**Subsea Leak Detection (SSLD) Philosophy**

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Fieldwood Energy, LLC

**Subsea Leak Detection (SSLD) Philosophy**

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Subsea Leak Detection (SSLD) Philosophy

REVISION MODIFICATION LOG

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<td>7.2</td>
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1.0 INTRODUCTION

Fieldwood Energy, LLC (FWE) is committed to safeguarding production assets against subsea leaks (prevention), ensuring adequate process monitoring (detection), and operator training and empowerment (response). Safeguarding production assets requires a ‘Think Leak First’ culture where uncertainty about an abnormal subsea condition that could be the result of a subsea leak causes the FWE Control Room Operator (CRO) to exercise Stop Work Authority and safely shut-in the producing wells.

Subsea Leak Detection (SSLD), as defined by this philosophy, is applicable to subsea systems with X-mas Trees (XT) installed subsea. Subsea XT(s) produce through subsea infrastructure, which requires remote surveillance and control.

- **Prevention:** FWE to conform to governmental regulations, applicable codes and standards, and industry best practices in facility design and operation.

- **Detection:** FWE is committed to basic and advanced leak detection monitoring. FWE to implement advanced leak detection monitoring capabilities on new flowlines. FWE to additionally investigate the feasibility of retroactively upgrading existing facilities for advanced monitoring capabilities.

- **Response:** FWE is committed to providing CRO guidance, training, and competency verification for subsea leak detection and response. Training to conform to the Offshore Operator Conference (OOC) Subsea Leak Detection (SSLD) Training and Competency Development Plan presented in July 2018 (refer to Appendix C: Offshore and Operator Training).

The formalization of the ‘Think Leak First’ and SSLD philosophy is intended to ensure consistency throughout the lifecycle of facilities, projects, and operations in support of the FWE commitment.

2.0 ROLES AND RESPONSIBILITIES

Each CRO is responsible for:

- Understanding Stop Work Authority as it pertains to ‘Think Leak First’.
- Understanding the required actions to take in response to an abnormal subsea process condition to include troubleshooting.
- Asking questions if there is any ambiguity or misunderstanding.
- Acknowledging their empowerment to shut-in the system following required hydrate mitigations if they suspect a leak subsea.
- Elevating any uncertainty to the Ultimate Work Authority (UWA) for approval to continue safe production.

Each Offshore Installation Manager (OIM)/Offshore Production Manager (OPM) and Production Team Leads (PTL)/Team Leads (TL) is responsible for:

- Ensuring CRO(s) understand any Standard Operating Procedure (SOP).
- Ensuring action plans / decision support charts are adequately posted and clearly visible.
- Discussing leak indications in each operation (shut-in, transient, and steady state conditions).
• Discussing the troubleshooting required to verify if any abnormal indications are indicative of a subsea leak or can be attributed to a benign (safe) condition.
• Discussing uncertainty and how trends can be reviewed to increase the confidence level if a leak is or is not present.
• Elevating any uncertainty to the UWA (if not the OIM/OPM) for approval to continue safe production.

The Ultimate Work Authority (UWA) is responsible for:
• Reviewing any uncertainty.
• Reviewing troubleshooting and verification activities.
• Approval of continued safe production.

The UWA is normally the OIM/OPM.

3.0 DEFINITIONS AND ACRONYMS
3.1 Definitions

CRO First line of responsibility to ensure safe operation of the Subsea Production System (SPS) through continuous surveillance by means of the Subsea Production Control System (SPCS).

Process monitoring instrumentation Temperature Transmitters (TT), Pressure Transmitters (PT), Pressure & Temperate Transmitters (PTT), Flow Meters (FM), and Acoustic Sand Detectors (ASD) can be used to indicate, investigate, and identify the presence of a subsea leak or lack thereof.

Subsea leak Any pressure boundary failure in the SPS that allows produced hydrocarbons to comingle with the environment. Hydrocarbons may leak out of the system or external seawater may leak in.

Large leak Any subsea leak detectable through changes in process conditions. Depends on the production profile (flow properties and flow regime), flow rates, pressures, etc. but is generally 5–10 % of total flow or between 50–100 bbl/hr. Detectability is also influenced by the amount of subsea instrumentation.

Stop Work Authority Authority given to, and expected of, all FWE employees and contractors to stop work if any unsafe condition is observed, inferred, indicated, or suspected.

Stop Production Authority Stop Work Authority includes the responsibility to stop production if any unsafe condition is observed, inferred, indicated, or suspected. This specifically includes indications of a subsea leak.

Think Leak First The initial thought of a CRO is that an abnormal subsea process condition could be a subsea leak and should be investigated immediately. If a subsea leak is suspected at any time, the CRO has the responsibility to implement Stop Work Authority (SWA) and immediately shut-in. If a subsea leak cannot be ruled out following troubleshooting, the CRO has the responsibility to implement Stop Work Authority within 4 hours and shut-in.
Ultimate Work Authority

The authority assigned to an individual or position to make final decisions relating to activities and operations on the facility. This individual should be identified before the operation commences and crew members should know who has ultimate work authority for their operation or facility.

