Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir & Injection System

RPSEA Project - 11121-5302-01
Safe Marine Transfer, LLC
Final Project Report – overview presentation

July 14, 2016; Houston, TX.
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Introductions

• Sign-in please

• RPSEA Technical Champion – role
  o Technical expertise & Facilitator

• Meeting purpose - SMT Final Project Presentation
  o PI & subcontractor summary presentation of project results
  o Solicit opportunities for SMT to follow-up with individual business need driven, targeted presentations
  o Solicit potential site-specific applications for subsequent business case analysis

• Meeting process
  o Traditional business etiquette
  o “Parking – lot” flipchart

• Introductions
  o Name, organization, area of expertise
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Why did RPSEA / DOE solicit this work? SMT undertake?

Very large number of smaller resource pools that in aggregate represent a significant resource.
Why did RPSEA / DOE solicit this work? SMT undertake?

Safe and environmental friendly development can:

- Improve US energy security
- Increase royalty payments
- Promote American jobs and tax base
- Improve America’s trade balance
The challenges

Technical;
production blockage
well bore integrity

Financial;
rising costs
low product price
Develop a qualified design for a 3,000 bbl subsea chemical storage and injection system suitable for Gulf of Mexico applications.

SMT - The SMarT Solution™

Enabling long-distance subsea tie-backs
- 3000 BBL chemical storage & injection (eliminate chemical umbilical)
- Subsea pig launcher (eliminate 2\textsuperscript{nd} flowline)

Platform for enabling brownfield EOR
- Seafloor placement of ‘kit’ enabling shuttle to – from surface for IRM

Video link
Vision of success

- Low cost (deliver as a service)
  - Low cost, commonly available anchor handlers / tugs to deploy / recover;
  - Short duration marine operations; minimize weather-window risks
  - “Redundancy” and safe-guards designed in
  - “Re-useable” / re-deploy when / where needed

- High availability and reliability
  - COTS
  - Shorter design life; lower costs & simpler design
  - Systems approach; fleet of shuttles to service a region

- Safe
  - Dual barrier chemical containment
  - Order of magnitude lower number of installation days
Business drivers

- Supplement existing umbilical solutions which may be;
  - Undersized due to;
    - ‘missed’ original estimates in well requirements,
    - Changing reservoir production characteristics, further field delineation
  - Damaged / fouled / corroded / plugged

- Enable development of smaller satellite fields that can not bear the complexity, cost (OPEX & CAPEX), operational risks associated with traditional system.

- Early Production Systems whereby umbilical purchase and installation could be delayed until full field assessment and/or development is complete.

- Chemical support services for subsea construction, commissioning, & decommissioning

- Use in well containment / spill response activities
Final report

1. Oceanworks

1.1. Reports (69 files – 87 MB)
   1.1.1. Engineering Design Report (1133-000-E00001_3 / 101 pages)
   1.1.2. Flow Calculations Report (1133-000-E10800_00 / 26 pages)
   1.1.3. Bladder Refill (1133-000-E10900_00 / 16 pages)
   1.1.4. Budgetary Cost Estimates SCIU (1133-000-E10900_00 / 15 pages)
   1.1.5. Compliance Matrix (SMT 1133 / xls)
   1.1.6. CONOPS (1133-000-E107800_02 / 28 pages)
   1.1.7. DFMECA (1133-000-E00010_2016.04.05_ / xls)
   1.1.8. TRL Report (1133-000-E10500_TRL / xls)

1.2. Data (30 files - 53 MB)
   1.2.1. Bill of Materials (1133-000-E10100 / xls)
   1.2.2. Data Sheets

1.3. Drawings – final (13 files – 4.5 MB - .pdf)
   1.3.1. LDHI SCIU (1133-120-A60000_2)
   1.3.2. MeOH SCIU (1133-120-A50000_2)
   1.3.3. Interface Control Diagram (1133-000-E00040_02)
   1.3.4. Electrical Schematics (1133-500-S10000_A_2016.04.11)
   1.3.5. Hydraulic Schematic (1133-000-E10000_15)

2. DeepStar Report 10302 (1 file – 3 MB)

3. Inflection Consulting (7 files – 5 MB)
   3.2. Data and support

Final report is a 130 page summary of work done.

Details are contained within the Appendices

These can selectively be made available for review
Shuttle System

Design Features:
Re-usable / re-deployable across very wide range of water depths – to 10,000 fsw

Chemical storage in hull (3 x 1100 bbls)

Space and capacity on deck to handle additional payload (shown with SCIU)

Buoyancy columns, re-purposed U.S. DOT approved CNG storage units

Shuttle structure is designed to applicable ABS and USCG CFR Rules and Regulations (AiP)
Subsea Chemical Storage System (SCSS)

Design features:

- Three (3) 1100 bbl bladders w/ dual barrier located in hull
- Capable of storing different chemicals
- Capacity for ‘small’ consumption chemical tanks on deck

Pressure compensated
No high differential pressures – depth independent

Double isolation of chemicals
Lower chance of leakage

Engineered fabric being utilized in critical duty military service
Subsea Chemical Injection Unit (SCIU)

OceanWorks Leverages and Costshares MWCC Experience with Subsea Dispersant Injection

Main components:
- Subsea pump/motor assembly (One shown independently recoverable)
- Multi Quick Connect (MQC) for connections to the bladders and wells
- ROV actuated valves
- Chemical Injection Metering Valves (CIMV) – independently recoverable
Marine operations

Deploy and recover the shuttle payload through the use of a catenary connection method to a pair of topside vessels.

- Minimal marine exposure + well within operational boundaries = safe
- Small vessels + short exposure = low cost

Operations:
- Deploy to Seafloor
- In-Situ Chemical Refill
- Recover to Surface
Models, Simulations, CFD, Testing, DFMECA Reviews, etc.

All identifiable risks were determined to be manageable and achieved overall TRL 4 with most components Commercial Off The Shelf (COTS)

Video output of model simulation
System differentiators

- Large volume (3000 bbls) vs multiple small (30 - 200 bbls)
- Low-cost vessels of opportunity vs massive derrick barge
- Safe & environmentally friendly
  - SIGNIFICANTLY less marine ops (comparable volumes)
  - Dual barrier containment

*Figure 4, Oceanusering Subsea Reservoir, 1290 gallons volume*
System differentiators

**Most common offshore practice**
- Chemicals carried in “Tote Tanks”, as deck cargo
- Tote Tanks generally are 1 to 5 tons set up to be moved with fork lifts or lifted crane
- Chemical stored on platform
- Chemicals pumped via umbilical to point of use.

**SMT system**
- Seal chemicals in a pressure compensated dual barrier bladder system at dockside
- Deliver to point of use in re-usable double hull shuttle
- Eliminate need for expensive & complex chemical umbilical
- Re-usable shuttle facilitates rigorous inspection, maintenance, repair and up-grades to system on a routine & cost effective basis
Collaboration & Cooperation

DeepStar:
- Identifying / defining the ‘need’
- DeepStar reports
  - Costshare & Start-point
- Support of RPSEA project funding
- SME review & project

Most important 1st steps

RPSEA & DOE / NETL:
- 2 year & $6 m project
- Major funding from DOE / NETL
- Technical Committee input and review

Working together

Safe Marine Transfer, LLC:
- Local (Houston) startup
- Leverage local / regional resources
- Best in class contactor support

Moving to new heights
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Shuttle Design Review

Presented by: Alan C. McClure Associates Inc.

