BSEE REPORT COVERSHEET

1. PUBLICATION / CREATION DATE (DD-MM-YYYY): 01-06-2023	2. SOURCE / REPORT TYPE (Interim, Final, etc.): Final Report	3. START DATE: (DD-MM-YYYY) 16-08-2016 4. END DATE: (DD-MM-YYYY) 31-03-2024

5. TITLE: Wireline Operations Safety Assessment through the Application of Success Paths and FMECA	6. DIGITAL OBJECT IDENTIFIER (DOI) NUMBER: N/A
7. CONTRACT/IAA NUMBER: E16PG00030	8. RESEARCH PROJECT NUMBER (TAP, TCP, etc.): TCP 5033
9. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): Argonne National Laboratory 9700 S. Cass Avenue Lemont, IL 60439	10. CREATOR / AUTHOR(S) + OPEN RESEARCHER AND CONTRIBUTOR ID (ORCID): Erna Gevondyan Roy Lindley Jack Ramsey Stephany Peyton
11. DISTRIBTION / AVAILABILITY / ACCESS RESTRICTIONS (e.g., Unrestricted, restriction limitations, CUI, etc.): Unrestricted	12. USE RESTRICTIONS (e.g. copyright, trademark, internal viewing only, N/A etc.): N/A 13. RIGHTS OWNER (If applicable): N/A
14. FILE RELATIONSHIP (e.g. Has part, Is Part Of): Is part of IAA	15. SUPPLEMENTARY NOTES (ex. level of influence, related documents): Not representing BSEE's Official position - No direct influence on BSEE decisions

16. ABSTRACT/ DESCRIPTION (brief, 200-word, factual summary of most significant information):

The Bureau of Safety and Environmental Enforcement (BSEE), the federal agency responsible for promoting safety, environmental protection, and resource conservation on the U.S. Outer Continental Shelf, participated in the development of API Recommended Practice (RP) 16WL to fulfill its mission and its obligations under the National Technology Transfer and Advancement Act of 1995. Recognizing that wireline operations represent a mature but highly siloed discipline with limited regulatory guidance and no existing API standards, BSEE engaged Argonne National Laboratory to support the API Subcommittee 16 workgroup by conducting Success Path and Failure Modes, Effects, and Criticality Analysis (FMECA) evaluations of key barrier and pressure-control systems. These analyses were intended to document prevailing assumptions about equipment configurations, identify potential single-point failures, and highlight areas requiring enhanced safety measures. Through biweekly technical exchanges with subject matter experts, the study revealed significant challenges in achieving consensus on terminology, nomenclature, system configurations, and definitions of barriers—issues that must be resolved to ensure consistent application of the widely accepted two-barrier philosophy. While the analyses demonstrated both robust system elements and areas needing further attention, additional agreement is required on what constitutes a barrier and how barriers can be reliably maintained across different wireline subsets, particularly braided-line operations. The study concludes with recommendations to continue applying Success Path and FMECA methodologies, advance terminology standardization, expand training to build stakeholder alignment, and pursue improved data collection and future research to strengthen the technical foundation of API RP 16WL.

17. SPONSORING AGENCY NAME(S) / JOINT INDUSTRY PROJECT (JIP): DOI BSEE and DOE	18. KEY WORDS/PHRASES/CATEGORIES: Well Integrity operations	19. DIMENSIONS / NUMBER OF PAGES: 96

20. CONTRACTING OFFICER REPRESENTATIVE (COR): Olivia Adrian	21. EMAIL ADDRESS: bsee_researchpubliccomment@bsee.gov

ADMINISTRATIVE RECORDS MANAGEMENT

1. FILE NAME (Computer file name + extension):	2. RECORD ID: 3. RECORDS SCHEDULE ITEM #:

BSEE-1302 (January 2026)

Argonne NATIONAL LABORATORY

ANL-23/33

Wireline Operations Safety Assessment through the Application of Success Paths and FMECA

A Safety Analysis Study for the Bureau of Safety and Environmental Enforcement

Final Draft

ESIA Division

BSEE

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the view of the funding agency. Based on BSEE's review of the impact of the original report as not being at least influential, no peer review was commenced.

