Human Factors and Risk Informed Decision Support for Underground Gas Storage

PHMSA Pipeline Safety Research and Development Forum
Cleveland, OH

Bill Nelson
16-17 November 2016
Lessons learned across industries: “Macondo was the offshore industry’s Three Mile Island”

- Continued occurrence and recurrence of major accidents across many industries

- Effective decision support is needed to continuously manage the barriers and success paths for preventing and mitigating major accidents
The Dynamic Barrier Management concept for managing well integrity risks for offshore operations and underground gas storage

- Two types of information - (1) the condition of barriers and success paths and (2) practical decision guidance – are needed to effectively manage risks of major accidents.
  - **Barrier**: Physical or non-physical means to prevent an accident or mitigate its consequences
  - **Success Path**: Equipment and processes (human, software, administrative) needed for the barrier to perform its function

**Solution** - Combine barriers and success paths to:

- Systematically identify information requirements for continuous barrier and success path management
- Provide **decision guidance** to restore degraded barriers and implement alternate success paths when needed, providing complementary failure and success perspectives
- Develop an intuitive, visual “common language” for communication, consensus, and action among:
  - Offshore operators
  - Industry groups
  - Regulatory bodies
  - External stakeholders
Bow tie diagrams and response trees form the foundation for decision support for dynamic barrier management.
Upper Blind Shear Ram Unavailable
Lower Middle Pipe Ram Unavailable
• **Consult with Regulatory Authorities**
• **Drilling Operations Can Continue**

Maintain Pathways of Hydraulic Fluid to Each Critical Function
Maintain Pathways of Hydraulic Fluid for Functions to Isolate Well
Maintain Pathways of Hydraulic Fluid for Functions to Circulate Well
Maintain Availability of Safety Functions
Maintain Availability of ROV Functions

Criteria for Continued Operation
DNV GL Joint Industry Project: Decision Support for Dynamic Barrier Management

**Challenge**
- Knowing the continuous status of barriers
- Lack of common risk language for communication
- Lack of practical decision support tools for operations

**Benefits**
- Continuous knowledge of barrier health
- Real time decision support and risk management
- Common language for communication and consensus among engineering, operations, maintenance, and management

**Delivery**
- The JIP participants will develop and test:
  - Methods, best practices, data sources, and tools
  - Standardized bow tie diagrams, response trees, and decision protocols
  - Pilot-scale decision support systems

Contact:
Bill.Nelson@dnvgl.com
+1 832 766-0514
Region:
North America
JIP Plug & Abandon (P&A) Case Study: Develop Success Paths to Design, Install, and Test a Cement Plug

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30''</td>
<td>Top of cement (400 ft)</td>
</tr>
<tr>
<td>20''</td>
<td>Top Cement Plug # 3 (600-800 ft, 200 ft)</td>
</tr>
<tr>
<td>9-5/8''</td>
<td>Top Cement Plug @ 4400</td>
</tr>
<tr>
<td>13 3/8'' Shoe</td>
<td>20'' Shoe @ 4000</td>
</tr>
<tr>
<td>13 3/8'' Shoe</td>
<td>Top of cement @ 5400</td>
</tr>
<tr>
<td>9 5/8'' Shoe</td>
<td>13 3/8'' Shoe @ 8800</td>
</tr>
<tr>
<td>7'' Tubing</td>
<td>Intermediate Cement Plug # 2 (200 ft, 10 200-10 400)</td>
</tr>
<tr>
<td>9 5/8'' Shoe</td>
<td>Perforations (200 ft) @ 13 400-13 600</td>
</tr>
<tr>
<td>9 5/8'' Shoe</td>
<td>Lower isolation plug (balanced, cement type); 13 400-13 600 TVD</td>
</tr>
<tr>
<td>Seabed (450 ft)</td>
<td></td>
</tr>
</tbody>
</table>

*Target Depth*
Dynamic Barrier Management Dashboard for P&A Case Study

Mission Level

Plug & Abandon Well – Install Multiple Plugs (Hydraulic Seals) for Pressure and Flow isolation in a Well

Barrier Level

Top Well Seal

Safety Function: To provide hydraulic seals for pressure and flow isolation in well