3.2 Acronyms

- **ASD**: Acoustic Sand Detector
- **bbl**: barrel (42 gallons)
- **BSDV**: Boarding Shutdown Valve
- **CRO**: Control Room Operator
- **CROC**: Conditional Rate of Change
- **DCS**: Distributed Control System
- **ESD**: Emergency Shutdown
- **FCV**: Flow Control Valve
- **FM**: Flow Meter
- **ft**: Foot (12 inches)
- **FWE**: Fieldwood Energy
- **hr**: Hour
- **MIMO**: Mass-In / Mass-Out (or Meter-In / Meter-Out)
- **MMIMO**: Modified Mass-In / Mass-Out (or Modified Meter-In / Meter-Out)
- **NLT**: No Later Than
- **OIM**: Offshore Installation Manager (equivalent to OPM)
- **PIC**: Person in Charge (equivalent to OIM or OPM)
- **PSH**: Pressure Safety High
- **PSHL**: Pressure Safety High/Low
- **psi**: Pounds per square inch (pressure)
- **PSL**: Pressure Safety Low
- **PT**: Pressure Transmitter
- **PTL**: Production Team Lead (equivalent to TL)
- **PTT**: Production & Temperature Transmitter
- **ROC**: Rate of Change
- **ROV**: Remotely Operated Vehicle
- **SIS**: Safety Instrumented System
- **SOP**: Standard Operating Procedure
- **SPCS**: Subsea Production Control System
- **SPS**: Subsea Production System
- **SSLD**: Subsea Leak Detection
- **SW**: Software
- **SWA**: Stop Work Authority
Subsea Leak Detection (SSLD) Philosophy

TL  Team Lead (equivalent to PTL)
TT  Temperature Transmitter
UWA Ultimate Work Authority
WH  Wellhead

4.0 OPERATING CONDITIONS

4.1 Shut-In
Well(s) are not flowing and have two barriers in place. Basic process monitoring can readily detect a subsea leak.

During shut-in conditions, any pressure boundary downstream of the last isolation valve can be pressurized or depressurized (blown-down) for additional verification of the SPS integrity.

4.2 Transient
Well(s) may be in a start-up or shutdown condition such that process indications are not stable. Slugging or other flow regimes may also be safely readily changing. Basic process indications such as pressures, temperatures, and flow rates can safely be readily changing.

During transient conditions, basic process monitoring may not readily detect a subsea leak with high confidence. CRO training is intended to supplement basic process monitoring in order to provide higher confidence of leak detection. Offshore facilities include basic process monitoring of subsea conditions.

Advanced process monitoring techniques can be employed to increase the detection threshold, confidence level, and reaction speed to a subsea leak. Not all FWE facilities have advanced monitoring in place; however, FWE is committed to retroactively implementing advanced process monitoring if existing SPS infrastructure supports it.

4.3 Steady State
Well(s) are flowing and process indications are stable, uniform, predictable, and match historical production behavior.

During steady state conditions, basic process monitoring may confidently detect a subsea leak with sufficient speed, however additional operator troubleshooting may still be required to confidently identify a subsea leak is not present. Similar to transient conditions, CRO training is intended to supplement basic process monitoring to ensure uncertainty is reduced. Offshore facilities include basic process monitoring of subsea conditions.

Similar to transient conditions, advanced process monitoring techniques can be employed to increase the detection threshold, confidence level, and reaction speed to a subsea leak. Not all FWE facilities have advanced monitoring in place. However, FWE is committed to retroactively implementing advanced process monitoring if existing SPS hardware supports it.
5.0 OPERATIONAL RESPONSE

Subsea leaks are rare, but CRO(s) should exercise Stop Work Authority if any subsea leak is suspected. During an abnormal subsea process condition and/or production anomaly, **Think Leak First.** Not all subsea abnormal conditions and/or process indications are indicative of a subsea leak. However, the general response and timing requirements are listed below:

**Immediately:** Shut-in the Subsea Production System (SPS) following any required hydrate inhibition immediately if a subsea leak is indicated and/or suspected.

If unsure, assess process conditions (troubleshoot).

**During the first hour:** Shut-in the SPS following any required hydrate inhibition if a subsea leak is indicated and/or suspected.

Any uncertainty about the integrity of the SPS should be elevated to the Offshore Installation Manager (OIM) or Offshore Production Manager (OPM) immediately. The OIM/OPM has Ultimate Work Authority (UWA) and is the only FWE designee who can approve continued operations following troubleshooting and/or subsea integrity verification.

If unsure, assess process conditions. If the SPS integrity is not suspect, continue to troubleshoot (review trends, perform diagnostics, etc.). However, any abnormal subsea process indication should be elevated to the UWA within 60 minutes if a subsea leak cannot be ruled out.

**Within 4 hr:** Elevate to OIM or OPM (UWA) within 60 minutes if not already done so.

If unsure of a subsea leak, continue to troubleshoot and assess process conditions. The FWE Houston office should be notified during the subsea leak detection troubleshooting stage to provide additional expertise and support where required.

The OIM/OPM has Ultimate Work Authority (UWA) and is the only FWE designee who can approve continued operations following troubleshooting and/or subsea integrity verification.

Shut-in the SPS following any required hydrate inhibition within four hours if the integrity of the SPS cannot be verified.
Refer to Figure 1: Standard SSLD Protocol for the illustrated workflow:

**Figure 1: Standard SSLD Protocol**

FWE employees and contractors to adhere to the company’s Stop Work Authority (SWA) policy. This includes Stop Production Authority if a subsea leak is suspected. The FWE Houston office should be notified during the subsea leak detection troubleshooting stage to provide additional expertise and support where required.

If a subsea leak is confirmed and/or the integrity of the SPS cannot be verified, then the SPS should be shut-in within the 4 hour response window following any hydrate inhibition. Facility specific Standard Operating Procedures (SOP) should be used for troubleshooting, but does not supersede the 4 hour shut-in response window.

Following shut-in, perform the site approved recovery plan if the integrity of the SPS cannot be verified through pressurization and/or de-pressurization.