Acknowledgments

The authors wish to acknowledge the staff of BSEE’s Office of Offshore Regulatory Programs (OORP), who made this analysis possible through sponsorship and expert participation in the technical meetings. The authors also wish to acknowledge API staff for creating a forum for the important discussions that took place during the course of this study. Finally, the authors are grateful for the informative conversations and thoughts that were shared by the many industry subject matter expert participants. Special thanks to Mike Worden, Jacqueline Roueche, Alexander Sas-Jaworsky, James McAllister, Chris Walker, Elliot Townsend, Kenneth Coull, Timothy Hall, Timothy Haynes, Randall Landry, Bill Dunford, Justin Frazier, Joshua Poindexter, Joe Braun, and many others for their input.

About Argonne National Laboratory

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ANL-23/33

Wireline Operations Safety Assessment through the Application of Success Paths and FMECA

A Safety Analysis Study for the Bureau of Safety and Environmental Enforcement

Final Draft

prepared by
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Prepared for the
U.S. Department of the Interior, Bureau of Safety and Environmental Enforcement

June, 2023

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List of Acronyms

API	American Petroleum Institute
Argonne	Argonne National Laboratory
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
CT	Coiled Tubing
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
FMECA	Failure modes, effects, and criticality assessment
IRC	Independent review certificate
MAOP	Maximum anticipated operating pressure
MASP	Maximum anticipated surface pressure
MPB	Multiple physical barriers
NRC	U.S. Nuclear Regulatory Commission
PRA	Probabilistic risk assessment
PC	Pressure Category
psig	Pounds per square inch-gage
RP	Recommended Practice
RWP	Rated working pressure
SC16	[API] Subcommittee 16
WIWC TG	Well Intervention/ Well Control Task Group (i.e., API SC16 Task Group 5)
WL	Wireline

Executive Summary

The Bureau of Safety and Environmental Enforcement (BSEE) is America's lead agency charged with advancing safety, environmental protection and conserving natural resources related to energy development on the U.S. Outer Continental Shelf (OCS). BSEE's collective goals include instilling a stronger sense of safety and environmental responsibility among Operators while promoting compliance with regulation. Additionally, BSEE's obligation as a Federal agency is subject to the National Technology Transfer and Advancement Act of 1995, which mandates, in the public interest, its participation in the development of consensus-driven safety best practices standards, which may be incorporated by reference into the regulatory framework in the future. To meet its mission and legal obligation, BSEE became a part of developing the American Petroleum Institute (API) Recommended Practice (RP) 16WL *Cased Hole Wireline Pressure Control Operations and Equipment Systems* (henceforth referred to as "API RP 16WL").

The impetus of this study, and, at a higher level, of the development of API RP 16WL arose from the understanding that wireline operations comprise a very matured industry. However, a lot of the knowledge, experience, and expertise has become siloed within organizations or even individual subject matter experts within the organizations. Further, there are only a small number of BSEE regulations pertinent to wireline, compared to other areas of oil and gas operations, and no existing API industry standards on the topic. To continue the evolution of the safety and applications of this technology, better governance over the key safety and operational aspects of wireline operations is warranted.

Leveraging the experience gained through a previous similar effort supporting development of the second edition of another well intervention technology API Recommended Practice, API 16ST 2nd Ed., *Coiled Tubing Well Control Equipment Systems* (API, 2022), BSEE enlisted Argonne National Laboratory (Argonne) to assist the expert workgroup involved in the development of API RP 16WL. This assistance was Success Path and Failure Modes, Effects, and Criticality Analysis (FMECA) analyses of the relevant physical barriers and pressure control systems. The analyses were envisioned as a tool for the experts to document and evaluate current assumptions on the sufficient degree of safety that a certain equipment configuration provides. Additionally, these analyses help pinpoint areas in need of improvements, such as single points of failure or others that present a relatively high risk to the system.

Argonne embarked on this work by establishing biweekly two-hour meetings with the select workgroup of subject matter experts from the API Subcommittee 16 (SC16), tasked with the development of API RP 16WL. The purpose of these meetings was to gain sufficient information regarding the current or preliminary consensus on the required safety system configurations and facilitate the Success Path and FMECA development and discussions.

Over the course of this study, it became apparent that unlike the experience with API RP 16ST 2nd Ed., where much of the trade language, including equipment operational configurations, had been captured in first edition of the document, for API RP 16WL, the discussions had to focus on gaining consensus on these systems. A prominent example includes a lack of common definitions for terminology and nomenclature. Additionally, while it appeared that most company policies with respect to wireline operations have already adopted the philosophy of two or more barriers in order to meet the safety and emergency response requirements that the operation warrants, there was not initially consensus on more detailed description of the barriers and safety systems in typical configurations. As a result conclusions may not necessarily be firm because working assumptions were made during the analysis rather than preceding the analysis. For this reason considerable discussion still needs to take place among the workgroup of API RP 16WL experts to establish how the two-barrier requirement can be achieved in certain subsets of operations, specifically with respect to braided line wireline operations.

