LLOG DELTA HOUSE PROJECT

SUBSEA LEAK DETECTION

DOCUMENT NO.

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Abbreviations

Abbreviation	Description
MMIMO	Modified Mass in Mass Out
ROC	Rate of Change
MPM	Multiphase Meter

SECTION 1 – Methods and Operating Environments

Method 1 – Modified Mass In Mass Out

This method utilizes mass measurement where multiphase meters are installed on/near well heads. The meter measurement is compared real time to the measurement of liquids at the first metered separator accounting for phase changes due to temperature and pressure. Logic is used to determine disposition of well fluid, the same logic approved in the safety system permit primarily dependent on limit switches.

Liquid @ Separator - $\Sigma\ MPM\ (T,P) = Liquid\ Balance$

If liquid balance is negative, it indicates more flow is being counted subsea than being counted topsides.

If liquid balance is positive it indicates more flow is being counted topsides than subsea.

LLOG measures deviation of the balance by the following:

$$\frac{\text{Liquid Balance}}{\Sigma\ \text{MPM (T,P)}} = \%\ \text{Dev}$$

If $\Sigma\ MPM\ (T,P) = 0$, % Dev = 0. This is to prevent processor faulting with a ∞ solution.

Accuracy is affected by several factors:

- Changes in hold up volume
- Flash table accuracy (MPM calibration)
- Refresh rates of subsea metering and topsides metering. Example: MPM rates are measured and sent via Ethernet from well site once every 15 seconds. Topsides metering is refreshed every 0.25 seconds.
- Accurate temperature and pressure data either subsea or topsides.

LLOG desires to stay within a +/- 7% band at initial separator conditions.

Method 2 – Rate of Change

This method utilizes a pressure transmitter at the well head to monitor for a significant pressure change that could account for a catastrophic loss of integrity.
For this method to be most effective, the pressure transmitter utilized for ROC should be located strategically close to the potential loss location.

ROC = $\frac{\text{Current Pressure – Last Pressure}}{\Delta t} \times \frac{\Delta t}{hr}$

Where $\frac{\Delta t}{Hr}$ is unit conversion for measured time increment to hours

For this method to limit false positives, the flow path to the flowline should be open and stable prior to measuring ROC. This eliminates rapid pressure elimination of small cavities at the well head from impacting the measurement.

LLOG currently uses +/- 10,000 psi/hr as an alarm threshold.

If a ROC alarm is activated, the control system must latch until the alarm is acknowledged. For LLOG's control system a red banner will appear in the ribbon and cannot be cleared until the appropriate measures are taken. The authority will be controlled via lead operator log in to ensure proper escalation within the organization.

As a failsafe option the ROC alarm will be accompanied by a 4 hour non-resettable timer. If the ROC alarm is not acknowledged within the timeframe the associated flowline will be shut in.

VALVE CLOSURE TIMING ROC ALARM 4 HOUR TIMER EXPIRATION							
Conditions	**Pipeline BSDV**	**USV1**	**USV2**	**Alternate Isolation Valve2**	**SCSSV**	**LP Hydraulic System**	**HP Hydraulic System**
ROC Alarm 4 hour timer expiration	Close within 45 seconds after sensor activation.	Close one or more valves within 2 minutes and 45 seconds after sensor activation. Close the designated USV1 within 20 minutes after sensor activation.			60-minute resettable timer; close within 24 hours after sensor activation.	No bleed.	Initiate unrestricted bleed within 24 hours after sensor activation.

Method 3 - Hydrostatic

Before wells are open on cold restart, LLOG verifies the flowline is not in communication with subsea by using a hydrostatic comparison to ambient conditions in the subsea environment

Operating Environment 1 – Shut In

No wells are flowing.

Leak Detection Method:
- Hydrostatic

Additional considerations for operating conditions at or near ambient hydrostatic conditions should be made during a prestart check. Depressurization or pressurization steps should be developed with technical assistance and approval.