The OIM/OPM has Ultimate Work Authority (UWA) and is the only FWE designee who can approve continued operations following troubleshooting and/or subsea integrity verification.

The initial uncertainty, troubleshooting/verification, and decision by the UWA to continue to safely produce to be recorded. If a facility specific form is unavailable, Appendix E: General SSLD Decision Record to be used.
6.0 APPENDIX A: GENERAL PROTOCOLS

6.1 General Protocol for Shut-In Conditions

For wells flowing above ambient pressures, the CRO should perform hydrostatic diagnostics and compare the non-flowing jumper and flowline pressures to ambient conditions.

If there is a subsea leak at flowing pressures greater than ambient subsea hydrostatic pressure:
- When a field is shut-in and the well is isolated from the well jumper / flowline system, the internal pressure should bleed down as the hydrocarbons escape to sea.
- The pressure should eventually equalize, although this may take 20 – 30 minutes depending on the leak size.
- Regardless of the leak size, the pressure should trend towards the ambient hydrostatic pressure.

A steady pressure ≥ 200 psi above ambient is evidence that a subsea leak is not present and system integrity is intact.

An example is a subsea leak (trend of pressure over time) is given for a single manifold for flowing conditions above ambient hydrostatic pressures, published by the Offshore Operators Conference (OOC) Technical Solutions for Subsea Leak Detection (SSLD) working group:

For wells flowing below external ambient pressures, the CRO should perform hydrostatic diagnostics and compare the non-flowing jumper and flowline temperatures and pressures to ambient conditions.

If there is a subsea leak at flowing pressures less than ambient subsea hydrostatic pressure:
- When a field is shut-in and the well is isolated from the well jumper / flowline system, the internal pressure should increase as water leaks into the system.
- The pressure should eventually equalize, although this may take 20 – 30 minutes depending on the leak size.
- Regardless of the leak size, the pressure should trend towards the ambient hydrostatic pressure.
- The temperature can also decrease from normal flowing temperatures to the subsea ambient temperature (typically 40 °F) more quickly than under normal conditions. This results from sea water ingress into the system.
For sub-ambient wells, a steady pressure ≥ 200 psi lower (less) than ambient is evidence that a subsea leak is not present and the system integrity is intact.

Generalized example decision chart following a PSHL when the SPS is shut-in (PSL is for above ambient wells and PSH is for below ambient wells):

**Flow Chart:**

1. **PSL Trip**
   - Notify PTL and OIM/OPM (UWA) immediately.
   - If safe, perform subsea system integrity verification (such as a blowdown/hydrostatic drawdown).
   - Can well jumpers/flowline maintain pressure?
     - **YES**
       - Request OIM/OPM (UWA) approval to restart.
     - **NO**
       - Ensure all valves are closed and system is shut-in.
       - Begin site recovery plan.

**Actions:**

Potential response to a Pressure Safety High/Low (PSHL) shutdown:

- Immediately notify the Production Team Lead (PTL) and the Offshore Installation Manager (OIM) / Offshore Production Manager (OPM) who has UWA.
- Notify the Houston office for troubleshooting assistance if unsure of a leak.
- If safe to do so, perform integrity verification of the Subsea Production System (SPS).
  - This may require opening the last isolation valve on the X-Mas Tree (XT) such as the Flowline Isolation Valve (FLIV) to measure the production flowline internal pressure.
  - If the flowline can maintain a steady state pressure ≥ 200 psi above the subsea ambient external pressure, then this is an indication the system integrity is intact.
  - If the flowline is sub-ambient or blown-down and can maintain ≥ 200 psi below ambient, then this is an indication the system integrity is intact.
- If the SPS system integrity cannot be verified, perform the site approved recovery plan. This may include:
  - Activation of the Oil Spill Response Plan.
  - Overflights of the area.
  - Boat surveys, inclusive of ROV(s).

- **Note 1:** The system can be blown down to sub-ambient conditions to verify system integrity for most subsea facilities (either flowing above or below ambient hydrostatic conditions). However, subsea valves may leak and production bypass should be considered during pressurization / depressurization.
- **Note 2:** Well jumpers and certain flowline segments can be pressurized subsea with MeOH to verify system integrity. Production bypass past the gate should be considered during MeOH pressurization.
Subsea Leak Detection (SSLD) Philosophy

The OIM/OPM has Ultimate Work Authority (UWA) and is the only FWE designee who can approve continued operations following troubleshooting and/or subsea integrity verification.

The initial uncertainty, troubleshooting/verification, and decision by the UWA to continue to safely produce to be recorded. If a facility specific form is unavailable, Appendix E: General SSLD Decision Record to be used.

6.2 General Protocol for Transient Conditions

Pressure, temperature, and flow rates may not be uniform throughout the system and safely change readily during transient conditions such as start-up, shutdown, or slugging.

Restart conditions should verify the flowline pressure boundary is intact by using a hydrostatic comparison before flowing the well.

- Example for flowing pressures greater than ambient: When using a Pressure Transmitter (PT) downstream of the last isolation valve on the X-mas Tree (XT), the flowline pressure should be ≥ 200 psi above ambient and/or not trend towards ambient conditions. Production bypass past the gate should be considered.