This study also served to capture other observations, which led to conclusions and recommendations beyond those resulting directly from FMECA and Success Path analyses. Once again, observations were made regarding the need to standardize the terminology for the various systems and operations. For example, clear definitions of the types of wireline operations and their subsets, with clear names for each type of wireline, is among one of the most important areas of consensus. As another example, a better definition of the term “barrier” and other relevant aspects of the operations is needed need for wireline operations and, ideally, would complement similar terminology pertinent to other operations. In the event that the terminology and operations are too different to build consensus in the medium-term future, at least a clear definition of what these terms mean for wireline versus other operations may be helpful to all stakeholders. Sections 5, 6, and 7 capture study results, observations, and conclusions.

To summarize the conclusions, there was clear evidence of the industry’s agreement on the fact that a minimum of two barriers should be a requirement for all wireline operations. The FMECA and Success Paths that were completed as part of this study were able to clearly demonstrate areas with sufficient system robustness along with areas in need of greater attention and potential resolution through requiring additional safety components in the development of API RP 16WL. However, further consensus is needed on what components or elements can represent these barriers and what support systems are needed to operate them. It is hoped that Success Paths and FMECA methods can continue to be used by the workgroup to capture and evaluate the assumptions made for the eventual API RP 16WL document.

The authors of this report noted several areas warranting recommendations, summarized below.

- The authors recommend that the workgroup consider continuing the use of Success Paths and FMECA as tools to document, analyze, and justify the requirements as part of API RP 16WL development.
- There is clear benefit to gaining consensus on the terminology and nomenclature of the equipment, operations, and other details of wireline operations, and the workgroup should continue their hard work on this standardization as part of API RP 16WL development.
- To gain further stakeholder consensus and buy-in, training may be a beneficial way to communicate the requirements of API RP 16WL as they become published or considered in pre-publication.
- In possible future Success Path and FMECA analyses, beyond API RP 16WL, it will be beneficial if the work on system configurations is completed to some degree prior to commencement of risk analysis. These configurations, regardless of status (final or proposed), should serve as inputs to the risk analysis and be refined as necessary to satisfy safety and reliability goals.

- FMECA analysis could be strengthened with actual failure data which provides information on the nature of the failure and the service time or conditions before the failure. It may be appropriate for the stakeholders, including BSEE and industry, to consider collaborating to establish a volunteer-based snubbing operations failure data collection mechanism. A precedent for this exists in the currently functioning SafeOCS system that tracks well control equipment, safety and pollution prevention equipment, and industry safety data.

Additional recommendations include potential further research areas with respect to assessment of barriers in H_2S services and remedies to potential shear-blind ram and/or power supply issues with respect to non-shearables, such as tools or entangled (or “birdnested”) wireline that may be stuck across the ram and does not allow for the shear-blind to seal off the bore.

1. Introduction

The Bureau of Safety and Environmental Enforcement (BSEE) mission is to promote safety, protect the environment, and conserve resources offshore through vigorous regulatory oversight and enforcement. BSEE's collective goals include instilling a stronger sense of safety and environmental responsibility among Operators while promoting compliance with regulation.

BSEE strives to expand its role as a world leader in offshore energy development while being proactive in safety and environmental stewardship. Through innovative regulatory oversight and appropriate collaboration with industry, BSEE fosters 1) a culture of risk reduction and compliance among Operators that results in fewer, less catastrophic accidents and spills and 2) an enhanced ability to respond to those that do occur with prompt and appropriate regulatory action. BSEE seeks to continue serving as a model for other regulatory agencies and international peers.

Through an addendum to the Interagency Agreement E16PG00036 with the Department of Energy, BSEE involved the technical assistance of Argonne National Laboratory (Argonne) to perform Success Path analysis and Failure Modes, Effects, and Criticality Analysis (FMECA) in support of the American Petroleum Institute (API) efforts to establish a consensus-driven best practice document for wireline (WL) operations. Argonne conducted Success Path analysis and FMECA on the systems addressed in American Petroleum Institute Recommended Practice 16WL, *Cased Hole Wireline Pressure Control Equipment Systems*. This report presents a summary of the study approach, observations, and conclusions.