Operating Environment 2 – Transient

Wells are in startup, shut down or slugging, pressure and temperatures are not stable, hold-up volumes are changing readily. It is challenging to discern loss of integrity.

Leak Detection Methods:
- MMIMO
- ROC

Operating Environment 3 – Steady State

Wells are flowing and conditions are relatively uniform throughout the system.

Leak Detection Methods:
- ROC
- MMIMO

One caveat to the utilization of MMIMO during a cold restart is that the % Dev is extremely high until the flowline is adequately inventoried. This hold up volume is accounted for in a cumulative counter. See Example Plot 1. Therefore a ROC alarm should take precedent over the MMIMO until hold up is established and a 7% deviation during a restart is not a good indication of compromised subsea integrity.

SECTION 2 – LEAK DETECTION PROTOCOLS

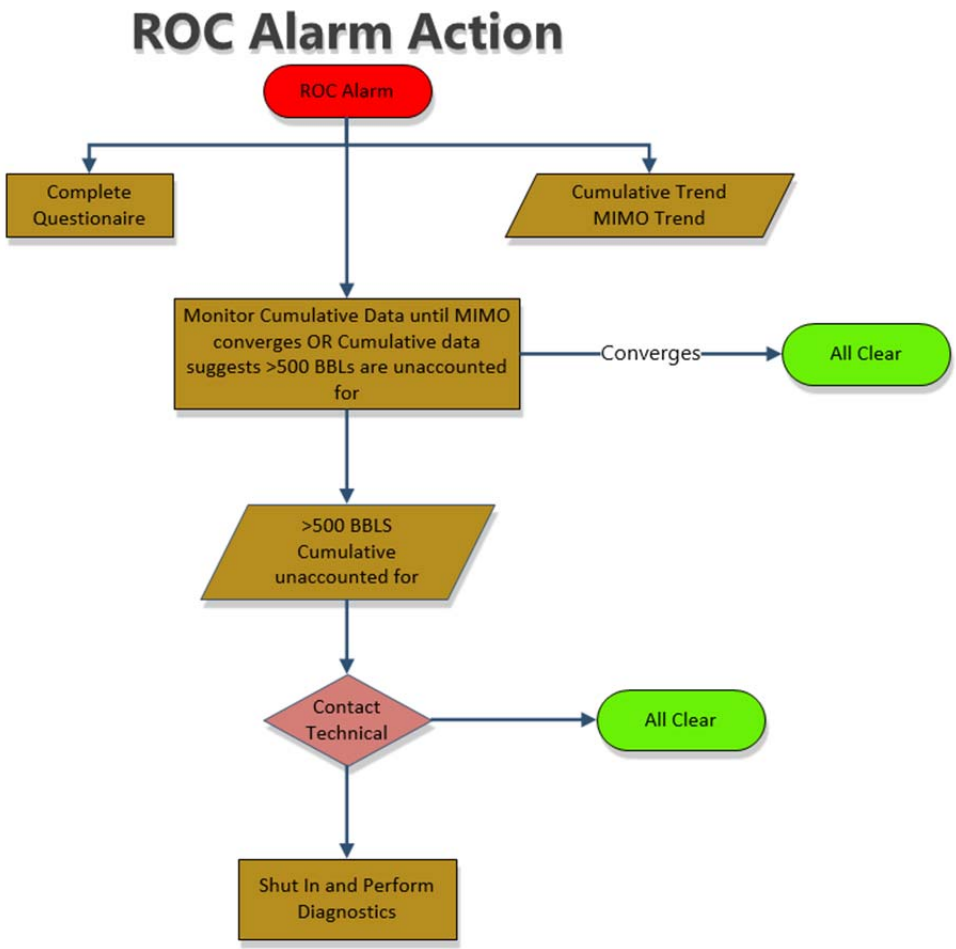
Before Restart

1. Perform hydrostatic diagnostic – Compare well jumper and desired restart flowline pressures to ambient conditions.
2. Ensure pressure transmitter utilized for comparison is open to flowline.
3. If flowline is within 200 psi of ambient condition, contact LLOG qualified person for permission to restart.