Abnormal process conditions such as readily changing pressures and temperatures are typical in restart and shutdown conditions and may not indicate a subsea leak. Any unexpected abnormal process condition should be reviewed against operator actions (below are typical examples):

- Did the tubing pressure increase or wellhead temperature decrease congruent with well choking?
- Did the boarding choke position change?
- Did the XT choke position change?
- Is the well slugging (easily confused with a subsea leak)?
- Is the boarding temperature normal?
- Did the topside separator pressure change?
- Is the anomaly explained in previous Daily Well Info Logs?
- Did the manifold flowline alignment change?
- Did the subsea flowline alignment change?
- Did an additional well open to the flowline?
- Did gas lift rates change?
- Did the subsea chemical injection rates change?
- Was annulus casing bled off?
Generalized example decision chart following an unexpected abnormal temperature indication during ramp-up:

**Flow Chart:**

1. **Abnormal temperature indication.**
   - Monitor topside rates.
     - **Normal** → Choke position doesn’t affect abnormal temperature.
     - **Low** → If boarding rates are lower than expected, perform trend analysis.

2. **Notify OIM/OPM (UWA) within 60 minutes.**

3. **If uncertainty exists, shut-in the well within 4 hours.**
   - Can well jumpers/flowline maintain pressure?
     - **YES** → Request OIM/OPM (UWA) approval to restart.
     - **NO** → Ensure all valves are closed and system is shut-in.

**Actions:**

Potential response to an abnormal process condition indicated by an unexpected temperature:

- Monitor the topside boarding / separator rates for verification of expected production flow rates.
- Adjust the topside and/or subsea chokes to verify system response as expected:
  - Example given: A subsea leak downstream of the subsea Flow Control Valve (FCV) may cause a temperature increase at the XT due to increased flow rates. Choking the XT should cause an expected temperature response based on the current pressure indications.
  - Perform trend analysis (pressure vs. time) of affected jumpers/flowlines. Notify the FWE Houston office at this stage to provide additional expertise and support where required.
  - If unsure, shut-in the well and immediately notify the Production Team Lead (PTL) and the Offshore Installation Manager (OIM) / Offshore Production Manager (OPM) who has UWA.
  - If safe to do so, perform integrity verification of the Subsea Production System (SPS):  
    - This may require opening the last isolation valve on the X-Mas Tree (XT) such as the Flowline Isolation Valve (FLIV) to measure the production flowline internal pressure.
    - If the flowline can maintain a steady state pressure ≥ 200 psi above the subsea ambient external pressure, then this is an indication the system integrity is intact.
    - If the flowline is sub-ambient or blown-down and can maintain ≥ 200 psi below ambient, then this is an indication the system integrity is intact.
  - If the SPS system integrity cannot be verified, perform the site approved recovery plan. This may include:
    - Activation of the Oil Spill Response Plan.
    - Overflights of the area.
    - Boat surveys, inclusive of ROV(s).

General protocols are not meant to supersede facility approved Standard Operating Procedures (SOP).
Subsea Leak Detection (SSLD) Philosophy

The OIM/OPM has Ultimate Work Authority (UWA) and is the only FWE designee who can approve continued operations following troubleshooting and/or subsea integrity verification.

The FWE Houston office should be notified during the subsea leak detection troubleshooting stage to provide additional expertise and support where required.

The initial uncertainty, troubleshooting/verification, and decision by the UWA to continue to safely produce to be recorded. If a facility specific form is unavailable, Appendix E: General SSLD Decision Record to be used.

6.3 General Protocol for Steady State Conditions

During steady state production, flowing conditions should be relatively stable throughout the system. Any abnormal or unexpected change in flowing conditions should be reviewed (below are typical examples of operator action, same as transient conditions):

- Did the tubing pressure increase or wellhead temperature decrease congruent with well choking?
- Did the boarding choke position change?
- Did the XT choke position change?
- Is the well slugging (easily confused with a subsea leak)?
- Is the boarding temperature normal?
- Did the topside separator pressure change?
- Is the anomaly explained in previous Daily Well Info Logs?
- Did the manifold flowline alignment change?
- Did the subsea flowline alignment change?
- Did an additional well open to the flowline?
- Did gas lift rates change?
- Did the subsea chemical injection rates change?
- Was annulus casing bled off?

If there is uncertainty of any abnormal condition, the well may be choked back and isolated from the flowline system to verify integrity. Verify the flowline pressure boundary is intact by using a hydrostatic comparison.

- Example for flowing pressures greater than ambient: When using a PT downstream of the last isolation valve on the XT, the flowline pressure should be ≥ 200 psi above ambient and/or not trend towards ambient conditions. Production bypass past the gate should be considered.
Generalized example decision chart following an abnormal pressure indication during steady state production:

**Flow Chart:**

1. **Abnormal pressure indication.**
2. **Choke position doesn’t affect abnormal pressure.**
3. **Trend analysis cannot verify if the pressure anomaly is a slug.**
4. **Notify OIM/OPM (UWA) within 60 minutes.**
   - **If uncertainty exists, shut-in the well within 4 hours.**
   - **Can well jumpers/flowline maintain pressure?**
     - **YES**
       - **Request OIM/OPM (UWA) approval to restart.**
     - **NO**
       - **Ensure all valves are closed and system is shut-in.**

**Actions:**

Potential response to an abnormal process condition indicated by an unexpected pressure:

- Adjust the topside and/or subsea chokes to verify system response is as expected:
  - Example given: Choking closed the topside Flow Control Valve (FCV) should cause the subsea flowline pressure to increase.

- Perform trend analysis (pressure vs. time) of affected jumpers/flowlines. Notify the FWE Houston office at this stage to provide additional expertise and support where required.

- If unsure, shut-in the well and immediately notify the Production Team Lead (PTL) and the Offshore Installation Manager (OIM) / Offshore Production Manager (OPM) who has UWA.