July 14, 2016
Houston, TX
ACMA Scope of Work

- Transport and Installation Vessel (Shuttle)
  - Overall Shuttle design
    - Dimensions and Arrangements
    - Structure
    - Weight
    - Buoyancy
    - Systems (ballast, vent, cargo, monitoring, high pressure buoyancy)
    - Operating Parameters
    - CFD Analysis
  - Analyze key components to class and regulatory requirements and show how the design will meet them (ABS, USCG, BSEE)
  - Develop installation and recovery plans (with Canyon Offshore)
  - DFMECA – API RP17N
  - Develop Specification and Design Package
  - Obtain Approval In Principal (AIP)
General Layout - Elevation

SCIU
(Dry Weight 30,000lbs)

20’

8’

15’

50’
ABS Approval in Principal

- Approval in Principal (AIP) is an intermediate approval step to provide proof of feasibility to project partners and Regulatory bodies.
- AIP is a process by which ABS issues a statement of fact that a proposed novel concept or new technology complies with the intent of the most applicable ABS Rules and Guides as well as appropriate industry codes and standards.
- Requires Qualitative Risk Assessments:
  - CONOPS (Concept of Operations)
  - FMEA (Failure Modes and Effects Analysis)

Products of AIP:

- Statement of Fact Letter attesting to feasibility of the concept and Approval in Principal.
- Approval Road Map which defines a list of required submittals in order to obtain full Class approval.
Systems Developed

- Steel Hull Structure
- Ballasting/Deballasting System (water)
- Tank Vents
- Double Containment Pressure Compensation System
- Weight Compensation Ballast Blocks (solid)
- Buoyancy Cylinders
- Chain Storage and Handling (winch)
- Containment System
- Hydraulic Valve Control System
- Bottom Water Jetting
Systems Developed by Others

- Chemical Storage Bladders
- Double Containment Expansion Bladders
- Electric Power and Control System
- Subsea Chemical Injection Unit (SCIU)
Shuttle structure is designed to applicable ABS Rules and CFR Regulations:

**Codes, Guides, Rules & Regulations**

1. ABS *Rules for Building and Classing Steel Barges*, 2015
2. ABS *Guide For Buckling And Ultimate Strength Assessment For Offshore Structures* - 2004 (Revised 2006)
3. ABS *Rules for Building and Classing Steel Vessels under 90 meters*, 2015
Steel Structure Design

Additional Standards used for structural design included:


- Column Design based on $90^\circ$ roll and pitch
- Hull structure designed for full head with columns just submerged
- Hull assumed fully flooded at seafloor
Water Ballasting/Deballasting System

**Piping**
- Schedule 40 Carbon Steel Pipe, ASTM

**Valves**
- Valves are open during submergence and recovery so there is no significant differential pressure on piping
- 316 Stainless Steel Butterfly Valves for 6” and 8” size
- 316 Stainless Steel Ball Valves for 2”, 3” and 4” size
- ANSI 125 lb
- Visual Open/Closed Position Indicator

**Actuators**
- Double Acting Hydraulic Actuators
- API Certified and Tested to 10,000 feet
- ISO 13628-8 Class 4 ROV Bucket
Weight Compensation

- Single Shuttle design will require mass adjustment for varying cargo densities

- Solid ballast blocks used to add mass to the shuttle when carrying lighter cargo such as Methanol

- Shuttle Recovery after Methanol:
  - Ballast blocks removed to reduce Shuttle mass due to replacement of Methanol with seawater
  - ROV actuates release mechanism to drop weights onto the seafloor
  - Two step system to release blocks utilized for safety
  - Pin must first be pulled by ROV then ROV provides power to a hydraulic piston to release blocks

- Alternative system uses direct crane liftoff of ballast blocks from deck of the Shuttle
Carbon Fiber Buoyancy Cylinders

- Existing technology currently approved for Type IV DOT transport of CNG on US roads and highways
- Inspection, certification and testing overseen by ABS
- 9,000 psi burst pressure
- 4,800 lbs empty
- Maximum Expansion Length: 2 inches
- Maximum Expansion Diameter: 0.3 inches
- Fill Gas: Nitrogen
- 5,000 ft water depth requires only 2,250 psi
- Pressurized to 100 psi above site water depth and sealed
- Cylinder Material has prior application as subsea riser
- Cylinder Support only at ends
- Cylinder Support designed for 90° Roll and Pitch
**Chain**

- 3” Stud Chain
- 600 ft of deployable chain on each end of shuttle
- Chain secured within chain locker to prevent loss of chain
- Net submerged weight for both chains is 88,000 lbs
- Chain Catenary serves two functions
  1. Creates motions disconnect between submerged shuttle and surface vessel
  2. Allows the mass of the shuttle to be adjusted during transit through the water column to control ascent/descent speed

**Chain Connection to Polyline**

- Ballgrab connector connects chain to polyline from surface vessel
- Subsea connection on recovery done by ROV
- ABS Approved
- API/ISO TSS29001 2010 Compliance
Chain Winch

- Used to deploy and recover 3” Stud chain onto shuttle
- Designed to recover total weight of submerged chain (44,000 lbs)
- Not used for mooring purposes so not designed to breaking strength
- Hydraulically driven by ROV on seafloor or by support vessel when near the surface
- Isolation valves allow recovery of a single chain if necessary
- Adaptation of an existing Markey Design

Approximate Dimensions:
- Length 8.75’
- Breadth 2.0’
- Height 5.5’
- Weight 10,000 lbs
Containment System

- Allows seawater to enter the annular space around the Chemical Bladder due to compression of the chemical in the Bladder during submergence
- Balances interior pressure in the Chemical Bladder with the ambient seawater pressure
- For recovery the sea-chest valve is closed and the valve to the expansion bladder is opened. As remaining liquid in the Chemical Bladder expands, seawater is pushed into the expansion bladder
- Provides double containment of the chemical cargo
- Valves, piping and actuators are the same as those listed under the Water Ballasting/Deballasting system
Containment System

- Topsides Connection
- Contamination Sensor
- Wing Tank Vent
- Sea chest valve For Containment System
- Expansion Bladder
- Wing Tank Ballast Inlet

NO HIGH DIFFERENTIAL PRESSURES
Hydraulic Control System

- Provides control of valve actuators and chain winches
- ROV provides hydraulic stab at seafloor to shuttle control system
- Supply boat provides hydraulic stab when shuttle is operating near the surface in lieu of the ROV
- Stainless Steel 316 Tubing is ¼” Swagelok type, minimum working pressure 3,700 psig
- Hot-stab receptacles are API 17H compliant
Water Jetting is provided as a contingency method for breaking bottom suction

- Shuttle net weight at the seafloor is small compared to the shuttle’s footprint.

- An unaided breakout analysis was performed which determined that the net buoyancy of the shuttle, once the chains are removed is sufficient to free the Shuttle from the seafloor.

- Should breakout be an issue the Shuttle is equipped with three water jet nozzles along its breadth approximately 24 feet from the bow.

- ROV can connect with the water jet piping via a Kamlok type connector located above the main deck of the Shuttle.
# CFD Analysis – 4 Stage Process

<table>
<thead>
<tr>
<th>Phase</th>
<th>CFD Setup</th>
<th>CFD Results</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steady Flow Analysis</td>
<td>Overturning Forces</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>2</td>
<td>Forced Shuttle Motions</td>
<td>Damping of Shuttle Motions</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>3</td>
<td>Free Rotation of Shuttle</td>
<td>Evolution of Shuttle Forces</td>
<td><img src="image3.png" alt="Image" /></td>
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<tr>
<td>4</td>
<td>Full Ascent</td>
<td>Full System w/ Lowering Lines</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>
CFD Results – Key Findings

Will shuttle remain stable?

- Yes
  - Remains upright when submerged and subjected to currents
  - Does not require lowering lines to remain upright

Will shuttle rotate? If so, how much?