Well Number	Subsea System	Well Head Depth ft	Ambient Hydrostatic psi
MC 208 Well SS001	Neidermeyer	4924	2174
MC 209 Well SS001	Neidermeyer	4653	2055
MC 252 Well SS001	Neidermeyer	4917	2171
MC 253 Well SS001	Neidermeyer	4927	2176
MC 255 Well SS001	Marmalard	5746	2537
MC 255 Well SS002	Marmalard	5746	2537
MC 300 Well SS001	Marmalard	6131	2707
MC 300 Well SS002	Marmalard	6134	2709
MC 301 Well SS001	Marmalard	6134	2709
MC 431 Well SS002	SOB2 Manifold	6427	2838
MC 79 Well SS001	Otis	3861	1705
MC 257 Well SS001	Red Zinger	5900	2605
MC 257 Well SS002	Red Zinger	5900	2605
MC 427 Well SS001 ST01	BWOLF	5820	2570
MC 427 Well SS002	BWOLF	5820	2570
MC 471 Well SS001	BWOLF	5900	2605

Transient

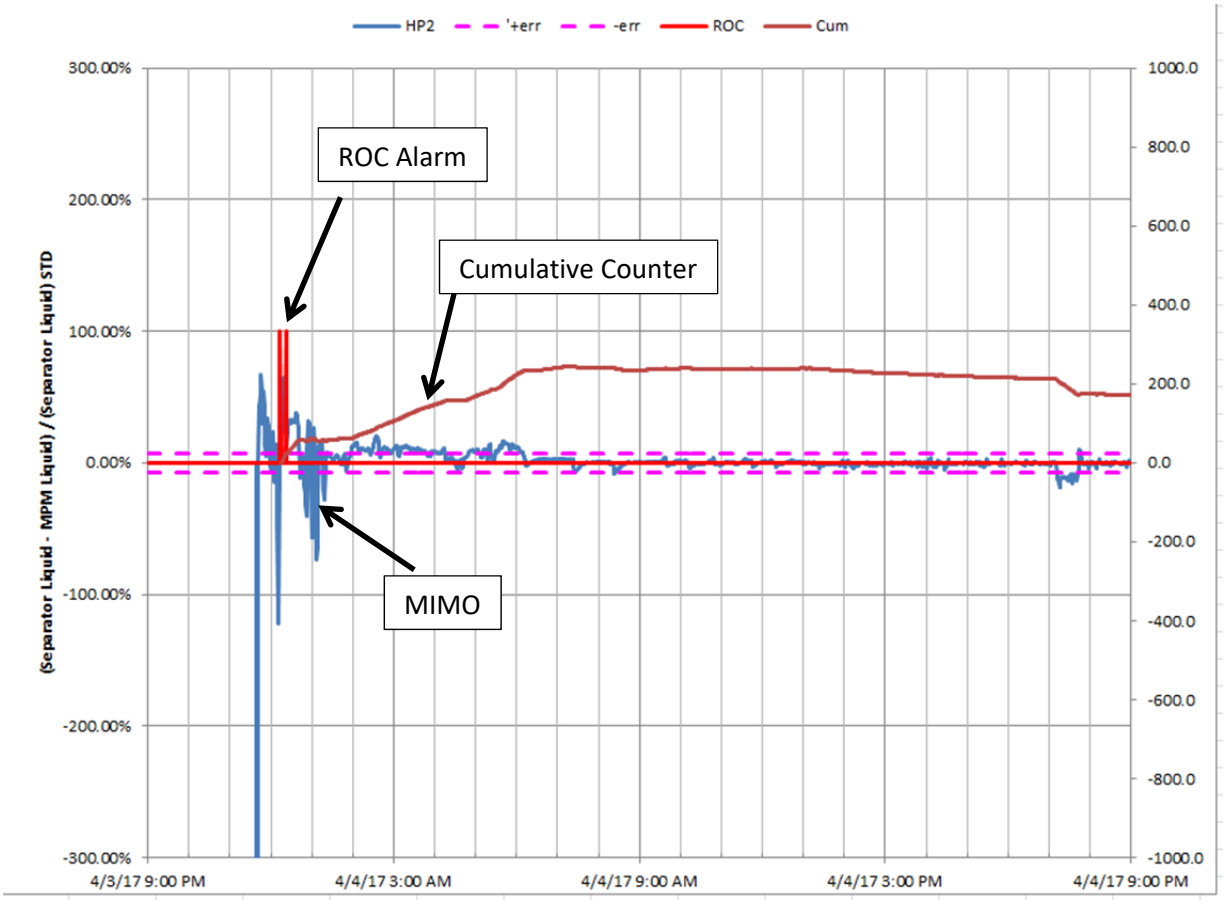
1. ROC set @ +/- 10,000 psi
2. MMIMO alarms can be muted for startup, however mass balance should converge to +/- 7% at first boarding separator and a trend should be utilized for monitoring.
3. If ROC alarm is tripped, a cumulative balance is automated for that well's corresponding flowline and separator
4. Cumulative balance is discontinued once ROC alarm is analyzed, acknowledged and disengaged.