2. Background

Oil and gas (O&G) service companies use wireline units to perform a subset of well workover operations on both onshore and offshore oil and gas wells. BSEE regulates well control equipment systems under 30 CFR 250 Subpart G – Well Operations and Equipment and has a few specific wireline operations requirements under 30 CFR 250.620.[1] However, it is recognized that BSEE's regulations on these systems could be possibly improved (e.g., the *Wireline Operations Research Report* (BSEE, 2017)). Since there is not a currently an API wireline recommended practice or standard there is limited expert consensus on which, if any, document would be appropriate to incorporate in the regulations by reference.

Having recognized the lack of consensus among industry experts, the API Subcommittee 16 (SC16) Well Intervention Well Control Task Group (WIWC TG, otherwise known as Task Group 5) is, as of this writing, developing Recommended Practice (RP) 16WL[2], covering Cased Hole Wireline Pressure Control Equipment Systems. Additionally, BSEE, through the involvement of Argonne, is supporting a parallel development of API RP 16SB[3], *Snubbing & Hydraulic Workover Well Control Equipment Systems*. A discussion of the observations and findings in that parallel effort is available through a separate document ANL-23/25.

2.1 BSEE Involvement through the National Technology Transfer and Advancement Act of 1995

BSEE's participation in developing this RP fulfills a federal agency obligation of the National Technology Transfer and Advancement Act of 1995[4], which states:

> . . . Federal agencies and departments shall consult with voluntary, private sector, consensus standards bodies and shall, when such participation is in the public interest and is compatible with agency and departmental missions, authorities, priorities, and budget resources, participate with such bodies in the development of technical standards.

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[1] The regulations at 30 CFR 250 Subpart F, *Oil and Gas Well-Workover Operations*, describe the few specific wireline operations requirements at 30 CFR 250.620.

[2] The current working title for Recommended Practice is API RP 16WL Cased Hole Wireline Pressure Control Operations and Equipment Systems. While the title of the document may change over the duration of its development, the subject matter will be the pressure control equipment used for wireline operations.

[3] The current working title for Recommended Practice is API RP 16SB Snubbing & Hydraulic Workover Well Control Equipment Systems. While the title of the document may change over the duration of the project, the subject matter will be the well control equipment used for snubbing and hydraulic workover operations.

[4] National Technology Transfer and Advancement Act of 1995, Pub. L. No. 104–113, § 12, 110 Stat. 775 (1996).

2.2 History of Argonne Success Path and FMECA Applications

Argonne National Laboratory had developed the Success Paths Approach through research sponsored by BSEE as a result of post-Deepwater Horizon Incident efforts to adopt safety best practices demonstrated in other industries. Specifically, the Success Path Approach modeled safety assessment and safety assurance commanded by the U.S. Nuclear Regulatory Commission (NRC) relative to safety at U.S. civilian nuclear power plants. A key feature of NRC's approach to safety is in the focus on physical barriers that reliably contain radioactive materials from reaching personnel, the public, or the environment. Multiple, redundant, and diverse physical barriers help to achieve this goal through the philosophy called *defense-in-depth* (U.S. NRC, 2021). Individual barriers, barrier elements, or the system are evaluated through the risk-based analysis technique called *probabilistic risk assessment (PRA)*.

Through an analysis of BSEE's and industry's practices prior to the Deepwater Horizon incident, Argonne uncovered that the risk-informed decision-making framework in oil and gas placed a focus on operational aspects of incident prevention, such as procedures and training, rather than on physical barriers. Further, traditional risk in oil and gas focused on individual safety. In contrast, defense-in-depth focuses on physical barriers and barrier assurance as part of process safety—a philosophy that appeared to be less prevalent in oil and gas industry and BSEE's regulatory framework (BSEE, 2011, pp. 206-208). As a result, the Success Path approach, which is similar to PRA, was developed and later applied to place the focus on risk-informed evaluation of physical barriers (Fraser, et al., 2015).

A key difference between PRA and Success Paths is that the PRA focuses on evaluating potential failures of systems and components, whereas Success Paths are effectively the inverse of PRA, placing a focus on the minimum required system components necessary for the system (or barrier) to succeed in performing its safety function. Argonne had performed several studies of individual offshore oil and gas operations and related safety systems for BSEE by using the Success Path Approach. A summary report of individual studies is available on the BSEE website (Hamilton, et al., 2018).

