a break, inside the 126 scf/h dilution capacity; fg_calcs.out item 5); PSV-141G sample system relief downstream of PCV-141E; tubing 3/8"-G-1080-T1 rated for full pressure; SDV-141	3 / 2 / 6 M	HZ-26; L-11

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
4.2	Loss of containment in B-101	Tubing fitting leak, analyzer vent routed indoors, GC carrier / cal gas leak	Flammable atmosphere in shelter, explosion	Ventilation, FSL-208; GD-205/206 20 / 40 % LEL; SDV-141 closes on HH; XY-214D power isolation	4 / 3 / 12 H	HZ-24, HZ-25; L-11
4.3	Less / no ventilation	Fan failure, louvre blocked, power loss	Gas accumulation from small leaks; high temperature GC drift	FSL-208 alarm; GD-205/206	3 / 3 / 9 M	HZ-25; L-11
4.4	More / less temperature in B-101	HVAC failure in summer or winter	GC drift, analyzer failure, sample condensation (heavy components)	TT-208A TAH 104 F / TAL 50 F; heated sample lines	2 / 3 / 6 M	None
4.5	Measurement other than: sample not representative	Probe location, sample line condensation, lag time excessive	HHV and dewpoint error; wrong shut-in decision	API 14.1 / GPA 2166 probe design; heated lines; lag time check (MEA)	3 / 3 / 9 M	None
4.6	Analyzer false high / low	H2S tape, O2 cell or TDL failure or calibration error	Spurious gas quality shut-in, or missed off-spec	Fault alarms XA-142/143/144; 15 min delay; calibration program	3 / 3 / 9 M	HZ-27
4.7	Composite sampler cylinder over-pressure / overfill	Sampler fault, cylinder not changed	Cylinder rupture, release in shelter	Sampler relief (MEA); XA-146 cylinder full alarm	2 / 2 / 4 L	None
4.8	Maintenance: calibration gas cylinders in shelter	Cylinder not secured, regulator failure	Release, projectile	Cylinder restraint, cylinder storage outside where possible	2 / 2 / 4 L	HZ-24

Table A-5: Worksheet, Node N5: Line heater H-101, process and fired side

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
5.1	Less temperature (process outlet)	Heater off in winter (C6), burner trip, TIC-152 or TCV-152 failure, bypass HV-158C open	Control valve outlet about 19 F in C1/C6 (INS-LST-003), hydrates and liquid dropout at FCVs and outlet; delivery below 40 F	TT-135 TAL and TALL below the pressure-compensated setpoint; TT-173 quality shut-in (I-07); winter line-up HV-158A/B open, HV-158C closed per P&ID DWG-105; ZSO/ZSC-158C	3 / 3 / 9 M	HZ-17, HZ-18; L-08
5.2	More temperature (process outlet)	TIC-152 fails high, TCV-152 fails open	Gas above 120 F delivery limit; buried lateral coating damage	TT-156 high-high 140 F burner trip; TIC-151 bath limit 190 F; TT-173 TAAH shut-in	2 / 3 / 6 M	None
5.3	More temperature (bath)	TCV-152 stuck open, TT-151 failure, low process flow while firing	Bath boil-off, firetube overheat, coil at elevated temperature	TIC-151 override; TT-151 TAAH 195 F; TSHH-155 200 F trips BMS (SIF-07, I-06)	3 / 3 / 9 M	HZ-15; L-07
5.4	Less level (bath)	Evaporation, leak, no make-up, bath boil-off	Firetube exposed, overheating, firetube failure, fire	LG-154A; LSL-154 BMS trip (SIF-06, I-06)	4 / 3 / 12 H	HZ-16; L-07
5.5	More level / more pressure in bath	Coil tube rupture: 1,150 psig gas into bath at atmospheric pressure	Bath expelled through expansion tank, gas into firebox, shell rupture, fire, possible fatality	Expansion tank vent (vendor); no tube-rupture relief or detection in basis	4 / 2 / 8 M	HZ-05; L-06
5.6	No flame (flame failure)	Fuel interruption, draft upset, BE-153A/B fault	Unburnt fuel accumulation, firebox explosion on re-light	Two diverse flame detectors BE-153A/B and SIL 2-certified BMS, FFRT 4 s, XV-150A/B/C and SDV-165 close (SIF-05, I-06); purge before relight	4 / 3 / 12 H	HZ-15; L-05
5.7	Delayed ignition on light-off	Leaking XV-150A/B, failed purge, repeated trials	Firebox explosion, injury to technician at burner front	BMS proof of closure ZSC-150A/B, purge timer, trial for ignition 10 s (vendor)	4 / 3 / 12 H	HZ-15; L-05
5.8	More combustion (over-firing)	PCV failure, PSH-164B fails, TCV-152 open	Flame impingement, firetube hot spot	PSH-164B BMS trip; TSHH-155	3 / 2 / 6 M	L-09