- If safe to do so, perform integrity verification of the Subsea Production System (SPS):
  - This may require opening the last isolation valve on the X-Mas Tree (XT) such as the Flowline Isolation Valve (FLIV) to measure the production flowline internal pressure.
  - If the flowline can maintain a steady state pressure ≥ 200 psi above the subsea ambient external pressure, then this is an indication the system integrity is intact.
  - If the flowline is sub-ambient or blown-down and can maintain ≥ 200 psi below ambient, then this is an indication the system integrity is intact.

- If the SPS system integrity cannot be verified, perform the site approved recovery plan. This may include:
  - Activation of the Oil Spill Response Plan.
  - Overflights of the area.
  - Boat surveys, inclusive of ROV(s).

General protocols are not meant to supersede facility approved SOP(s).
The OIM/OPM has Ultimate Work Authority (UWA) and is the only FWE designee who can approve continued operations following troubleshooting and/or subsea integrity verification.

The FWE Houston office should be notified during the subsea leak detection troubleshooting stage to provide additional expertise and support where required.

7.0 APPENDIX B: SUBSEA LEAK DETECTION METHODS

FWE has identified the following methods for Subsea Leak Detection:

- Basic process monitoring including threshold and Rates of Change (ROC) alarms.
  - Threshold: Discrete set point outside the normal process.
  - Rate of Change (ROC): Changes in process conditions per unit time.
- Basic hydrostatic verification.
- Basic visual surveillance.
- Advanced Conditional Rate of Change (CROC).
- Advanced Mass-In/Mass-Out (MIMO).

7.1 Basic Process Monitoring

Existing FWE subsea facilities include surveillance capabilities to include Pressure, Temperature, Acoustics, and Flow Rates.

Not all FWE subsea facilities include the same instrumentation capabilities, but generally are instrumented sufficiently to support basic leak detection. The existing facility hardware may include some or all of the following:

Pressure Safety High/Low (PSHL):
- Subsea Production Systems (SPS) are required to shut-in upon a pipeline/flowline PSHL:
  - For flowing pressures above ambient: A large leak should cause the pressure to drop below the normal operating pressure and trend towards ambient pressures.
  - For flowing pressures below ambient: A large leak should cause the pressure to increase above the normal operating pressure and trend towards ambient pressures.
- The PSHL setpoint(s) should be set correctly to trip the shut-in.
- Small leaks may not be detected; hence additional leak detection monitoring is required.

Abnormal process conditions (including a subsea leak), can be identified through:
- Real time monitoring: Process conditions are continuously monitored by the CRO. Any deviation between the expected or normal condition and any transient condition is cause for troubleshooting to identify the anomaly.
- Trend monitoring: Process indications such as temperature and pressure can be plotted over time and compared to historical data and/or expected process conditions to help identify the root cause of the abnormal condition.
Acoustic monitoring:
- Well jumpers are typically instrumented with Acoustic Sand Detectors (ASD) to identify potential subsurface equipment failure and/or sand ingress into the production flowlines.
- Acoustic thresholds and/or acoustic ROC can be used to indicate sand, but also other abnormal process conditions.
- Real time acoustic indications, ROC alarms, and trend monitoring should be used to identify the cause of any subsea abnormal condition.

Temperature monitoring:
- Various points in the production flow path are instrumented for temperature indications.
- Instrument location, accuracy, and alarm set points affect the ability to detect a subsea leak.
- Temperature thresholds and/or temperature ROC can be used to indicate abnormal process conditions.
- Trends (temperature vs. time) can be used to identify an abnormal process condition.
- A subsea leak can exhibit a temperature drop downstream of the leak, but may exhibit an increase in temperature at the well (upstream of the leak).

Pressure monitoring:
- Various points in the production flow path are instrumented for pressure indications.
- Instrument location, accuracy, and alarm set points affect the ability to detect a subsea leak.
- Pressure thresholds and/or pressure ROC can be used to indicate abnormal process conditions.
- Trends (pressure vs. time) can be used to identify an abnormal process condition.
- A subsea leak should exhibit a pressure drop that does not recover and stabilizes below normal operating pressures.

- A slug is indicted by a transient pressure drop that recovers to normal and expected conditions:

![Graph showing a slug event]

- A leak is indicated by a transient pressure drop that stabilizes at a pressure lower than normal or expected conditions:

![Graph showing a leak event]
7.2 Basic Hydrostatic Monitoring

The hydrostatic method can be used on cold start after shut-in periods to verify that the flowline is not in communication with ambient conditions in the subsea environment. This method compares the pressure in the flowline to the ambient hydrostatic pressure of the seawater at the desired location to be monitored. This method assumes that the shut-in pressure in the subsea system is not equal to the ambient hydrostatic pressure of the seawater during shut-in periods. If the pressure in the subsea system reaches an equilibrium with the ambient hydrostatic pressure of the seawater, then additional investigation is recommended before the startup of the subsea well(s).

Refer to Appendix D: Subsea Well Ambient Pressures for further information.

7.2.1 Water Depths at Subsea Locations

Water depth varies on a per facility basis and the depth ranges and hydrostatic pressures for each location to be called out and listed within each of the field specific procedures where this method is used. The value used for calculating the subsea hydrostatic pressure of the seawater is 0.445 psi per ft water depth.

Example: Subsea Hardware located at a depth of 2000 ft is calculated as 2000 ft x 0.445 psi per ft = 890 psi.

Refer to Appendix D: Subsea Well Ambient Pressures for further information.

7.2.2 Existing Facilities & Subsea Infrastructure

The integrity of the topside isolation valves and the subsea tree valves should be maintained when using the subsea hydrostatic method.