- Negligible rotation
  - Lowering lines only control position
  - Shuttle stays upright during transit to/from seabed
CFD – Phase I

- Steady Flow Fixed Rotation Analysis
  - Descent / Ascent Rate: +/- 0.50 knots
  - Current Speed: 2.0 knots
- Buoyancy vs Hydrodynamics
- Worst Equilibrium Angle: 7 deg Roll

Stream Line Visualizations (Quartering)
CFD Phase I - Operational Impacts

- Shuttle orientation
  - Practically static
  - Lowering lines only control shuttle position

- Submerged currents
  - Will not flip shuttle (up to 2 knots)
  - Barely rotates the shuttle
  - Operations are NOT limited by shuttle stability
○ Forced Rotation for Damping (Submerged)

- Natural Periods:

<table>
<thead>
<tr>
<th>Roll Natural Period ($s$)</th>
<th>Pitch Natural Period ($s$)</th>
<th>Yaw Natural Period ($s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.39</td>
<td>19.47</td>
<td>20.73</td>
</tr>
</tbody>
</table>

- Slow natural period
- Slow rotation motions
  - Negligible concern for fatigue on columns
Results: Rotational Damping Coefficient

- Shuttle has supercritical damping
- No fluttering or oscillation
- Shuttle is **not** a dynamic body
  - Hydrostatic stiffness significantly greater than inertia
  - Shuttle will be readily controlled by surface vessels

### Damping is Very Good

<table>
<thead>
<tr>
<th>Multiplier of Natural Frequency</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
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</thead>
<tbody>
<tr>
<td>Frequency (rad/s)</td>
<td>0.2582</td>
<td>0.2904</td>
<td>0.3227</td>
<td>0.355</td>
<td>0.3872</td>
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<tr>
<td>Damping Ratio</td>
<td>1.337</td>
<td>1.399</td>
<td>1.465</td>
<td>1.516</td>
<td>1.564</td>
</tr>
</tbody>
</table>
CFD Phase III

- Free Rotation Analysis
  - Descent / Ascent Rate: +/- 0.50 knots
  - Current Speed: 2.0 knots
- Worst Pitch Angle: 1.6 deg
- Pitch Negligible
- Hydrostatics Conservative
CFD Phase III

- Compare Pitch Angles
  - CFD Phase I (Hydrostatic): 1.61 deg
  - CFD Phase III (Dynamic): 1.60 deg

- Hydrostatic Analysis is Suitable for Future Designs
  - No more dynamic analysis of Shuttle
  - No lifting forces

- Shuttle Descent
  - Behaves like a stone dropping in water
Shuttle can be regarded as essentially static in orientation

Extremely good stability

Flutter is not a concern

Little concern for fatigue on columns

Negligible rotation angles

Shuttle behaves typical to objects descending in a water column

Hydrostatic analysis is a suitable method for calculating stability and rotational angles of the Shuttle
Global Simulation of Ascent

- CFD model included full length of both catenaries
- Used same Shuttle model as all previous Phases
- Direct modeling of physics of fluids around Shuttle
- Elastic stretch of polyline included in catenary model
- Time connected physics modeling of fully dynamic catenary lines
- Simulation assumed:
  - Vertical ascent at 0.5 knots
  - Ocean current of 2.0 knots from abeam
  - Starting position 5,000 ft down
Global Simulation of catenary lines and Shuttle in full water column

Catenary Line physics time connected to Shuttle with full interaction and dynamic feedback

Ascent water velocity

0.5 knots

Current velocity

2 knots

Surface vessels
Flow Visualization
CFD IV Results – Key Findings

- Catenary lines do provide longitudinal restoring forces
- Current from purely abeam direction causes Shuttle to drift laterally
- Movement is sufficiently slow to allow the surface vessels to re-orient the system to align with the current
- Catenary lines do not degrade Shuttle stability
- Catenary lines provide coupling between Shuttle yaw and pitch
- Rotational magnitudes (yaw and pitch) are small
DFMECA Introduction

DFMECA Review of Shuttle Design

- Adaptation of Failure Mode, Effects and Criticality Analysis and API RP 17N Technology Risk and Readiness Assessment

- Each Component of each system is given a Technology Readiness Level (TRL). The TRL numbers range from 0 for an unproven concept with no analysis or testing having been performed, to 7 for a field proven system

- System is then assigned a TRL number based on the lowest number from each of its components
TRL Example

- Each Component is listed and reference is given
- Each Component is assigned its own TRL
- Minimum of all the components sets the TRL for the entire system

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Ref Dwg No.</th>
<th>TRL of Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Deballasting/Vent System</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Steel Piping</td>
<td>B1228-1-506-001</td>
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<td>2.1.2</td>
<td>Flanges</td>
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<td>2.1.3</td>
<td>Gate Valves</td>
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<td>2.1.4</td>
<td>Pressure Relief Valve</td>
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<td>2.1.5</td>
<td>Hydraulic Actuator</td>
<td>B1228-1-506-005</td>
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<tr>
<td>2.1.6</td>
<td>Compressed Air Connection</td>
<td>B1228-1-506-005</td>
<td>6</td>
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</tbody>
</table>

A separate column (Not shown above for clarity) lists the rational of the TRL.
DFMECA Review of Shuttle Design

- Each failure mode is listed, along with its effect, indicators and safeguards.

- For each failure mode, a numerical value from 1 to 5 and a descriptive consequence is assigned.

- Probability/frequency of this failure is given a letter assignment from A-E. The resulting values are cross referenced to the risk matrix to assign a color: red, yellow or green.

- For Consequence, 1 is considered minor (less than $100,000) and 5 is considered catastrophic (damages greater than $100 million).

- For Probability/Frequency, A is considered Unlikely and E is Very Frequent.
DFMECA Example Failure Mode

Failure Mode, Effect, Indicators etc. are defined
TRL is carried over from TRL Tab.

<table>
<thead>
<tr>
<th>No.</th>
<th>Equipment / Function / Requirement</th>
<th>TRL of component</th>
<th>Failure Mode</th>
<th>Effect</th>
<th>Indicators / Detection</th>
<th>Safeguards</th>
<th>Mitigation / Prevention</th>
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<tr>
<td></td>
<td>Shuttle Systems</td>
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<td></td>
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<td>2.0</td>
<td>Shuttle Systems</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Deballasting / Vent System</td>
<td>6.0</td>
<td>Vent Valves fails to open on submergence</td>
<td>Ballast tank collapse</td>
<td>Visual Inspection of Valve Status</td>
<td>Visual inspection before deployment</td>
<td></td>
</tr>
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</table>

Consequence and Probability are Assigned, which provide the Risk Color.
Consequence and Probability are Assigned, which provide the Risk Color

<table>
<thead>
<tr>
<th>No.</th>
<th>Equipment / Function / Requirement</th>
<th>Consequence (1-5)</th>
<th>Consequence Description</th>
<th>Probability/ Frequency (A-E)</th>
<th>Risk Category (Color)</th>
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<td>Shuttle Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Deballasting/Vent System</td>
<td>2</td>
<td>Cannot deballast tank upon recovery</td>
<td>B</td>
<td></td>
</tr>
</tbody>
</table>

Additional columns to the right of the Risk Category allow for comments on Recommended action and other comments (Not shown above for clarity)
## DFMECA Risk Matrix

### Probability:

- **Unlikely**: Never heard of in the Oil & Gas Offshore Industry (but still is a possibility).
- **Remote**: Heard of in the Oil & Gas Offshore Industry (unlikely but has still happened to others).
- **Occasional**: Incident has occurred in Company Operations.
- **Frequent**: Incident has occurred several times a year in Company wide Operations.
- **Very Frequent**: Happens several times a year at an individual asset.