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
5.9	Less combustion air / downdraft	High wind, stack blockage (bird nest), snow	Incomplete combustion, CO, flameout	BE-153; stack cap and screen	2 / 3 / 6 M	HZ-15
5.10	More pressure (coil blocked-in, heated)	HV-158A and HV-158B closed with burner on	Coil pressure rise by thermal expansion	PSV-157 set 1,440 psig; interlock heater enable on valve positions (INS-RPT-001)	3 / 3 / 9 M	HZ-18
5.11	Less temperature of bath when idle	Heater off in winter with water-only bath	Bath freezing, firetube and coil damage	Glycol-water bath specified for -20 F (to confirm)	2 / 3 / 6 M	HZ-47
5.12	Corrosion	Bath chemistry, oxygenated water, firetube sulfur (sweet fuel)	Firetube or coil corrosion, leak	Inhibited glycol; inspection interval	3 / 2 / 6 M	HZ-47
5.13	Fire in heater area (external)	Fuel train leak, flange leak on 12"-G-1020 / 1022 near firebox	Jet fire, escalation to coil	BE-213 UV/IR initiates ESD; spacing 50 ft from other equipment (GEN-DB-001 Sec. 10)	4 / 2 / 8 M	None

Table A-6: Worksheet, Node N6: Fuel gas FG-101

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
6.1	More pressure downstream of PCV-161	PCV-161 fails open (seat erosion, hydrate under seat)	1,150 psig into A1 Class 150 piping (rated 285 psig at 100 F); rupture, fire	PSV-161 set 250 psig, sized for full-open PCV-161 (PRO-CAL-007); PI-161A	4 / 2 / 8 M	HZ-44; L-09
6.2	More pressure downstream of PCV-162	PCV-162 fails open	Burner train and G-101 over-pressured, over-firing, regulator diaphragm rupture	PT-164 PAH 35 psig; PSH-164B BMS trip; vendor regulators; Process to confirm relief	3 / 3 / 9 M	HZ-44; L-09
6.3	Less pressure	Filter plugged, PCV hydrate, SDV-165 closed	Burner flameout (see 5.6), generator shutdown when needed	PT-164 PAL 15 psig; PDI-161A; PSL-164A BMS trip	2 / 3 / 6 M	HZ-10