2.3 Coiled Tubing Success Path and FMECA Studies

The original structure of the study that supports the development of API RP 16WL and is summarized in this report was modeled after a previous similar BSEE-sponsored effort focused on coiled tubing safety system evaluation (Hamilton, et al., 2018, pp. 39-42) that became a part of the development of API RP 16ST 2nd Ed., *Coiled Tubing Well Control Equipment Systems* (API, 2022). In the study supporting API RP 16ST 2nd Ed, it became clear that employing a Failure Modes, Effects, and Criticality Assessment (FMECA) as an additional safety analysis tool in concert with the Success Path Approach would enable performing more detailed analyses of lower-level components in the system identified through Success Paths. While FMECA (or FMEA, which is similar but does not take into account failure criticality and is therefore more qualitative) is a generally accepted approach industry-wide, the innovative part in this study was basing FMECA on Success Paths and attempting to quantify the analysis in terms of barrier performance, where any hydrocarbon or hazardous substance release should be prevented.

Several key findings were made in that study. They are summarized below:

- It was discovered that the recommendation to include a shear-blind ram as an emergency safety system in coiled tubing operations that was being proposed for API RP 16ST 2nd Ed. was insufficient as there was no requirement for a redundant power system for the dedicated shear-blind ram. This means that the power system was potentially a single-point failure for all rams, including the dedicated shear-blind ram. As a result, the study recommended that API RP 16ST 2nd Ed. include considerations for separating and diversifying power sources such that the dedicated shear-blind ram could qualify as a truly redundant barrier.
  - A similar philosophy of barrier robustness and redundancy may be considered for adoption in wireline operations and API RP 16WL when it is published.
- When analyzing the stripper assembly, it became apparent that due to the nature of this element, it could not qualify as a barrier on the same footing as the rams and could not necessarily be counted on in well control situations. It was recommended to re-classify the stripper assembly designation in well control situations from a barrier to a pressure control device only.
  - The philosophy of potential re-classification of wearable and other non-barrier elements in wireline operations, such as packoff, stuffing box, wireline valves may apply to API RP 16WL when is published.

The scope of the support study for API RP 16ST 2nd Ed. solely focused on the enhancement of requirements for well control elements through risk analysis, as much of the bigger picture elements had been effectively captured in the previous edition. However, in this present study, it became evident that the focus would need to primarily encompass pressure control in wireline operations. In addition, this included elements of personnel safety, environmental protection, and protection of communities[5]—in emergency pressure control situations as well as normal maintenance and repair activities. Also, the concept of well control, as in controlling sudden influx of pressure from the well using drilling type well control equipment and fluids is outside scope of routine wireline operations.

[5] The "communities protection" metric was determined by the workgroup subject matter experts to merit a separate designation, since many of the sites requiring well workover using wirelines are located very near places that have direct impact on the livelihoods of the surrounding communities. Examples include operation sites near schools or in prominent locations in underserved community areas.

3. Report Structure and Importance

3.1 General

This study took place at a time when the industry recognized a gap and a need to standardize practices in wireline operations, both onshore and offshore. Although well intervention using wireline has been the practice for decades, there are many nuances to the operations, which have yet to be captured and standardized. API has taken on the monumental task of attempting to standardize the operations by drafting the first version of the future API RP16WL, which is slated to set precedence over future safety practices applied to wireline operations.

The course of this study changed several times, which was primarily driven by the sheer amount of information that was discovered to be compartmentalized within the silos of individual companies or even individual subject matter experts. Rather than guiding a detailed technical analysis of already understood and agreed upon information regarding safety systems, barriers, and so forth, the research team and discussions that Argonne facilitated had to be brought up to a higher level and focus on helping the industry reach preliminary consensus on a number of issues, ranging from elementary items such as nomenclature and definitions, to more substantive issues such as safety and barrier philosophy. The value of a rigorous analysis through the Success Paths and FMECA is to provide a documented basis for existing or proposed safety philosophies for the eventual recommended practice document to be built upon.

While this study was originally intended to "fine tune" and document already existing knowledge through risk analysis using Success Paths and FMECA, in the end, one of its benefits may have been in bringing long-standing differences—as well as unspoken agreements and industry norms regarding certain practices—to light.