7.3 Basic Visual Surveillance

Visual surveillance methods are currently employed for leak detection, however, good visibility is required for visual surveillance to be an effective tool and as such visual surveillance does not provide a full time method for Subsea Leak Detection. Visual surveillance is utilized in operating environments and current methods of visual surveillance include the following:

- Operator surveillance from the host facility.
- Aerial and Marine surveillance.
- Remotely Operated Vehicle (ROV) inspections.

7.3.1 Operator surveillance

Operator surveillance from the host facility is an effective tool for detecting leakage in the flowline/riser system and the portion of the flowline system within view of the host facility. This type of surveillance is performed daily by the host facility operations personnel. During periods of good visibility visual surveillance of the subsea systems can be very effective.
7.3.2 Aerial and Marine surveillance
Helicopter and marine support vessels travel to and from the host facility frequently. If, at any time oil is detected on the seawater surface by helicopter and/or marine vessel operators, it is reported to the host facility supervisor for additional investigation. Aerial and marine surveillance is conducted in accordance with Fieldwood Energy’s overall surveillance plans and procedures. However, some of the subsea developments may not be in the marine vessel’s normal route to and from the host facilities, due to longer step outs and distances from the facility. In these circumstances, marine vessel visual surveillance may not be effective for that specific well site and aerial surveillance would be more effective.

7.3.3 Remotely Operated Vehicles Inspections
Remotely Operated Vehicle (ROV) inspections are not routine or frequent. If Operator visual surveillance or Aerial and Marine surveillance reveals evidence of a potential leak in the subsea system an ROV inspection can be used for confirmation of the source of the leakage.

ROV usage for maintenance and repairs also provides an opportunity to perform subsea surveillance to confirm that there is no leakage from the system.

7.4 Advanced Detection Techniques
New FWE subsea facilities to implement advanced detection techniques. Existing FWE subsea facilities to be reviewed for retrofitting advanced instrumentation and control system capabilities where existing SPS hardware support it.

Subsea process instrumentation is logically managed by the stand-alone Master Control Station (MCS), which is part of the Subsea Production Control System (SPCS):

- The SPCS is not a Safety Instrumented System (SIS).
- Standard commercially available SPCS(s) do not typically support advanced logic handling suitable for advanced detection techniques.
- The Production Control System (PCS), Distributed Control System (DCS), or Integrated Control and Safety System (ICSS) are more suitable to perform advanced monitoring algorithms such as CROC and MIMO.

Advanced monitoring techniques may require Software (SW) updates of the existing control system and/or additional operator training to include hands-on training with an Operator Training Simulator (OTS):

- Conditional Rate of Change (CROC): Conditional ROC uses rates of change thresholds to indicate an abnormal process, but also applies logic comparing several nodes in the system. For instance, the CROC algorithm compares the ROC at the wellhead and flowline for a higher confidence level.
- Mass-In/Mass-Out or Meter-In/Meter-Out (MIMO): Mass balance comparison between the subsea meters and topsides meters. For example, if negative, then more flow is occurring at the subsea meters than at the topside meters and indicates a potential subsea leak. May require steady state flowing conditions.
7.4.1 Conditional Rate of Change

The Conditional Rate of Change (CROC) method uses the ROC alarm and further adds a set of conditions to the logic in an effort to reduce false alarms. This method utilizes a Pressure Transmitter (PT) located at the wellhead or at nodes throughout the flowline to monitor for a significant pressure change that could account for a catastrophic loss of integrity. The PT should be located strategically close to the potential loss location for this method to be the most effective.

The CROC technical specification developed by Shell (Shell document # OPS0228) will be considered as guidance for software logic implementation on new facilities/projects. Refer to Shell document # OPS0228.

7.4.2 Mass-In/Mass-Out

The Mass-In/Mass-Out (MIMO) method utilizes mass measurement where subsea flowmeters are installed at or near the Wellheads (WH). The subsea meter measurements are compared real time to the liquids at the metered well test separator. Phase changes to be taken into consideration due to temperature and pressure variations. The topside control system may contain logic to determine the difference in mass that left the WH compared to that which arrived at the facility.

The accuracy of the MIMO method can be affected by several factors:

- Change in hold up volume.
- Flash table accuracy (Multiphase Flowmeter Calibration).
- The refresh rates of the topside and subsea metering equipment.
- Accurate temperature and pressure data.

The Modified Mass-In/Mass-Out (MIMO) method utilizes mass measurement where multiphase meters are installed at or near the wellheads and adds a set of conditions to the logic, similar to the CROC method. This method requires accurate metering at both, the subsea wells and at the host facility. Logic is then used to determine the disposition of the well fluid. With accurate metering the MIMO method is the most reliable for a full time detection of non-catastrophic leaks.
8.0 APPENDIX C: OFFSHORE AND OPERATOR TRAINING

FWE is implementing a phased approach to CRO training in order to ensure a minimum level of training is implemented before progressing to higher and more advanced training.

Each module to include a knowledge check assessment. Modules 1 and 2 are Computer Based Training (CBT) and to be implemented and tracked within FWE Safety and Environmental Management System (SEMS) training portal.

- **Phase (module) 1 Training:** Introductory course for offshore personnel to gain a basic overview of what Subsea Leak Detection is, the methods used, and the protocols followed.
- **Phase (module) 2 Training:** Advanced and specifically designed for the CRO. Training to cover the Facility specific information, protocols covered, the topside controls system software, how to use it and the actions required to be undertaken by the CRO.
- **Phase (module) 3 Training:** Hands-on (or equivalent) training using an Operator Training Simulator (OTS).