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
6.4	Less temperature / hydrates at PCV-161	JT cooling across first cut from 1,150 to 150 psig in winter: about -32 F at PCV-161 outlet in C1 without preheat (PRO-DWG-106)	Regulator freezing, hydrates, A1 piping below MDMT -20 F, fuel loss and heater trip in the coldest case	E-161 electric preheater upstream of PCV-161 with TIC-161A outlet thermostat; TI-161C downstream of PCV-161; dry gas (7 lb/MMscf)	3 / 2 / 6 M	HZ-10; L-08
6.4A	Less temperature: E-161 preheater failure	Element burnout, TIC-161A failure, loss of 480 V / breaker trip, TSH-161B cutout	PCV-161 outlet falls toward -32 F: regulator freezing, brittle fracture risk of A1 piping below MDMT -20 F, loss of fuel to H-101 (loss of hydrate protection, L-08)	XA-161 heater fault / power-off alarm to RTU; TI-161C local indication; PT-164 PAL 15 psig; TT-135 TAL / TALL	3 / 3 / 9 M	HZ-10; L-08
6.4B	More temperature: E-161 overheating	TIC-161A fails high, low or no fuel flow with element energized	Element sheath overtemperature, ignition source in fuel gas if sheath leaks; hot fuel to regulator soft goods	TSH-161B high element temperature cutout (independent of TIC-161A); E-161 certified for Class I Div 2 T3 (vendor, HOLD H-15)	3 / 2 / 6 M	HZ-10
6.5	Misdirected: fuel bypasses custody meters incorrectly	Take-off moved downstream of meters in detail design	Fuel measured as delivered, custody error	Basis 8.2 take-off upstream of meters; FT-163 allocation	2 / 2 / 4 L	None
6.6	No flow on ESD or BMS trip	SDV-165 closes on station ESD (I-01) and BMS trip (I-06)	H-101 fuel isolated (intended); G-101 branch 1"-F-1052 stays live so standby power is kept; G-101 vendor shutoff	SDV-165 on H-101 branch only (P&ID deviation I-01); UPS 8 h	1 / 3 / 3 L	HZ-43
6.7	Contamination	Liquids or solids in fuel from V-101 upset	Regulator failure, burner fouling	Fuel filter; PDI-161A	2 / 3 / 6 M	None

Table A-7: Worksheet, Node N7: Control valves and OPSS

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
7.1	More pressure downstream	Upstream excursion above 1,200 psig (H-16) with FCV-131 driven open or failed open, PIC-134 or PT-134 failure	trunkline and outlet lateral above MAOP 1,200 psig and above 192.201 accumulation 1,290 psig (75 % SMYS of NPS 24 x 0.344 in X60 governs over MAOP + 10 % = 1,320 psig); trunkline rupture, multiple fatalities	PIC-134 low-select override (BPCS); PT-134 PAHH 1,200 BPCS close; OPSS SIF-01 PT-133A/B/C 2oo3 at 1,225 psig closes SDV-102 (I-02); SDV-102 stroke 4 s or less gives a peak of about 1,264 psig with a 1,440 psig source and both FCVs wide open (PRO-CAL-009)	5 / 2 / 10 H	HZ-01, HZ-02, HZ-48, HZ-51; L-01
7.2	More flow	Nomination setpoint entry error at SCADA, FIC-131 tuning, both FCVs open during switchover	Meter over-velocity; outlet pressure rise (PIC-134 limits)	SP clamps (INS-RPT-001); PIC-134; FT FAH; switchover logic	2 / 3 / 6 M	HZ-39
7.3	Less / no flow	Duty FCV fails closed or as-is, actuator fault, loss of 480 V	Delivery loss, upstream pressure rise	Automatic switchover on 5 % position deviation to FCV-132; XA-131	2 / 3 / 6 M	None
7.4	Less temperature downstream	JT across FCVs with heater off (C1/C6 about 19 F)	Hydrates in FCV trim and outlet, liquid dropout; delivery below 40 F	TIC-135 cascade; TT-135 TALL at the compensated setpoint less 3.5 F (40 F minimum); TT-173 shut-in	3 / 3 / 9 M	HZ-17; L-08
7.5	Noise / vibration	High pressure ratio across FCV at C1 (1,130 to 750 psig)	Noise above OSHA limits at the valve station, pipe fatigue, USM interference	3-stage low-noise trim, 85.6 dBA predicted at 1 m before insulation, acoustic insulation of body and 10 ft downstream mandatory (PRO-CAL-006); hearing protection signage	2 / 2 / 4 L	HZ-07