3.2 The Role of Wireline Operations

Before moving further, it is important to outline the scope and importance of wireline operations. Wireline is a well intervention technique used for a multitude of purposes, both in the onshore and offshore oil and gas operations. Examples of wireline operations include: well status examination and logging, perforation, "fishing" applications—meaning retrieving lost or disassociated items or tools, operating certain in-well equipment, such as opening/shutting valves, setting packers, sliding sleeves, installation and removal of plugs and other flow devices, cutting and milling of tubing, removing scale, asphaltenes, paraffins, and other well bore impairments, and removing and installing gas lift valves and other artificial lift devices.

3.3 Report Structure

The remainder of this report documents the approach, observations, findings, conclusions, and recommendations that resulted from the study.

- Section 4 provides the approach to the study and discusses the specifics, including adjustments, in the application of Success Path and FMECA analysis approaches to this study.

- Section 5 summarizes the discussion on barriers and pressure categories. This section provides important definitions that underpin important decisions from the subject matter experts on the future of barrier and process safety philosophy.
- Section 6 outlines important observations and findings from the Success Path and FMECA exercises.
- Section 7 provides brief conclusions, and
- Section 8 points to further recommendations for the relevant stakeholders.
- Appendix A contains the full collection of resulting Success Paths.
- Appendix B contains the FMECA sheet structure and example.
- Appendix C contains typical wireline stackup diagrams.
- Appendix D contains the API rules and policies that governed the workgroup discussions.
- Appendix E contains a brief summary of observations made throughout the study.

4. Approach

The initial approach in this study was modeled after the aforementioned study by Argonne in support of the development of API RP 16ST 2nd Ed. (API, 2022), whereby the workgroup, consisting of oil and gas volunteer subject matter experts in the WIWC TG were selected to meet periodically to gain consensus on the criticality of certain process equipment. The role of the Argonne team was that of a facilitator and moderator. Argonne facilitated the information gathering through biweekly teleconferences with the larger workgroup and additional literature search on the subject of wireline operations in order to construct Success Path models of the system elements and to subsequently facilitate the group discussion in the Success Path-based FMECA. As will be discussed in the Observations and Findings Section (Section 6) of this report, this approach had to be modified for a number of reasons in the course of the study. The subsections immediately below will summarize the decided upon guidelines for constructing Success Paths and FMECA sheets.

4.1 Workgroup Structure

The key component of this project was focused on reaching consensus among a group of volunteer subject matter experts in the field of wireline operations. This includes contractors and service providers, manufacturers, and operators. BSEE also participated in the meetings in the capacity of subject matter expertise and to further support the workgroup's efforts. The chair of WIWC-TG selected a focused sub-group from within the API SC-16 subcommittee who would be available for biweekly discussions led by Argonne to gain consensus on critical safety components and their features, which make them effective pressure control barriers. In sum:

- Everyone provided input according to their expertise in a respectful manner, and
- Meetings took place in accordance with API meeting rules and antitrust guidelines; shown in Appendix D.

4.2 Success Path Approach

The driving principle for modeling the system using Success Path methods was to analyze components and systems that have safety and pressure control functions.

The team embarked on the study by identifying critical pressure control barrier and non-barrier pressure control elements[6] in wireline operations and constructing Success Paths for these barrier elements. Selected barriers and pressure control devices that were subject to Success Path analysis included:

- Accumulator system
- Blind ram
- Braided line (or E-Line) packoff

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[6] The distinction between pressure control barriers and pressure control devices was made as part of the workgroup meetings and is discussed in Section 5.1.

- Grease injector
- Grease supply hardware
- Greasehead
- Flow check device (as part of stuffing box or packoff)
- Hydraulic and other types of motive power
- Inverted ram (as part of multi-strand wireline ram assembly)
- Lubricator
- Riser
- Shear ram
- Shear-seal (or shear-blind) ram
- Sheave
- Slickline packoff
- Slickline wireline ram (for single strand or jacketed cable)
- Stuffing box
- Tool catcher (note, not part of every situation, only applies if used)
- Wireline ram assembly (for multi-strand and cable wirelines, includes grease injection system)

The approach to constructing the barrier or non-barrier pressure control element Success Paths, in most cases, involved applying a similar logic across the elements, including design, construction, operation, and maintenance. Additionally, because power supply to actuate the barrier elements is a significant consideration, an additional "branch" for motive power on Success Paths concerning actuated devices was included. An example resulting Success Path for a shear-blind ram barrier is shown in Figure 1.

The general convention for these Success Paths is as follows:

- If the top event is achieved through the combination of events or elements under it that are tied with an AND gate, then all elements below must be present and all elements below must succeed. Failure of one element will mean failure of the top event.
- If the top event is achieved through the combination of events or elements under it that are tied with an OR gate, then all elements below must be present, but it is sufficient that only one or more succeed. The top event will only fail if none of the elements below succeed (any one of the subordinate features can satisfy the need or requirement.).