### Consequence:

- **Minor**: Less than $100,000: insignificant damage to plant and equipment
- **Moderate**: $100,000 - $1,000,000: limited damage to plant and equipment
- **Significant**: $1,000,000 - $10 million: significant damage to local area or essential plant or equipment
- **Severe**: $10-100 million: Damage extending to several areas/significant impairment of installation / equipment integrity
- **Catastrophic**: >$100 million: Severe and extensive damage to plant and/or total asset loss

The two scales together form a risk matrix, as follows:

<table>
<thead>
<tr>
<th></th>
<th>A - Unlikely</th>
<th>B - Remote</th>
<th>C - Occasional</th>
<th>D - Frequent</th>
<th>E - Very Frequent</th>
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<tbody>
<tr>
<td>1 - Minor</td>
<td>1A</td>
<td>1B</td>
<td>1C</td>
<td>1D</td>
<td>1E</td>
</tr>
<tr>
<td>2 - Moderate</td>
<td>2A</td>
<td>2B</td>
<td>2C</td>
<td>2D</td>
<td>2E</td>
</tr>
<tr>
<td>3 - Significant</td>
<td>3A</td>
<td>3B</td>
<td>3C</td>
<td>3D</td>
<td>3E</td>
</tr>
<tr>
<td>4 - Severe</td>
<td>4A</td>
<td>4B</td>
<td>4C</td>
<td>4D</td>
<td>4E</td>
</tr>
<tr>
<td>5 - Catastrophic</td>
<td>5A</td>
<td>5B</td>
<td>5C</td>
<td>5D</td>
<td>5E</td>
</tr>
</tbody>
</table>
DFMECA Results

Two Systems Needed Additional Attention:

- Buoyancy Cylinders
- Ballast Blocks

Reduce failure consequence or probability of failure (or both)

<table>
<thead>
<tr>
<th>Ballast Blocks</th>
<th>Buoyancy Cylinders</th>
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<tr>
<td>TRL – 5</td>
<td>TRL - 4</td>
</tr>
<tr>
<td>Consequence – 2</td>
<td>Consequence - 3</td>
</tr>
<tr>
<td>Probability – C</td>
<td>Probability - B</td>
</tr>
<tr>
<td>Risk Category – Yellow</td>
<td>Risk Category – Yellow</td>
</tr>
</tbody>
</table>

- Removal of Blocks
- Migration Simplify System
- Submerged service and water
- Excess internal pressure
Systems That Need Improving:

Buoyancy Cylinders

- TRL – 4
- Consequence - 3
- Probability – B
- Risk Category – Yellow

Challenge is to improve either the failure consequence or its probability of failure (or both)
ABS AMERICAS-HOUSTON
Offshore Engineering Department
Inter-Group Memorandum

5 May 2016

From: Safety Team
To: Structures Team
Attn: M Liao / J. He

Subject: Subsea Chemical Shuttle
Approval In Principle

With regard to the safety related aspects of the design, we have received the following items:

B1228-1-001, Rev. 3 “Shuttle Basis of Design”
B1228-1-002, Rev. 0 “Shuttle Design Report”
B1228-1-070-001, Rev. 0 “General Arrangement”
B1228-1-070-002, Rev. 0 “Tank Plan”

for the subject unit for our approval in principle in accordance with the following Rules and Regulations:

♦ ABS Rules for Building and Classing Steel Barges, 2013
♦ ABS Review and Approval of Novel Concepts, 2003

We have completed our evaluation and found the arrangements as indicated can be satisfactory upon satisfactory review. We have no reservations on the issuance of an Approval In Principle for the design.

Daniel Son

Please credit our group with hours as noted in O2E

ABS Total Comments: 44
6 Closed
18 Site Specific
20 Phase III Fabrication
<table>
<thead>
<tr>
<th>Time</th>
<th>Duration</th>
<th>Event Description</th>
<th>Presenter(s)</th>
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<tbody>
<tr>
<td>8:00 AM - 8:30 AM</td>
<td>30</td>
<td>Arrival and pre-meeting networking</td>
<td></td>
</tr>
<tr>
<td>8:30 AM - 8:35 AM</td>
<td>5</td>
<td>Building safety</td>
<td>Canyon</td>
</tr>
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<td>8:35 AM - 8:55 AM</td>
<td>20</td>
<td>Introductions &amp; meeting &quot;process&quot;</td>
<td>RPSEA Technical Champion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tom Gay</td>
</tr>
<tr>
<td>8:55 AM - 9:15 AM</td>
<td>20</td>
<td>Project scope &amp; results - overview</td>
<td>SMT</td>
</tr>
<tr>
<td>9:15 AM - 9:45 AM</td>
<td>30</td>
<td>Shuttle</td>
<td>ACMA</td>
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<tr>
<td></td>
<td></td>
<td>a) Design</td>
<td>Scott McClure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Analysis &amp; CFD</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) ABS - AiP</td>
<td></td>
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<tr>
<td>9:45 AM - 10:00 AM</td>
<td>15</td>
<td>Break</td>
<td>SMT</td>
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<tr>
<td>10:00 AM - 10:10 AM</td>
<td>10</td>
<td>Subsea Chemical Storage System (SCSS); overview</td>
<td>Trelleborg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Jay Poole</td>
</tr>
<tr>
<td>10:10 AM - 10:20 AM</td>
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<td>Bladder material; elastomeric material</td>
<td>AIRE Industrial</td>
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<td>Tim Lewis</td>
</tr>
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<td>10:20 AM - 10:30 AM</td>
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<td>Bladder fabrication; plastic material</td>
<td></td>
</tr>
<tr>
<td>10:30 AM - 10:45 AM</td>
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<td>Material - chemical; validation</td>
<td>Argen polymer, LLC</td>
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<td></td>
<td></td>
<td>Jeff Bahr</td>
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<td>10:45 AM - 11:00 AM</td>
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<td>SMT</td>
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<td></td>
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<td></td>
<td>Jim Chitwood</td>
</tr>
<tr>
<td>11:00 AM - 11:45 AM</td>
<td>45</td>
<td>Lunch provided</td>
<td>OceanWorks Int'l</td>
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<td>11:45 AM - 12:30 PM</td>
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<td>Subsea Chemical Injection Unit (SCIU)</td>
<td>Menno Huizinga</td>
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<td>12:30 PM - 12:45 PM</td>
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<td>Break</td>
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<td>12:45 PM - 1:15 PM</td>
<td>30</td>
<td>Marine operations</td>
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<td></td>
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<td>Ops simulation and operational planning</td>
<td>Tim Krasin</td>
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<td></td>
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<td>GRI</td>
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<tr>
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<td></td>
<td>Steve Dodd</td>
</tr>
<tr>
<td>1:15 PM - 1:45 PM</td>
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<td>Open discussion</td>
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<td></td>
<td></td>
<td></td>
<td>Tom Gay lead</td>
</tr>
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<td>1:45 PM - 2:00 PM</td>
<td>15</td>
<td>Meeting Summary</td>
<td>RPSEA technical Champion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) Action items (what)</td>
<td>Tom Gay lead</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Follow-up (who &amp; when)</td>
<td></td>
</tr>
<tr>
<td>2:00 PM - 2:00 PM</td>
<td>0</td>
<td>Adjourn</td>
<td>All</td>
</tr>
</tbody>
</table>
Engineer fabric; 1000’s of uses over decades

- Abrasion resistant
- Tear resistant
- Tremendous tensile strength
- Wet environment properties
- Material – matched to chemical use
- 10-year + life expectancy in many applications
Subsea Chemical Storage System (SCSS) Engineered Fabrics

Two different bladder fabrics & design qualified:

- A plastic bladder material from Seaman’ with fabrication by Aire

- An elastomeric bladder material developed by Trelleberg with fabrication by Avon

The 1100 bbl designs will fit within the 3 rectangular cargo holds in the shuttle.
Chemical / fabric compatibility; 3rd party validation
ARGEN POLYMERS (Woodlands)

Chemical / fabric tests – leverage earlier work by Stress

1. MeOH
2. LDHI
3. Scale Inhibitor
4. Corrosion Inhibitor
5. Asphaltene Inhibitor
6. Dispersant
7. Seawater
Scale Model Test Apparatus
(1/5 scale)

Model System Layout

- 500 gal tank sea water simulation fluid
- Model containing bladder, approx. volume 450 gal
- Pump capable of up to 20 gpm @ a low head, 10 psi or less
- 500 gal tank chemical simulation fluid
- 500 gal tank mixing tank

Bladder and Hold Detail

- Connector to allow inside flexible hose connection to outside piping
- Flexible hose connecting the bladder to the hold opening

bladder attachments at three levels to study effects of the attachments

Construct & operate Oceanworks Int’l
<table>
<thead>
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<td>6) Meeting Summary</td>
<td>RPSEA technical Champion- Tom Gay lead</td>
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<td>Adjourn</td>
<td>All</td>
</tr>
</tbody>
</table>
Welcome to the World of Trelleborg

Engineered Fabrics - Rutherfordton, NC Facility

July 14, 2016
Customer Partnerships

UTC Aerospace Systems

Honeywell

conEdison, inc.