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
7.6	Instrument failure: common cause on PT-133A/B/C	Shared tap plugging, shared root valve closed, calibration error applied to all three	OPSS fails to trip on demand	Independent taps (HU-P2), deviation alarm 25 psi, out-of-range voting	5 / 2 / 10 H	HZ-48, HZ-51; L-01
7.7	SIS bypass left in place	OPSS bypassed for proof test and not removed	Loss of the last layer against trunkline overpressure	HS-200B maintenance override key; bypass alarm	5 / 2 / 10 H	HZ-28; L-01
7.8	SDV-102 fails to close / slow closure	Actuator hydraulic loss, spring failure, valve seized, debris	OPSS demand not met; overpressure (7.1)	SDV-102 full stroke 4 s or less, maximum allowable 7.4 s; PST; travel alarm at 5 s (INS-LST-003); proof test	5 / 2 / 10 H	HZ-02; L-01
7.9	Spurious OPSS trip	Transmitter fault votes, SIS fault, solenoid failure	Sudden stop of 120 MMSCFD; upstream surge; commercial loss	2oo3 voting; diagnostics	2 / 3 / 6 M	None
7.10	More pressure blocked-in between SDV-102 and SDV-103	ESD with both closed, solar heating	Thermal pressure rise	TSV-136 set 1,440 psig	2 / 3 / 6 M	HZ-21
7.11	Reset of OPSS with high downstream pressure	Operator resets before cause removed	Repeat trip, water hammer on reopening with DP across SDV-102	Local key reset HS-102 only; reset permissives (INS-RPT-001)	2 / 3 / 6 M	None
7.12	Maintenance: line 1033 vent HV-133D left open or passing	Valve not re-closed after maintenance vent to VS-101	Continuous release to vent header while delivering; reverse flow path from trunkline if SDV-103 open	Procedure, lock closed; LDAR	2 / 3 / 6 M	HZ-35; L-12

Table A-8: Worksheet, Node N8: Outlet and receiving pipeline interface

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
8.1	Reverse flow	Station depressured for maintenance or blowdown while trunkline at up to 1,050 psig; CKV-171 passing; SDV-103 open	Trunkline gas flows back into station, over the meters in reverse, uncontrolled release through open blowdown	CKV-171; SDV-103 closes on ESD (I-01) and gas quality shut-in (I-07); procedure to close SDV-103 before blowdown	4 / 2 / 8 M	HZ-40; L-12
8.1A	Reverse flow through outlet lateral blowdown	HV-172A / RO-172B (2"-V-1170-S1) opened to blow down 1041 / 1042 while the tap valve is open or passing	Continuous trunkline gas to VS-101, large release, noise, low temperature at RO-172B	Procedure: tap valve closed and confirmed before HV-172A opened; RO-172B limits rate	3 / 3 / 9 M	HZ-11, HZ-40; L-12
8.2	More pressure from trunkline	trunkline at MAOP 1,200 psig	Outlet section below its 1,440 psig MAOP: no concern	Design 1,440 psig	1 / 2 / 2 L	None
8.3	Less pressure	Trunkline rupture or blowdown	High station flow limited by FIC-131; high FCV DP and noise	PT-172 PAL 700; FIC-131	3 / 2 / 6 M	None
8.4	No flow	remote shutdown HS-215, tap valve closed without notice	Outlet blocked, station pressure rises to supply pressure (below 1,440 psig)	HS-215 initiates ESD; PIC-134	2 / 3 / 6 M	HZ-11
8.5	Interface: hot tap and tie-in	Hot tap by on a live 24 in trunkline (API RP 2201); tie-in weld to live line	Burn-through, release, fire during construction	procedure (scope)	4 / 2 / 8 M	HZ-41
8.6	Interface: data link lost	RTU link failure (HOLD H-14)	cannot see status, remote shutdown not possible from	Hardwired HS-215 and status contacts through JB-W01; comm alarm	2 / 3 / 6 M	HZ-30
8.7	Corrosion / CP on buried outlet lateral	IJ-102 shorted, coating damage	External corrosion of 12"-G-1042	CP (Electrical); IJ-102 surge protection	3 / 2 / 6 M	HZ-12