End State Level: Elements Required to Achieve Success

Regulations and company compliance

Success Criteria (IF)  Action (IF NOT THEN)  Alternative

Calibrated Chart-recorded test

Complete PRD Documentation

WOC Based on Lab Test

Design, Construct, Operate, Maintain Level

Plug Designed to Meet Safety function

Success Criteria (IF)  Action (IF NOT THEN)  Alternative

Plug Installed to Meet Safety function

Success Criteria (IF)  Action (IF NOT THEN)  Alternative

Design, Construct, Operate, Maintain Level

Plug Tested to Meet Safety Function

Success Criteria (IF)  Action (IF NOT THEN)  Alternative

Appropriate intervention equipment and well access

Success Criteria (IF)  Action (IF NOT THEN)  Alternative

Existing well conditions and requirements

Success Criteria (IF)  Action (IF NOT THEN)  Alternative

Δ 1 Wellbore design

Δ 2 Mud weight PF FG

Δ 3 Wall configuration

Δ 4 Volume calculation

Δ 5 Bottomhole circulating and static temperature

RACI
<table>
<thead>
<tr>
<th>Success Criteria (IF)</th>
<th>Action (IF NOT THEN)</th>
<th>ALTERNATIVE</th>
<th>SOURCE OF INFORMATION</th>
<th>DECISION MAKER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well mechanical integrity meets design criteria</td>
<td></td>
<td></td>
<td>Direct</td>
<td>Internal</td>
</tr>
<tr>
<td>Injection test confirms design criteria</td>
<td></td>
<td></td>
<td>Indirect</td>
<td>Communication</td>
</tr>
<tr>
<td>Well tubular surface prepared for sealing</td>
<td></td>
<td></td>
<td></td>
<td>External</td>
</tr>
<tr>
<td>Equipment meets slurry mixing requirements</td>
<td></td>
<td></td>
<td></td>
<td>Communication</td>
</tr>
<tr>
<td>Slurry quality supports isolation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOC at designed location</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Compliance Assessment Tree for P&A Based on 30 CFR 250.1715

Plug and Abandon Well – Install multiple plugs [hydraulic seals] for pressure and flow isolation in a well

A. Submit BSEE-124

B. Isolation Plugs – Installation to meet safety function and compliance (30 CFR 250.1715)

1. Provide isolation for zones in open hole
   - Success Criteria: A) Plug >=100 ft below the bottom to 100 ft above top of zones (oil, gas, fresh waters)

2. Provide isolation for zones in open hole below casing
   - Success Criteria: A) Placement via displacement
   - B) Plug >=100 ft above and below deepest casing shoe

3. Provide isolation for perforated zone currently open and not previously squeezed and isolated
   - Method to squeeze cement to all perforations
   - Success Criteria: A) Placement via displacement
   - B) Plug >=100 ft above and below perforated interval

4. Provide isolation for casing stub where the stub end is within the casing
   - Success Criteria: A) Length >= 100 ft above and below stub end

5. Provide isolation for casing stub where the stub end is below the casing
   - Success Criteria: A) Length >= 100 ft above and below stub end

6. Provide isolation for annular space the communicates with hole and extends to mud line
   - Success Criteria: A) 50-100 ft above casing shoe
   - B) 50 ft above retainer

Cement plug

Bridge plug

Cement Plug* and Cement Retainer**

*Plug A) >=100 ft below casing shoe
**Plug B) >= 50 ft above retainer
Application of Dynamic Barrier Management to the P&A Case Study

Bow Tie Diagram

Response Tree: Success Path for Cement Plug
Summary

- The barrier-success path approach has been applied to industry projects:
  - Post-accident assessment of corrective actions for major pipeline leak events
  - Erosion integrity management for offshore production installation
  - Design and regulatory approval for a BOP control system
- JIP participants believe the approach can be applied within their organizations
- The success path dashboard provides:
  - A systematic way to continuously monitor and communicate status of well integrity across operators and contractor organizations
  - Guidance for action when unexpected conditions are encountered
  - A neutral framework to establish decision criteria and communicate compliance status between operators and regulatory authorities
Potential applications for underground gas storage

- Post-accident assessment of major events
- Identify common factors and lessons learned across events
- Systematically identify success paths and information requirements for monitoring well integrity barriers
- Establish decision criteria and guidance for action for unexpected conditions
- Continuous monitoring of well integrity within and across assets
- Systematic, neutral framework for assessment of regulatory requirements and industry-regulator communication
Questions?

Bill Nelson
Bill.Nelson@dnvgl.com
832-766-0514

www.dnvgl.com

SAFER, SMARTER, GREENER