ROC Alarm Questionnaire

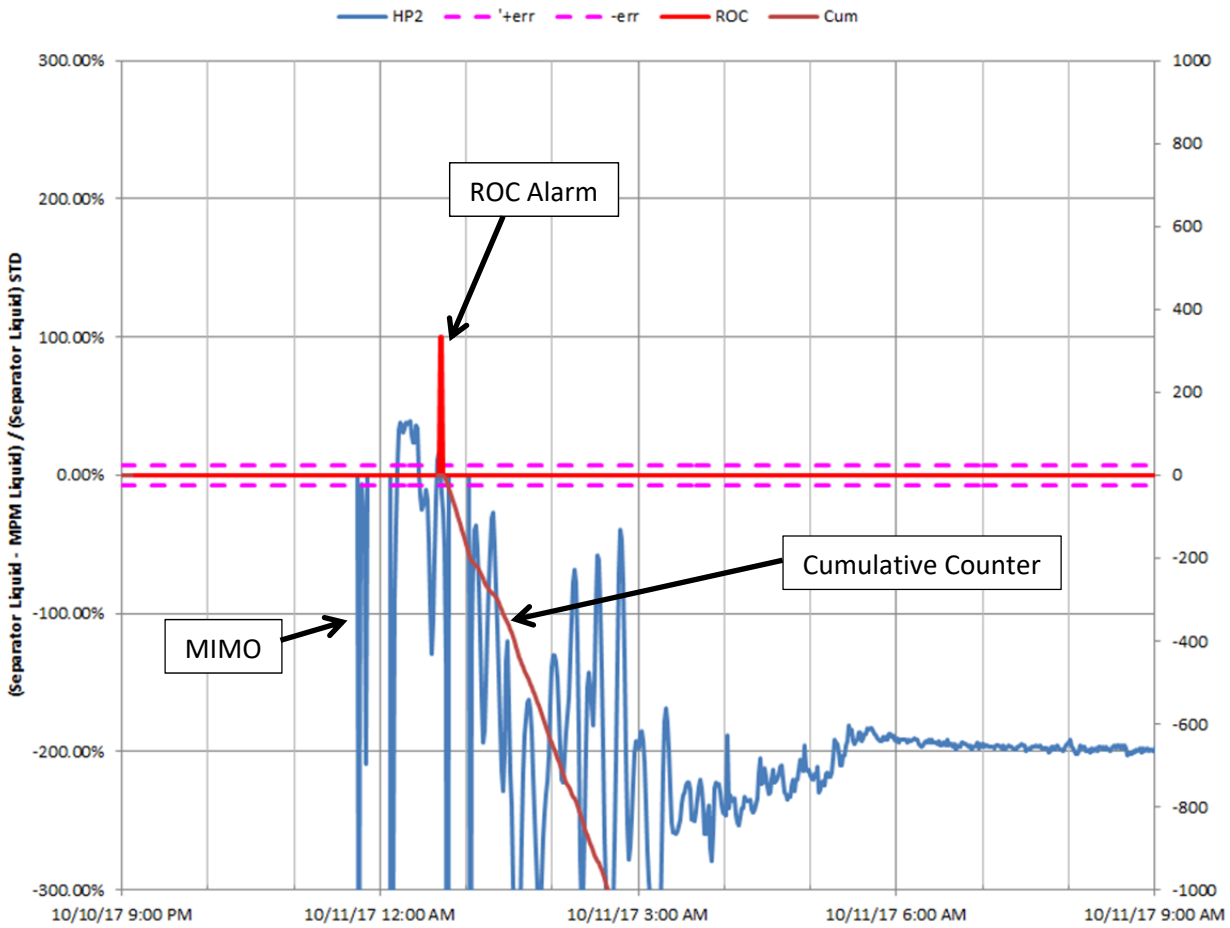
- ☐ Was alignment on flowline changed?
  - Topsides separator or separator pressure change
  - Additional well opened to system
  - Manifold or pigging valves opened to alternate subsea flowline
- ☐ Did tubing pressure Increase or well head temperature decrease indicating well was choked?
- ☐ Did boarding choke position change?
- ☐ Did the well head choke position change?
- ☐ Is the well slugging?
- ☐ Is boarding choke DP normal?
- ☐ Is boarding temperature normal?
- ☐ Confirm MPM SEM status.
  - Light is green
  - SEM A is active