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
8.8	Third-party damage to buried outlet lateral	Excavation in ROW	Rupture, release	36 in cover (48 in at roads), markers, OKIE811	4 / 2 / 8 M	None

Table A-9: Worksheet, Node N9: Vent and blowdown

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
9.1	Less temperature	Manual blowdown through RO-181/182/183 and BDV-102 / RO-102 from 1,150 psig at -5 F ambient	Vent piping and RO downstream below MDMT -20 F; brittle fracture	RO limits rate; Process to confirm by calc	3 / 3 / 9 M	HZ-08
9.2	More pressure in vent header	Simultaneous blowdown of several sections plus PSV relief	Back-pressure on PSV-101 / PSV-157 above their allowable, reduced relief capacity	One section at a time procedure, an O&M requirement (simultaneous blowdown would need a 43 ft stack); PRO header check	3 / 2 / 6 M	HZ-34
9.3	Ignited vent	Lightning strike at VS-101 during blowdown or relief	Radiation at grade, burns	VS-101 location 25 ft above grade, spacing (GEN-DB-001 Sec. 10)	3 / 3 / 9 M	HZ-33
9.4	Unignited vent dispersion	Heavy gas relative to air not expected (SG 0.64); downwash in wind	Flammable cloud at grade or at B-101 / B-102 HVAC intake	Stack height and location (PRO dispersion)	3 / 2 / 6 M	HZ-33
9.5	Blowdown valve passing or left open	BDV-181/182/183 seat leak, not re-closed	Continuous methane emission (OOOOb), loss of product, reverse flow path (8.1)	Lock closed, inspection; LDAR	2 / 3 / 6 M	HZ-35; L-12
9.6	Liquid in vent header	Carryover from V-101 relief or drain misrouted	Liquid spray from stack, fire	Vent header low point drain	2 / 2 / 4 L	HZ-34

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
9.7	Noise	High velocity at RO during blowdown	Noise above 85 dBA at grade, hearing damage	Hearing protection; procedure	2 / 3 / 6 M	None
9.8	Liquid / water in VS-101 base; purge connection misuse	Rainwater or ice in stack base not drained; drain valve HV-180A opened or plug left off during venting; HV-180B purge / snuffing connection left open	Stack blockage by ice; gas release at grade at the stack base	No drain line to T-101; HV-180A is a 2 in drain valve with plug and portable collection pan, emptied by vacuum truck; HV-180A / HV-180B normally closed with locks, open only by procedure	2 / 2 / 4 L	HZ-35

Table A-10: Worksheet, Node N10: Drains and T-101

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
10.1	More pressure in T-101	Gas blow-by from V-101 (2.2) or PR-101 drain valve left open on 2"-L-1061	Tank roof or shell rupture, fire, fatality if technician present	SIF-03 (LSLL-106 to SDV-106); RO-104 plus EV-193 16 in emergency vent; PVRV-193; PR-101 drain by procedure	4 / 2 / 8 M	HZ-03, HZ-09; L-03
10.2	More level (overflow)	Truck not scheduled, LT-191 failure, continuous dumping	Spill into containment; condensate vapor, fire risk; environmental release if containment full	LT-191 LAH 57.6 in, LAHH 76.8 in; LSHH-192 SIF-04 at 86.4 in closes SDV-106 and LCV-104 (I-05); containment	3 / 3 / 9 M	HZ-14, HZ-37; L-04
10.3	Less pressure (vacuum)	Truck loadout pump-out with PVRV vacuum side blocked (ice)	Tank collapse	PVRV-193 vacuum side	2 / 2 / 4 L	HZ-09
10.4	Flame in vent	Lightning ignition of tank vapor	Flashback into tank, explosion	FA-193 flame arrestor	3 / 2 / 6 M	HZ-12
10.5	Static ignition at loadout	Truck not bonded, splash loading	Flash fire at truck	Bonding and grounding (MEC / ELE), procedure	3 / 3 / 9 M	HZ-36; L-04