SALISBURY by Honeywell

GOODRICH

BOEING

NASA

Mercedes-Benz

Bell Helicopter

A Textron Company

Sikorsky

A United Technologies Company

CHRYSLER

TRELLEBORG
Demanding Environments

- TCS has polymer coated constructions in a vast number of demanding applications.
Subsea Storage

Material selection process /
- In tanks currently storing jet fuels, racing fuels, military grade fuels and many other variants of petroleum.
- Currently in storage platforms from 500 – 210,000 gallons
- Currently in wet, dry, extreme hot and cold, wind, dust and UV.
  - Successful fabricators in each
- We have pulled from this performance history
  - Strength
  - Chemical compatibility – polymer selection – testing in fluids
  - Other aspects of FFF – design engineering based on tank FEA
- End results – Subsea chemical storage tank.
Jay Poole
Technical Sales
Jay.poole@Trelleborg.com
828-286-7195
828-289-8801 (cell)
<table>
<thead>
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Deepwater Permanent Subsea
Pressure Compensated
Chemical Reservoir & Injection System

11121-5302-01
Tim Lewis
AIRE, INC

Safe Marine Transfer, LLC, Final Close-out Presentation
July 14, 2016
Houston, TX
AIRE, INC

- 60,000 sq ft facility located in Boise, ID
- 25+ years of experience with industrial fabrics
- Background in oil and gas is broad, we have designed and built custom well head containment, full frack containment, and multiple bladder applications.
- We have also built for Nuclear, Disaster Preparedness, Government and multiple research and development projects
Quick overview of tasks

• Under contract 12/2015
• Design multiple scale model bladders
• Locate suitable fabric
• Assist with fabric qualification
• Develop an operating process for bladder
Scale Model Submersion Testing

To view videos of testing visit these links

https://youtu.be/-uMulYhPIUY

https://youtu.be/O6HORrBWGeY
Scale version for verification testing

Verticle threaded V-link attachment patches provided around tank perimeter on three planes spaced off the centerline. V-Link attachments will provide direct attachment to hard attachment points constructed along the inside of test tank. V-links will be adjustable from one patch to another ...(McMaster Carr P/N 3709133)

*Bladder intended to be flipped over within test tank for top draw / bottom draw tests

© 2014 SMT
Fabric Selection/ Qualification

- Selected Seaman's XR-5
- Performed 30 and 60 day analysis

Results
- Scale Inhibitor - A rating
- Methanol – A rating
- Sea Water – A rating
- Corexit – still in testing
Contacts

PI: Tim Lewis
AIRE, INC
tim.lewis@aire.com
1-800-247-3846
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Polymer Materials Testing, Analysis, Consulting

Focused Elastomer & Polymer Expertise

Deep Oil & Gas Experience

Extensive Capabilities

Rapid Turnaround

Driven to Deliver Material Information
Environmental Aging of Polymers

- Drilling, Completion, Stimulation etc.
- Sour (H₂S) Environments
- Nitrogen, Carbon Dioxide, Methane, etc.
- UV Weatherometer

Autoclave Aging & Pressure Testing
- Pressures up to 25,000 psig
- Temperatures up to 340°C

Methods
- API, ISO, NACE, NORSOK
- Life Estimation, Test to Failure
- Custom Methods

www.argenpolymer.com
Materials Testing and Analytical Solutions

Thermal Analysis
- TGA – Thermal Stability
- DSC – Glass Transition, Melt, Crystallization Temps
- DMA – Viscoelastic Behavior
- Fox 50 – Thermal Conductivity

Chemical Analysis
- FTIR – Polymer, Additive ID
- Pyrolysis GC-MS – Detailed Chemical Composition
- Thermal Desorption, Headspace GC-MS
- Solvent Extraction

Mechanical Testing
- Tensile, Compression, Flex, Shear
- Testing From -70 °C to +300 °C
- Tear, Fatigue, Stress Relaxation
- Puncture Resistance
- Load Capacities to 56,000 lbf (250 kN)

www.argenpolymer.com
Compound and Process Development

Custom Development
- Broad Range of Elastomers
- Sulfur, Peroxide Cure Systems, Filler, Anti-degradants etc.
- Targeted Properties

Expertise
- Oil & Gas Seals
- HPHT Elastomers
- Tire Technology
- Rubber Manufacturing
- Process Troubleshooting

Laboratory Scale Compounding
- Internal Mixer
- Two-roll Mill
- ODR Cure Kinetics & Rheology
- Compression Molding
- Die Cutting Specimens

www.argenpolymer.com
Objectives:

- Asses bladder material chemical compatibility with fluids of interest [will it work?]
- Estimate useful life from a chemical interaction perspective [how long will it work?]
- Develop process for evaluating material / fluid combinations in future
I. Aging conditions validity check

II. Large specimen aging for testing at material supplier [supplier warranty]
   Aging at 136 °F (higher than maximum anticipated exposure temperature)

I. Short term aging (7, 14, 28 day intervals) [will it work?]
   Aging at 136 °F (higher than maximum anticipated exposure temperature)

IV. Long term aging (45, 60, 90 day intervals) [how long will it work?]
   Aging at three different temperatures, all above operating temperature
   Time/Temperature superposition for extrapolation out in time
Candidate Bladder Materials

Polyester fabric + ethylene copolymer
Previously Discussed

Previously Discussed
SMT Materials Testing Program

Current Fluids of Interest

- Methanol
  Commercial; test lab provided

- Low Dose Hydrate Inhibitor
  BHI cost share; RE32117HIW

- Corrosion Inhibitor
  BHI cost share; CRW9218

- Scale Inhibitor
  BHI cost share; SCW356

- Asphaltene Inhibitor
  BHI cost share; PFR83

- Dispersant
  NALCO Environmental Solutions LLC cost share; Corexit®

- Seawater
  ASTM D1411; test lab provided
SMT Materials Testing Program

Logistics of Testing

Prepare Specimens  →  Age in Fluid  →  Test Mechanical & Physical Properties
SMT Materials Testing Program

Uniaxial Tensile
Two Orientations
ASTM D1708

Puncture
ASTM D751

Seam (Shear)
Custom Method

Trapezoidal Tear
ASTM D751

Typically employ triplicate specimens
Also track changes in weight, volume, appearance (ASTM D471)
Spot check low temperature tensile properties (ASTM D412)
Spot check abrasion resistance (Taber)
Spot check ‘aged while strained’ specimens
### Operating Conditions
- ca. 120 °F max when topside
- ca. 36 °F when deployed
- Minimal net differential pressure across bladder
- Hydrostatic pressure ca. 4,500 psig (10,000 ft water depth)

Must we perform chemical compatibility testing under these conditions?