Example Plot 1:



ROC Alarm Occurs, cumulative count begins and never exceeds 500 bbls, MMIMO converges to within +/- 7%. Questionnaire should be filled out as the plot is developing. Alarm can be acknowledged and cleared.

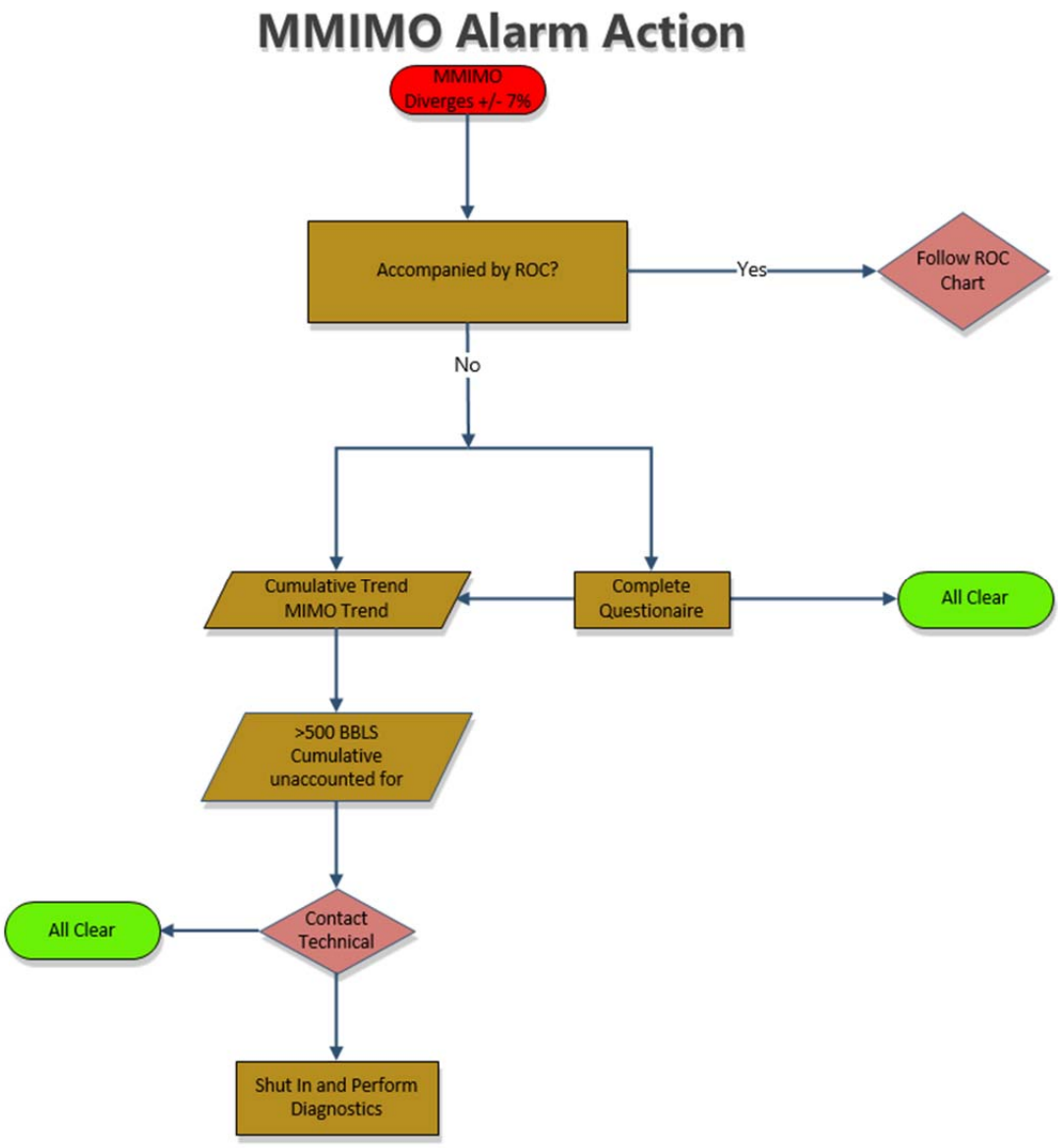
Example Plot 2:



ROC Alarm Occurs, cumulative count begins and exceeds 500 bbls in 90 minutes, MMIMO never converges to within +/- 7%. Questionnaire should be filled out as the plot is developing. Well would be shut with technical assistance.

Steady State

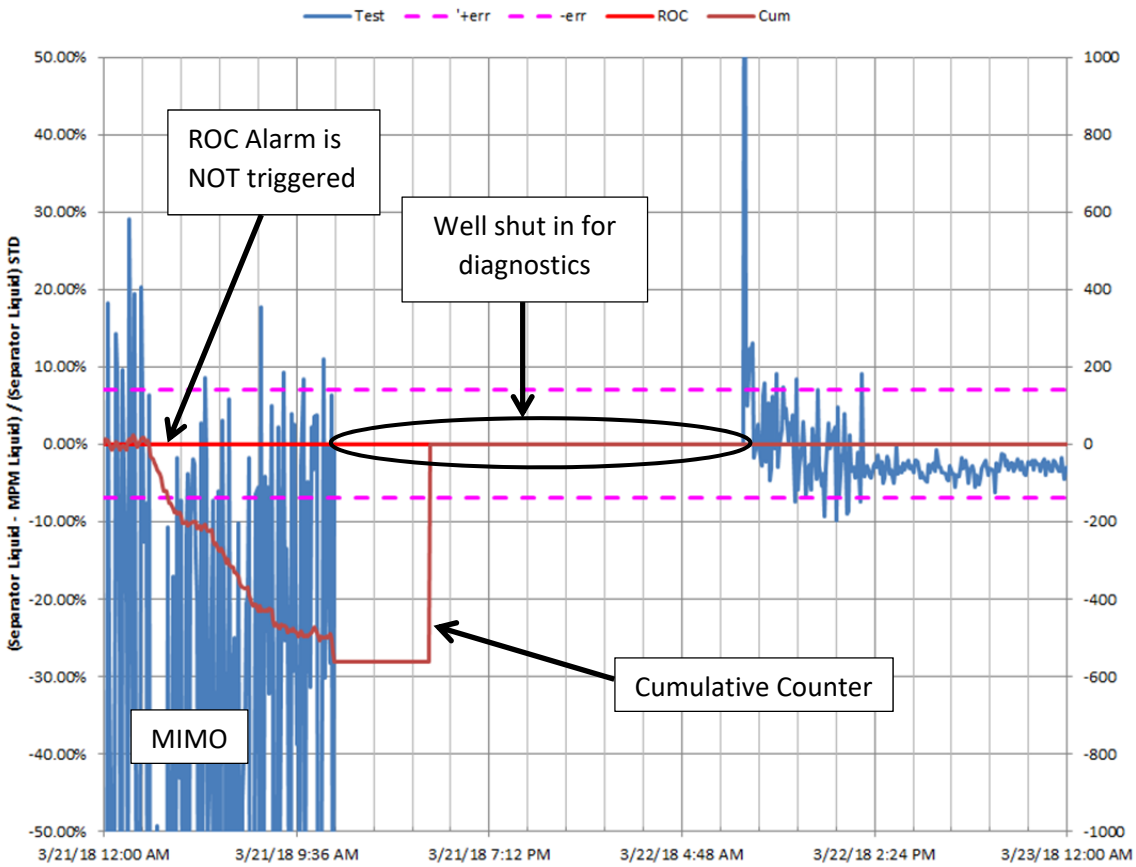
- MMIMO – monitor for deviation of liquid balancing outside of +/- 7% band at separator.
- Monitor for continued degradation of balance.
- ROC – ROC is intended for rapid detection of catastrophic failure. If ROC alarm activates, utilize transient strategy.