Importantly, the OR gate is not to be treated as a list of "menu" options for components that *could* be installed. In other words, if a component is on the Success Path, it means it must be present, installed, and operational. Its relationship with another component via an OR gate simply implies that there is redundancy built into the system.

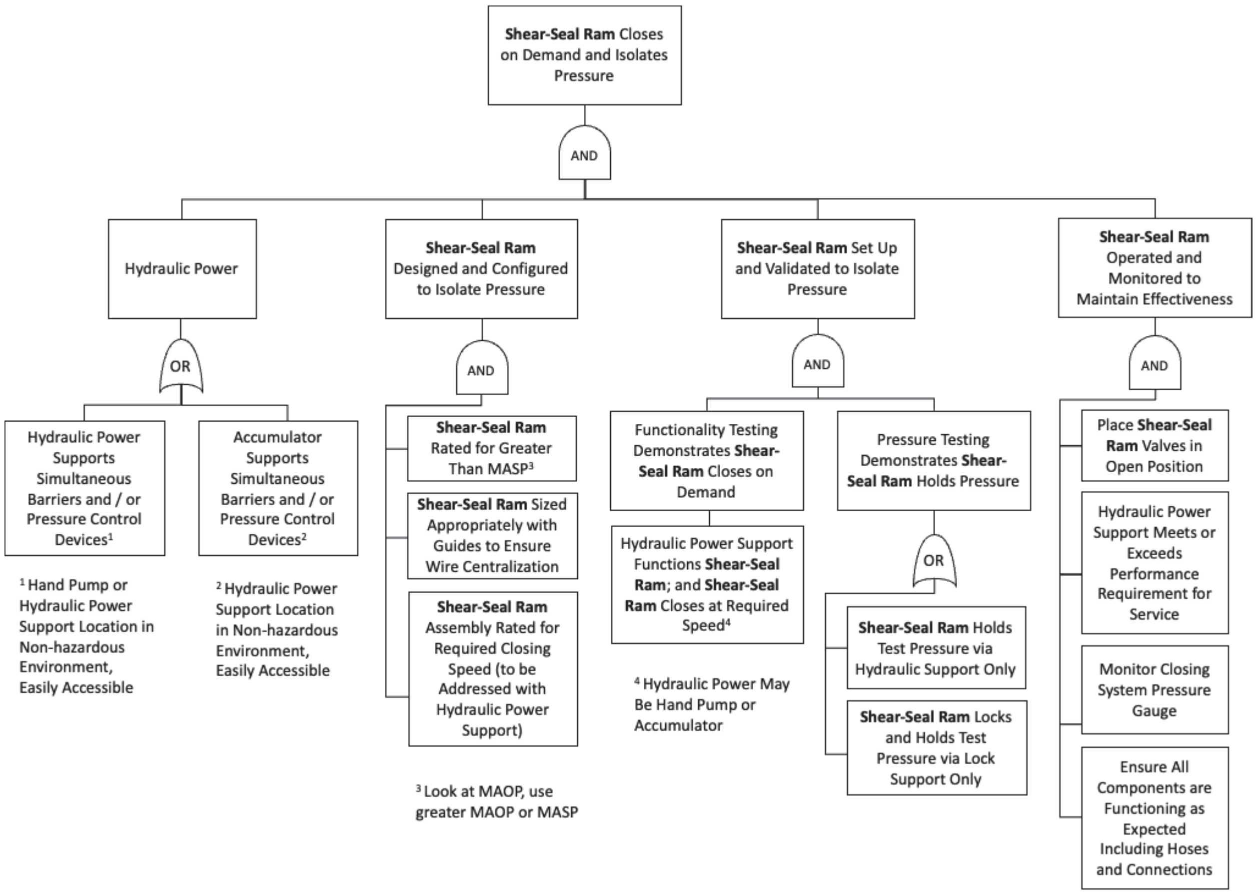


Figure 1: Example Success Path for the Shear-Blind Ram.

A complete set of finished Success Paths is shown in Appendix A.

To better tie in the FMECA, discussed in the next section, to the success paths, the two were linked by including a requirement in the success trees to *"Ensure that all relevant components are functioning as expected"* as part of each physical barrier's success path. This requirement can be interpreted as having an AND gate under it that contains individual key systems or components that must be in good working condition in order for this physical barrier to succeed. An example of the linking of the FMECA to the success paths is provided in Figure 2.