Phase 1 (introductory course) should be retaken on an annual basis.

8.1 Competency

Upon completion of the phased training, minimum competency to be verified for each offshore personnel type.

8.1.1 Offshore Personnel

Operators to be trained in Subsea Leak Detection methods and the processes involved. Operators should be able to:
- Understand what a Subsea Leak is.
- Understand what the different Subsea Leak scenarios are.
- Perform Visual Inspection & Identify a sheen if visible.
- Know the SOP for reporting a Subsea Leak to the CRO / Lead Operator.

8.1.2 Control Room Operator(s)

CRO(s) to be trained on SSLD methods and the processes involved. Each CRO should be able to:
- Quickly identify detectable subsea leaks and anomalies in production systems.
- Understand asset-specific monitoring methods.
- Rationalize process upset indications utilizing available tools and resources.
- Respond properly to leak alarms, including escalation protocols.
- Understand Approvals required for each operating environment and alarm type.
- Calculate hydrostatic pressure by knowing the water depth.
- Calculate the bottom up time.
8.1.3 Lead Operator

Lead Operators to be trained on SSLD methods and the processes involved. The Lead Operator’s Authority can be superseded by the OIM or FWE Management as required. The Lead Operator is responsible for:

- Understanding asset-specific monitoring methods.
- Quickly identify detectable subsea leaks and anomalies in production systems.
- Understand asset-specific monitoring methods.
- Rationalize process upset indications utilizing available tools and resources.
- Respond properly to leak alarms, including escalation protocols.
- Understand Approvals required for each operating environment and alarm type.
- Calculate hydrostatic pressure by knowing the water depth.
- Calculate the bottom up time.
- Clearing Alarms related to the Subsea Leak Detection System.
- Documenting and logging any variance from Subsea Leak Detection Alarms.
- Training the CRO(s).

8.2 Training Plans

Training to focus on the above stated competencies. Training plans intended to achieve the required competencies include (taken directly from the OOC SSLD working group July 2018 meeting):

Module 1, General Training (released in 2018):

- Recognize the significance of CRO training (Think Leak First).
- Compare Subsea system vs. pipeline leak detection.
- Identify types of leaks.
- Identify Rupture Escalation Barrier Components.

Module 2, Facility Specific Training (begin roll-out in 2019):

- Discuss the limitations of Alarms and Advanced monitoring.
- Identify Monitoring Techniques and Best Practices.
- Review the three (3) subsea leak alarms:
  - Conditional Rate of Change (CROC).
  - Flow Management Tools.
  - Alternate indications of potential subsea leak.
- Identify Anomalies and diagnostics:
  - Review diagnostic steps to validate or invalidate an alarm.
  - Review Flow Assurance Flow Chart for a Suspected Subsea Leak.
- Identify Response Actions Required:
  - Review time requirements for specific actions.
  - Demonstrate how to use Tools (exercise, checklists, decision matrix/trees, etc.).
  - Review proper notification requirements (what/who/when).

Module 3, Advanced Hands-On Training (begin roll-out following completion of Module 2):

- Using an Operator Training Simulator (OTS) or equivalent (e.g.: Test MCS), review scenarios specific to subsea leak.
- Using an OTS or equivalent, perform leak detection and response.
### 9.0 APPENDIX D: SUBSEA WELL AMBIENT PRESSURES