MMIMO Alarm Questionnaire

- ☐ Was the alignment to the separator recently changed?
- ☐ Is the system slugging?
- ☐ Is the topsides meter strainer clean?
- ☐ Is the topsides meter functioning correctly? Counting? Bypass Leaking?
- ☐ Are the separator P/T transmitters reasonable and functioning?
- ☐ Is the gas meter showing losses or gains that correspond to the liquid meter?
- ☐ Are the chemical pumps at appropriate dosage rates to separator?

Example Plot 1:



MMIMO is noisy and showing out of tolerance, cumulative count begins and reaches 500 bbls, Questionnaire should be filled out as the plot is developing. Well was shut for diagnostics.

SECTION 3 – Noise Minimization

Well and Flowline Restart Recommendations

When multiple flowlines are lined up to the same separator and multiple wells are restarting the system may take a much longer time to resolve and converge topsides. To minimize noise at the separators, it is recommended that only one line be routed to any separator until the MIMO converges and that flow line is at steady state.

SECTION 4 – Training

Initial Training

Initial training for subsea leak detection will be provided by LLOG technical personnel responsible for development and upkeep of the leak detection procedures and methods. Upon completion, LLOG Operations Manager will designate a Lead Operator to serve as the offshore approver and trainer for Subsea Leak Detection PLC Monitoring procedure. This designee will have delegated technical authority for initial onsite training and of new operations personnel.

Refresher training and procedure review should be performed annually and documented. The LLOG Operations Manager will be responsible for training documentation and records. The table listed in this document will serve as the training record.

Control Room Operators (CRO)

Control Room Operator (CRO) must be trained on subsea leak detection and understand approvals required for each operating environment and alarm type. The Lead Operator will be responsible to ensure CRO understands protocols and provide sign off on their training before a CRO is unaccompanied at the console.

Lead Operator

Lead Operator is responsible to clear alarms related to subsea leak detection. Their log in is required for documentation of the exceedance. A brief description of the event is also entered into the PLC. The lead operator is responsible for training of the CRO.

The Lead Operator's authority can be superseded by the OIM or LLOG Operations Manager as required.

Trained Personnel

Name	Role (Lead Operator/CRO)	Date	Signature	Approval Signature

*Procedure and training is to be reviewed and updated annually.