Optimize conditions in light of rigor, cost, efficiency of testing

**Initial Evaluation in Methanol under three different aging conditions:**

1. Specimens submerged; 50 psig nitrogen gas in vessel headspace
2. Specimens submerged; 4,000 psig nitrogen gas in headspace
3. Autoclave liquid full (hydrostatic pressure)

   Aging at 136 °F
Conclusions:

- Noticeable effect on volume change
  50 psig N₂ < 4,000 psig N₂ < 4,000 psig liquid full
- Some rapid gas decompression damage for 4,000 psig gas
- Overall, insignificant difference between aging conditions
- Proceed with the most time and cost efficient conditions

Exemplary Result:

Tensile Test of Aged Specimens
## SMT Materials Testing: Testing by Seaman

- Specimens aged at Argen, Tested at Seaman:
- Testing comprising mechanical properties and appearance
- Completed results are positive, indicating ‘A’ rating for Scale Inhibitor, Seawater, Methanol
- ‘B’ rating for Corrosion Inhibitor; ‘minor to moderate’ effect

<table>
<thead>
<tr>
<th>8130 XR5</th>
<th>Strip Tensile (ASTM D751, Procedure B)</th>
<th>Grab Tensile (ASTM D751)</th>
<th>Trapezoidal Tear (ASTM D751)</th>
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<tbody>
<tr>
<td>Scale Inhibitor</td>
<td>404 lb/in (warp) 406 lb/in (fill)</td>
<td>565 lbf (warp) 609 lbf (fill)</td>
<td>60 lbf (warp) 82 lbf (fill)</td>
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<tr>
<td>Methanol</td>
<td>416 lb/in (warp) 449 lb/in (fill)</td>
<td>597 lbf (warp) 604 lbf (fill)</td>
<td>69 lbf (warp) 106 lbf (fill)</td>
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<tr>
<td>Corrosion Inhibitor</td>
<td>354 lb/in (warp) 350 lb/in (fill)</td>
<td>585 lbf (warp) 623 lbf (fill)</td>
<td>116 lbf (warp) 168 lbf (fill)</td>
</tr>
<tr>
<td>Sea Water</td>
<td>429 lb/in (warp) 402 lb/in (fill)</td>
<td>572 lbf (warp) 629 lbf (fill)</td>
<td>63 lbf (warp) 91 lbf (fill)</td>
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</table>

*Data from Seaman Corp.*
Specimens aged at Argen, tested at Argen [Short Term Aging]:

- Methanol, Seawater, Scale Inhibitor, Dispersant show acceptable performance thus far
- Early indications for LDHI indicate caution, not conclusive yet, further data to confirm
- Corrosion Inhibitor has a significant effect (swelling, tensile, tear)....indication of less than desirable compatibility

### Short Term Aging - Excerpted Summary Data

#### Maximum Changes Observed Thus Far

<table>
<thead>
<tr>
<th></th>
<th>Percent Change</th>
<th>Tensile (parallel)</th>
<th>Tensile Strength</th>
<th>Strain at Peak Stress</th>
<th>Tensile Strength (Seam)</th>
<th>Trap Tear</th>
<th>Weight</th>
<th>Volume</th>
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<tr>
<td>Methanol</td>
<td>-0.5%</td>
<td>-3.1%</td>
<td>0.9%</td>
<td>3.1%</td>
<td>42.1%</td>
<td>-8.9%</td>
<td>-10.6%</td>
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<tr>
<td>Seawater</td>
<td>2.4%</td>
<td>-1.7%</td>
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<td>31.7%</td>
<td>0.3%</td>
<td>-0.7%</td>
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<tr>
<td>Scale Inhibitor</td>
<td>-3.9%</td>
<td>-10.6%</td>
<td>-16.2%</td>
<td>-12.9%</td>
<td>24.4%</td>
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<td>Corexit</td>
<td>-2.2%</td>
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<td>76.7%</td>
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<td>LDHI</td>
<td>-6.3%</td>
<td>3.5%</td>
<td>33.3%</td>
<td>5.7%</td>
<td>130.1%</td>
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<td>-10.5%</td>
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<tr>
<td>Corrosion Inhibitor</td>
<td>-8.9%</td>
<td>3.6%</td>
<td>35.1%</td>
<td>-22.6%</td>
<td>124.3%</td>
<td>42.0%</td>
<td>52.1%</td>
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SMT Materials Testing: Conclusions

- Findings at Argen are thus far consistent with findings at Seaman Corp. **VALIDATION**
- Will this material work with some fluids? **YES**
- Will this material work with all fluids? **NO**
- We have a process/method for evaluating material + fluid combinations in the future (delineates good vs. bad)
- Life estimations and Validation of other candidate material forthcoming

- Methanol
- Low Dose Hydrate Inhibitor
- Corrosion Inhibitor
- Scale Inhibitor
- Asphaltene Inhibitor
- Dispersant
- Seawater
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| 2:00 PM - 2:00 PM | 0        | Adjourn                                                                                     | All                              |
HOLD and Bladder 1/5th Scale Model Testing

11121-5302-01
Presenter Name
Organization Name

Safe Marine Transfer, LLC, Final Close-out Presentation
July 14, 2016
Houston, TX
Test Objectives

- Evaluate the mechanical behavior of the bladder in a fluid filled Shuttle HOLD simulating operations.
  - Repeatable behavior
  - Detrimental bladder material behavior
- Evaluate the impact of fluids (chemicals) with Specific Gravities different from Seawater (0.790 to 1.2)
- Evaluate differences (if any) between bladder materials and designs.
  - Rounded bladder edges vs square edges
- Evaluate the physical attachment of the bladder to the HOLD, both mechanical and fluid porting.
- Evaluate bladder fluid retention and retention factors.
The bladders tested were attached with links at the mid-height centerline of the HOLD.

Fluid densities were safely simulating using salt brine and fresh water.

The Bladder Port was connected with flexible hose to the HOLD Piping.
Results – Operational Performance

- The bladder behavior was consistent and repeatable; especially with greater Sg differences.

- There was no observed detrimental bladder material behavior.

Bladder Nearly Full

Bladder depleting with Bottom doming upward

- There was no observed detrimental bladder material behavior.
Results – Bladder Designs

- Chemical Sgs near Seawater were more influenced with bladder and fluid port construction.
  - The corners and edges of the bladders were “stiffer” and dominated the bladder collapse in low differential Sgs.
  - The bladder port flanges were “heavy” and served to pull-down the top of the bladder in low differential Sgs.

- The two bladder designs tested differed with one having all edges rounded, while the second only rounded the vertical corners.
  - Slight difference existed in the bladder volumes.
Results – Bladder Attachments

- The bladder was soft connected in the fluid filled HOLD. The vinyl hose connected the bladder port to the HOLD hard piping.

- D-Links connected the bladder corners to the HOLD at the vertical mid-point.

- Attachments avoid bladder Hard-Spots that may be detrimental in a seaway.
Results – Port Location

- Top center ports were prematurely sealing off with the bottom of the bladder closing the exit port as it flexed upward.
- Side vents in port flange was not effective.
- Putting a port in each corner appears to be one possible solution.
- The HOLD fluid port required a cage.
- Piccolo tubes will enable “tighter” fitting bladders in the HOLD by allowing fluid flow to the port.
- Due to the premature sealing, this bladder design had significant chemical retainage. Improvements exist.
Conclusions

- A successful and educational SMT testing program was performed. All of the testing objectives were met.
- The bladder behavior is repeatable and operationally acceptable.
- Two qualified bladder designs exist, but may be improved by relocating the fluid ports.
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</tbody>
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Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir & Injection System

Safe Marine Transfer, LLC
OceanWorks International Inc.

SCIU Design review

July 14, 2016 - Thursday
Houston, TX.
Agenda

- OceanWorks Scope and Objectives
- Block Diagram and Schematic
- DFMECA and TRL
- Conclusion
OceanWorks SCIU Project Team

Dan Krohn
Technical Specialist/Subject Matter Expert

Menno Huizinga
Project Manager

Alex Paramonoff
Lead Mechanical Engineer

Scott Williams
Lead Electrical Engineer
OceanWorks

Extensive experience in custom projects for subsea oil and gas applications

Bladder systems

Battery Powered Pump Skids for MWCC
The system is rated for the following:
• 10,000 ft. water depth
• 10,000 psi pressure delta across pump
• Five year life
• Injection of:
  • LDHI; continuous, precisely metered flow
  • MeOH; batch, high flow rate against high SIWP

The system is sized for the following case study:
Performance requirements for each well, for six (6) wells simultaneously:

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Scenario 1</th>
<th>Scenario 1a</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
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<tr>
<td>Description</td>
<td>MeOH</td>
<td>MeOH</td>
<td>MeOH</td>
<td>LDHI etc.</td>
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<tr>
<td>delta P (psi)</td>
<td>3123</td>
<td>604</td>
<td>604</td>
<td>604</td>
</tr>
<tr>
<td>Volume pumped</td>
<td>100 bbl</td>
<td>100 bbl</td>
<td>200 bbl</td>
<td>n/a</td>
</tr>
<tr>
<td>Time</td>
<td>3 bbl / min = 126 gpm</td>
<td>3 bbl / min = 126 gpm</td>
<td>0.5 bbl / min = 21 gpm</td>
<td>15 bbl/day = 0.438 gpm</td>
</tr>
<tr>
<td>Comments</td>
<td>upstream of SCSSV</td>
<td>downstream of SCSSV</td>
<td>Into a flowing well</td>
<td>Into FWP, always on</td>
</tr>
</tbody>
</table>
Project Deliverables

- Design and Analysis Documentation Deliverables:
  - Compliance Matrix
  - Schematics (hydraulic, electrical/controls)
  - Conceptual drawings and BOM, cost estimate
  - Interface Control Document
  - TRL-TRC analysis,
  - Gap analysis and identify scope to TRL 4 where required
  - DFMECA
  - IMR outline
  - Refill nozzle system
  - Design Document
Shuttle and Subsea Chemical Injection Unit (SCIU) on seafloor

Overall Project Scope:

- Shuttle
- Three (3) 1100 BBL bladders
- Buoyancy and ballast system
- Deployment winches
- SCIU (pump/motor assembly) with interface hardware to bladder and well(s)
- Subsea bladder refill connection
- Electronic controls for buoyancy valves and deployment winches
OceanWorks Design Process

Start of the project

Organize high-level project requirements in a compliance matrix

Concept design

Develop derived requirements

Concept Design Review

Develop Concept

Create Block Diagram & CONOPS

Create initial BOM & schematics

Start DFMECA

Preliminary Design Review

Develop Preliminary Design

Develop BOM and schematics

DFMECA (failure modes/impact and detectability)

Define corrective actions to reduce criticality

DFMECA review

Develop Design

TRL definitions + plans to close TRL gaps

Finalize Report

Final Presentation
Agenda

- OceanWorks Scope and Objectives
- Block Diagram and Schematic
- DFMECA and TRL
- Conclusion
Block Diagram of SCIU and context

- Surface interface umbilical (power and comms)
- SCIU Master Control Assembly
- Well
- SCIU
- Shuttle
- Supplemental subsea chemical storage tank
- Shuttle deployment control assembly
- Surface asset
SCIU CAD model

- Field-removable pump
- Field-removable filter pack
- Backup pump
- ROV valve actuators
- Subsea fluid connectors
- CIMV’s
- Electronics control can
Hydraulic System - MeOH

1. Bladder (tank) interface
2. Filters
3. Pumps
4. Output to wells

- Suction and
- Pressure relief
Bladder and Subsea-end Surface refill Schematics

BLADDER HYDRAULICS SYSTEM

Bladder  Surface refill  Output

SURFACE REFILL HYDRAULICS

Return  Supply

Supply
Agenda

- OceanWorks Scope and Objectives
- Block Diagram and Schematic
- DFMECA and TRL
- Conclusion
CONOPS

- Concept of operations produced at level of detail of O&M manual headings for all of the following modes of operation:
  - Testing
  - Storage
  - Transport
  - Deployment & connection
  - Operation
  - Surface refill
  - Subsea maintenance
  - Recovery
A DFMECA is a structured risk analysis method that is used to identify potential failure modes in components, subassemblies and systems and to plan mitigations so that these failure modes can no longer occur.

**DFMECA Definition**

- **Cause**: What fails
- **Failure Mode**: Functional deficiency
- **Effect**: Consequences of the failure

**Diagram**

- Cause → Leads to → Failure Mode
- Can result in → Effect
DFMECA Summary

○ “Yellow” risks:
  • Green Water Damage, mitigate by design
  • ROV friendly design, mitigate by API 17H / best practices
  • Pump fails, mitigate by EFAT testing and redundancy
  • Pump leaks, mitigate by detection and redundancy
  • Fluid connectors fail, mitigate buy using TRL 7 subsea connectors
  • Surface disconnect fitting fails, mitigate by modification of TRL 7 component, testing to TRL 4, isolation valves on both sides
  • Ball valves fail open, mitigate by TRL 7 components, zero-leak connectors
  • Control compromised, mitigate by TRL 7 components, A/B system redundancy
  • Medium voltage converter failure, mitigate by TRL 7 components, redundancy
- A Bill Of Materials (BOM) for the entire system has been created
- A TRL analysis in accordance with the Shell TRL/TRC process has been performed
- All items that are not already at TRL 7 have a defined method to bring them to at least TRL 4

### API 17N interpretation: Risk (TRC) / Readiness (TRL) Matrix

| Year High Technical Risk / Unacceptable Reliability | A | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| High Technical Risk / Low Reliability | B | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Medium Technical Risk / Moderate Reliability | C | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Low Technical Risk / Acceptable Reliability | D | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

<table>
<thead>
<tr>
<th>Technical Readiness level</th>
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<tbody>
<tr>
<td>Field Proven</td>
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<td>7</td>
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</table>
Moderate TRL items (yellow):

- Methanol and LDHI pumps
- Large diameter subsea quick connect / quick-disconnect
- Subsea remotely actuated surface-refill quick connect / quick-disconnect
- Large diameter subsea pressure reducing valve
- Hose management to bladder inside a shuttle hold
- Hull penetrator at shuttle hold
- Piping
- Control can electronics
- Interface can electronics
- ROV switch
Agenda

- OceanWorks Scope and Objectives
- Block Diagram and Schematic
- DFMECA and TRL
- Conclusion
Conclusion

- The outcome of the study provides sufficient confidence that an SCIU which will meet the performance requirements equivalent to an existing chemical injection umbilical.

- The system maximizes the use of high TRL components.

- The risk analysis shows that the lower level TRL components can brought to TRL 4 with identified tasks.

- The study provides the basis for the detailed design of a field specific system.
Contacts

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Project Manager:
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RPSEA Working Project Group (WPG) Champion:
Tom.A.Gay@gmail.com

Technical Coordinator:
James Pappas
Jpappas@RPSEA.org
(281) 690-5511
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Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir & Injection System

11121-5302-01
Tim Krasin
Helix, Canyon Offshore

Safe Marine Transfer, LLC, Final Close-Out Presentation
July 14, 2016
Houston, TX
Contacts

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Project Engineer: Brian Lee
Helix, Canyon Offshore
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Canyon Goals, Objectives, and Scope

Engineering Support

- Refine operational storyboard
  - Operational planning tool
  - Add intermediate steps
  - QRA driven risk mitigation
  - QRA driven clarifications

- Refine conceptualized safe, reliable, and cost effective methodology

- Detail the ROV requirements, tasks, specifications, and interface scenarios

- Interfaces
  - GRi and DSA for shuttle property updates for simulator and analysis
  - ACMA-Inc. for CFD analysis inputs and results
  - OceanWorks International for ROV intervention interfaces
Deploy and recover the shuttle payload through the use of a catenary connection method to a pair of topside vessels.

**Catenary Benefits**
- Decouple deployment payload from topside handling vessel(s)
- Reduces crane/winches & vessel size requirements
- More vessels of opportunity (VOO) and reduced vessel costs

**Multiple Vessel Benefits**
- Better seabed land-out positional accuracy
- Better payload orientation on seabed
- More control with subsea loop currents
Deployment and Recovery Development

Chain weight: 25T per end, 50/50 between shuttle and vessel

Vessel Spacing: 2000m offset

Positively Buoyant: +15T to 25T, payload dependent

3” studded chain, 600ft per side
GRi and DSA have built a project simulator with analysis capability.