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
10.6	Truck overfill / hose failure	Operator error, hose not rated	Spill	Driver attendance, dry-break coupling, containment	2 / 3 / 6 M	HZ-36
10.7	Emissions	Flash gas from pressurized liquids, working and breathing losses	OOOOb storage vessel threshold 6 tpy VOC exceeded	Regulatory emission calculation (GEN-DB-001 Sec. 13)	2 / 3 / 6 M	HZ-09
10.8	Less temperature	Winter freezing of water in drains	Blocked drain line, loss of dump	Heat trace on 2"-L-1060 above grade if water expected (PRO)	2 / 3 / 6 M	HZ-36
10.9	Vehicle impact	Truck strikes tank or loadout	Release	Containment wall, bollards	2 / 2 / 4 L	HZ-36

Table A-11: Worksheet, Node N11: Utilities, control and communications

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
11.1	Loss of utility power	Utility outage, storm	MOVs and FCVs stop as-is; heater BMS lost if not on UPS; G-101 start	ATS to G-101; 8 h UPS on RTU, SIS, FC, solenoids (GEN-DB-001 Sec. 9.8)	2 / 5 / 10 H	HZ-29
11.2	Loss of 24 VDC control power	UPS failure, DC bus fault	SIS de-energizes: station ESD (fail safe); BPCS loss	Fail-safe design; EI-210A alarms; XA-210	2 / 3 / 6 M	HZ-29
11.3	Loss of SCADA communications	Cellular outage, radio fade	Gas control blind; setpoint changes impossible	Secondary path (radio / satellite); RTU holds last setpoint; SIS independent	2 / 4 / 8 M	HZ-30
11.4	Control system failure	RTU CPU fault, configuration error	FCVs hold as-is; loss of PIC-134 override (IE for L-01)	OPSS independent in safety PLC; watchdog alarm	3 / 3 / 9 M	L-01
11.5	Unauthorized access (cyber)	Remote attack on SCADA, compromised vendor access	Malicious setpoint changes, FCV open, alarms suppressed	SIS independent and write-protected; API 1164 program (INS-RPT-002)	5 / 2 / 10 H	HZ-31; L-01

Ref	Deviation	Cause	Consequence	Safeguards	Risk (S/L/R)	Rec. and LOPA
11.6	Unauthorized access (physical)	Intrusion, vandalism, theft	Valve tampering, release	Fence, ZS-211 intrusion alarms, locks	3 / 3 / 9 M	HZ-32
11.7	Human factors: alarm flood	ESD generates many alarms at an unmanned site	Operator misses first cause	First-out logic; alarm rationalization (ISA-18.2)	2 / 3 / 6 M	HZ-52
11.8	Lightning	Direct strike on stacks, antenna mast, buildings	Equipment damage, SIS / RTU I/O damage, spurious trips, ignition at vents	NFPA 780 protection (Electrical); surge protection	3 / 3 / 9 M	HZ-12
11.9	Severe weather (tornado, ice)	tornado / ice storm	Structural damage, release, loss of access	ESD, ERP (SAF-RPT-005)	4 / 2 / 8 M	HZ-53
11.10	Induced seismicity	Central induced events	Small-bore failure, IJ damage	SDC B design (GEN-DB-001 Sec. 3); post-event inspection	3 / 2 / 6 M	HZ-53
11.11	Startup: air in system	First gas-in without purge	Flammable mixture in piping, O2 off-spec at AT-144	Nitrogen purge procedure	4 / 2 / 8 M	HZ-42
11.12	Gas release inside B-102	Instrument tubing or gas entering via HVAC intake	Ignition in non-classified building	No process tubing into B-102 (to confirm); GD-207 at HVAC intake; XY-214C HVAC trip	4 / 2 / 8 M	HZ-45