<table>
<thead>
<tr>
<th>Facility</th>
<th>Water Depth (ft)</th>
<th>SPS</th>
<th>Well</th>
<th>Water Depth (WDR)</th>
<th>STP</th>
<th>Flowing UPT (Tree)</th>
<th>Flowing DPT (Flowline)</th>
<th>Arrival Pressure @ BSDV</th>
<th>Ambient Hydrostatic Pressure</th>
<th>Flowing Condition</th>
<th>Flowline</th>
<th>Flowline MAOP</th>
<th>Total Flowline Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne Kika</td>
<td>6,340</td>
<td>Galapagos</td>
<td>Santa Cruz MC-607</td>
<td>6,326 ft</td>
<td>5,604 psia</td>
<td>3,355 psia</td>
<td>3,153 psia</td>
<td>600 psig</td>
<td>2,911 psia</td>
<td>ABOVE-AMBIENT</td>
<td>P: FA-2 A: FA-1</td>
<td>11,000 psia</td>
<td>61,124 ft</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Santiago MC-607</td>
<td>6,500 ft</td>
<td>4,962 psia</td>
<td>3,178 psia</td>
<td>3,126 psia</td>
<td>600 psig</td>
<td>2,900 psia</td>
<td>ABOVE-AMBIENT</td>
<td>P: FA-2 A: FA-1</td>
<td>11,000 psia</td>
<td>61,124 ft</td>
</tr>
<tr>
<td>Gulf Star 1</td>
<td>4,600</td>
<td>Gunflint</td>
<td>Gunflint #2 MC-948</td>
<td>6,150 ft</td>
<td>9,129 psia</td>
<td>6,869 psia</td>
<td>6,523 psia</td>
<td>1,600 psig</td>
<td>2,744 psia</td>
<td>ABOVE-AMBIENT</td>
<td>P: FA-200 A: FA-210</td>
<td>12,620 psia</td>
<td>111,594 ft</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Gunflint #4 MC-948</td>
<td>6,094 ft</td>
<td>11,185 psia</td>
<td>8,864 psia</td>
<td>8,613 psia</td>
<td>1,600 psig</td>
<td>2,719 psia</td>
<td>ABOVE-AMBIENT</td>
<td>P: FA-210 A: FA-200</td>
<td>12,620 psia</td>
<td>112,063 ft</td>
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<tr>
<td>Thunderhawk</td>
<td>6,050</td>
<td>Rio Grande</td>
<td>Big Bend MC-988</td>
<td>7,221 ft</td>
<td>2,557 psia</td>
<td>1,865 psia</td>
<td>1,820 psia</td>
<td>240 psig</td>
<td>3,220 psia</td>
<td>BELOW-AMBIENT</td>
<td>FA-1-0130 (RGL-N-R)</td>
<td>9,000 psia</td>
<td>99,421 ft</td>
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<tr>
<td></td>
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<td></td>
<td>Dantzler #1 MC-782</td>
<td>6,581 ft</td>
<td>7,030 psia</td>
<td>3,300 psia</td>
<td>2,130 psia</td>
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<td>2,936 psia</td>
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<td>FA-1-0140 (RGL-S-R)</td>
<td>9,000 psia</td>
<td>43,400 ft</td>
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<tr>
<td>Neptune</td>
<td>1,980</td>
<td>Swordfish</td>
<td>ST1 VK-917</td>
<td>4,370 ft</td>
<td>2,400 psia</td>
<td>1,400 psia</td>
<td>1,390 psia</td>
<td>85 psig</td>
<td>1,954 psia</td>
<td>BELOW-AMBIENT</td>
<td>KAA-1120 Flowline 2</td>
<td>6,000 psig</td>
<td>72,092 ft</td>
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<td></td>
<td></td>
<td></td>
<td>ST1 VK-962</td>
<td>4,677 ft</td>
<td>2,941 psia</td>
<td>1,740 psia</td>
<td>1,650 psia</td>
<td>85 psig</td>
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<td>BELOW-AMBIENT</td>
<td>KAA-1120 Flowline 2</td>
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<tr>
<td>Builwinkle</td>
<td>1,353</td>
<td>Troika</td>
<td>TA-6 GC-244</td>
<td>2,672 ft</td>
<td>5,600 psia</td>
<td>2,960 psia</td>
<td>2,900 psia</td>
<td>1,500 psig</td>
<td>1,201 psia</td>
<td>ABOVE-AMBIENT</td>
<td>FA-1-1011</td>
<td>7,584 psig</td>
<td>81,875 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TA-2 (FUTURE) GC-244</td>
<td>2,672 ft</td>
<td>6,283 psia</td>
<td>4,500 psia</td>
<td>4,500 psia</td>
<td>2,000 psig</td>
<td>1,201 psia</td>
<td>ABOVE-AMBIENT</td>
<td>FA-1-1011</td>
<td>7,584 psig</td>
<td>81,875 ft</td>
</tr>
<tr>
<td>Builwinkle</td>
<td>1,353</td>
<td>Orlov</td>
<td>TA-9 (FUTURE) GC-244</td>
<td>2,531 ft</td>
<td>8,420 psia</td>
<td>6,500 psia</td>
<td>5,500 psia</td>
<td>1,200 psig</td>
<td>1,186 psia</td>
<td>ABOVE-AMBIENT</td>
<td>FA-1-1019</td>
<td>9,200 psig</td>
<td>83,228 ft</td>
</tr>
<tr>
<td>Tarantula</td>
<td>484</td>
<td>Katmai</td>
<td>K1 (FUTURE) GC-40</td>
<td>2,079 ft</td>
<td>14,775 psia</td>
<td>11,400 psia</td>
<td>9,000 psia</td>
<td>4,750 psig</td>
<td>987 psia</td>
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<td>FA-2-0200</td>
<td>15,000 psig</td>
<td>137,970 ft</td>
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<td></td>
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<td>K2 (FUTURE) GC-89</td>
<td>1,921 ft</td>
<td>14,775 psia</td>
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<td>4,750 psig</td>
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<td>ABOVE-AMBIENT</td>
<td>FA-2-0200</td>
<td>15,000 psig</td>
<td>137,970 ft</td>
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</tbody>
</table>

**Note 1:** Water density is 62.4 lb/ft³. Subsea ambient pressure assumes the s.g. of seawater is 1.027. The pressure per foot water depth is then 62.4 lb/ft³ / 144 inches per square foot * 1.027 = 0.445 psi per foot water depth.

**Note 2:** Sub-ambient conditions may safely exist because oil is less dense than water. The s.g. of oil can range between 0.7 – 0.9, but can increase with water-cut.

**Note 3:** This is a generalization and depends on the elevation of the subsea flowline system, but if flowing conditions are greater than ambient then no subsea leak exists and system integrity is intact if any flowline can keep ≥ 200 psi above the referenced ambient pressure at the wellhead in a no-flow condition.
Note 4: This is a generalization and depends on the elevation of the subsea flowline system, but if flowing conditions are less than ambient (sub-ambient) then no subsea leak exists and system integrity is intact if any flowline can keep \( \geq 200 \) psi below the referenced ambient pressure at the wellhead in a no-flow condition.
### 10.0 APPENDIX E: GENERAL SSLD DECISION RECORD

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<th>Time:</th>
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<tr>
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Operator:

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<th>Initial Condition / Reason of Uncertainty:</th>
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<table>
<thead>
<tr>
<th>Troubleshooting / System Verification:</th>
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<table>
<thead>
<tr>
<th>UWA Decision to Continue to Produce:</th>
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<thead>
<tr>
<th>UWA (Print Name):</th>
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<table>
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<tr>
<th>Signature:</th>
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<th>Date:</th>
<th>Time:</th>
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Note: If a facility specific form is unavailable, this form to be used to record any production uncertainty and UWA approval to continue safe production.