- GRi developed the simulator for project operational scenarios
  - Operational planning tool
  - Operational training tool
  - Site specific met ocean data
  - Job specific details
  - Custom scenarios

- DSA developed the analysis module to operate within the GRi simulator – ProteusDS
  - Realtime line loads
  - Realtime stresses
GRi’s main deliverable is a comprehensive software program that is coded, validated, and delivered to the project for future operational planning and training purposes.
# Project Results
## Canyon Master Document Register

| Master Document Register: Safe Marine DEEP-10 RESERVOIR, Stage 2 |
|-----------------|-----------------|-----------------|
| **Design Calculations** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| DC-0017-425 | SMT Development Liquid Simulante Analysis | Calculated | 1 | 7/7/2016 |
| DC-0017-426 | Static and Dynamic Analysis | Calculated | 2 | 7/7/2016 |
| DC-0017-427 | Deck Report - Twp Analysis | Calculated | 1 | 7/7/2016 |

| **Economic Data Micro** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| DC-0017-441 | SMT Economic Comparison Matrix | Calculated | 4 | 7/7/2016 |
| DC-0017-442 | SMT Eagle Twp Economic Comparison Matrix | Calculated | 2 | 7/7/2016 |

| **Engineering Reports** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| CH-0017-445 | SMT Canyon Site Committee Minutes | Presentation | 12b | 5/19/2016 |

| **Minutes Of Meetings** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| MCA-0017-471 | Minutes of Meeting 1-4-2013 | Minutes | A | 1/6/2013 |
| MCA-0017-473 | Minutes of Meeting 1-4-2013 | Minutes | A | 1/6/2013 |
| MCA-0017-475 | Minutes of Meeting 1-4-2013 | Minutes | A | 1/6/2013 |

| **Technical Documents** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| TP-0017-452 | SMT Mesa Qualification Assessment Report | Report | 7 | 7/7/2016 |
| TP-0017-460 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TP-0017-462 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TD-0017-463 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TP-0017-466 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TD-0017-467 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TP-0017-468 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TD-0017-469 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TP-0017-470 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TP-0017-472 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |
| TP-0017-474 | SMT Design Project Summary Report | Report | 7 | 7/7/2016 |

| **Drawings** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| OH-0017-521 | SMT Design Concept Development Drawings | Drawing | D | 7/7/2016 |
| OH-0017-523 | SMT Design Concept Development Drawings | Drawing | D | 7/7/2016 |
| OH-0017-525 | SMT Design Concept Development Drawings | Drawing | D | 7/7/2016 |

| **Vendor Documents** | **Document Title** | **Document Type** | **Revision** | **Revision/Issue Date** |
| N/A | Contractor/Supplier Agreement | Agreement | C | 10/24/2016 |
| N/A | Contractor/Supplier Agreement | Agreement | C | 10/24/2016 |
| N/A | Contractor/Supplier Agreement | Agreement | C | 10/24/2016 |
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| N/A | Contractor/Supplier Agreement | Agreement | C | 10/24/2016 |
Dual Catenary Risk Analysis

- Qualitative Risk Assessment (QRA)
  - SME’s participated in review
- Operations FMECA and Design FMECA
  - SME’s participated in review

Conclusion from each event:
No “Showstoppers”

The two scales together form a risk matrix, as follows:

<table>
<thead>
<tr>
<th>Probability</th>
<th>A - Unlikely</th>
<th>B - Remote</th>
<th>C - Occasional</th>
<th>D - Frequent</th>
<th>E - Very Frequent</th>
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<tr>
<td>1 - Minor</td>
<td>1A</td>
<td>1B</td>
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<td>1D</td>
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<td>2 - Moderate</td>
<td>2A</td>
<td>2B</td>
<td>2C</td>
<td>2D</td>
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<tr>
<td>3 - Significant</td>
<td>3A</td>
<td>3B</td>
<td>3C</td>
<td>3D</td>
<td>3E</td>
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<tr>
<td>4 - Severe</td>
<td>4A</td>
<td>4B</td>
<td>4C</td>
<td>4D</td>
<td>4E</td>
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<tr>
<td>5 - Catastrophic</td>
<td>5A</td>
<td>5B</td>
<td>5C</td>
<td>5D</td>
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</tbody>
</table>

The Matrix will be considered as follows:

- LOW: Acceptable - Not considered further
- MEDIUM: Requirement to demonstrate that it is not reasonably practicable to reduce to LOW
- HIGH: Not Acceptable - Reduce to MEDIUM at least
# Dual Catenary Risk Analysis
## Canyon Operation FMECA

<table>
<thead>
<tr>
<th>No.</th>
<th>Operational Step</th>
<th>Shuttle</th>
<th>Tow</th>
<th>AHTS</th>
<th>Lines</th>
<th>ROV</th>
<th>ROV</th>
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<tbody>
<tr>
<td>1</td>
<td>Shuttle Tow Out</td>
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<tr>
<td>1.3</td>
<td>Your Shuttle to site</td>
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<tr>
<td>1.3a</td>
<td>Transit Shuttle to site with Tug</td>
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<tr>
<td>2</td>
<td>Vessel Exchange</td>
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<tr>
<td>2.2</td>
<td>Connect Anchor Handler Vessel to Shuttle</td>
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<tr>
<td>2.2a</td>
<td>Deploy anchor chain from Shuttle (remote controlled release/payout)</td>
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<tr>
<td>2.3</td>
<td>Pre-dive Shuttle Inspection</td>
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<tr>
<td>2.3a</td>
<td>Place personnel on board Shuttle with billy-pugh</td>
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<tr>
<td>2.3b</td>
<td>Personnel onboard Shuttle perform pre-dive inspection of SCU and other systems</td>
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<td>2.3c</td>
<td>Lift personnel off shuttle with billy-pugh</td>
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<tr>
<td>3</td>
<td>Deploy Subsea</td>
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<tr>
<td>3.2</td>
<td>Sink Shuttle</td>
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<tr>
<td>3.2a</td>
<td>Open Shuttle column ballast valve(s) (remotely controlled)</td>
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<tr>
<td>3.2b</td>
<td>Shuttle will sink to balanced position with catenary chains (controlled submersion)</td>
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<tr>
<td>4</td>
<td>Seafloor Landout</td>
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<td>4.1</td>
<td>Catenary chain reaches Seafloor</td>
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<tr>
<td>4.1b</td>
<td>Anchor Handlers maneuver to lay chain out on seafloor</td>
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<tr>
<td>4.2</td>
<td>Retrieve Anchor Chain</td>
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<tr>
<td>4.2a</td>
<td>Use ROV to retrieve anchor chain into/on Shuttle</td>
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<tr>
<td>5</td>
<td>Prepare Shuttle Recovery (worst case scenario is shuttle gained chemical weight during subsea use)</td>
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<td>7.3</td>
<td>Remove Ballast Weight</td>
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<td>7.3a</td>
<td>Use ROV to release ballast weights as planned for particular chemistry weight change scenario</td>
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<td>8</td>
<td>Shuttle seafloor Liftoff</td>
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<td>8.1</td>
<td>Chain Deployment</td>
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<tr>
<td>8.1a</td>
<td>Deploy anchor chain from Shuttle (ROV release)</td>
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<tr>
<td>8.2</td>
<td>Articling Operations (if required)</td>
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<tr>
<td>8.2a</td>
<td>Use ROV to power jetting pump built into Shuttle to aid with Shuttle hull release from seafloor</td>
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<tr>
<td>8.2b</td>
<td>Repeat for each zone, or until Shuttle lifts off seafloor</td>
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<td>9</td>
<td>Shuttle Recovery to Surface</td>
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<td>Surfacing</td>
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<td>9.2e</td>
<td>Use remote control to close necessary Shuttle hull valves</td>
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<td>10</td>
<td>Disconnect Anchor Handler Vessels</td>
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<tr>
<td>10.0</td>
<td>Recover Shuttle chain into chain hold (Remote controlled battery powered recovery)</td>
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<tr>
<td>10.1</td>
<td>Connect Tag Vessels to Shuttle</td>
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<tr>
<td>10.1a</td>
<td>Deploy tow harness from Shuttle (Remote controlled release)</td>
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</table>
Conclusions

The Shuttle System deployment and recovery methodologies use industry standard interfaces, procedures, and processes, that when partnered together, provide a path to deployment of 3000bbl of chemical storage on the seabed in a safe, reliable, and cost effective manner.