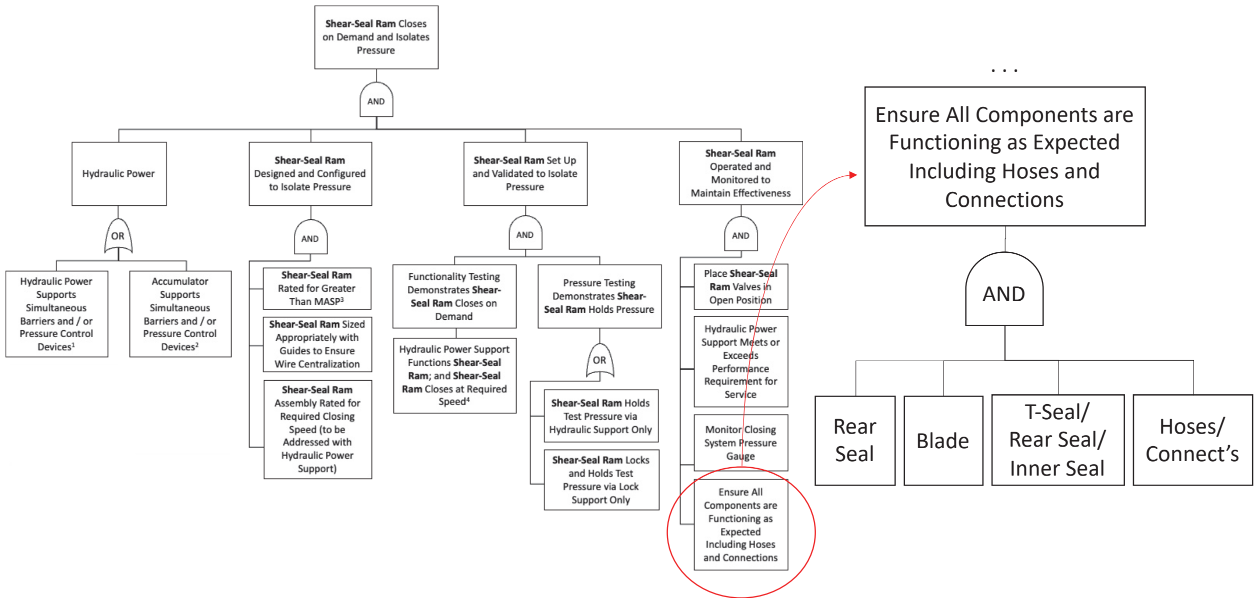


Figure 2: Example of the Relationship Between a Barrier Success Path and Barrier Components Evaluated in the FMECA.

The elements under the "*Ensure that all relevant components are functioning as expected*" AND gate are analyzed in the FMECA and evaluated in terms of the FMECA metrics discussed below.

Notably, in the end, not all Success Path- and FMECA relationships were represented in a one-to-one match. In many cases, one FMECA sheet would represent elements from several success paths and vice versa. Additionally, because of delays that were encountered, the workgroup simply ran out of time to complete additional FMECA sheets with Argonne's involvement. However, it is hoped that this FMECA is a tool that can continue to be used by the WIWC TG (API SC16 Task Group 5) as needed for further documentation of assumptions and recommendations as they continue work on developing API RP 16WL.

4.3 FMECA Application

4.3.1 Structure

Argonne worked with the API SC16 WIWC TG, which is tasked with developing API RP 16WL, *Cased Hole Wireline Pressure Control Operations and Equipment Systems*, on providing technical support to evaluating the robustness of the safety elements under consideration as the group is working to gain consensus. To ensure the integrity of the physical systems that support or comprise the physical barriers or other critical operational components, the Task Group members proposed performing a Failure Modes, Effects, and Criticality Assessment (FMECA), similar to the application of FMECA to the development of API RP 16ST 2nd Ed., with the aim of documenting the logic for consideration or potential eventual recommendation of certain safety systems or practices in wireline operations. For the approach supporting this project, the

FMECA was slightly modified from the version developed in support of API RP 16ST 2nd Ed. to include additional features, as discussed below.

Argonne's original recommendation involved utilizing the FMECA to identify the effects of a component and/or system failure on the physical barriers; i.e., clearly indicate the failure effect and other consequences in terms of potentially compromising physical barriers controlling hydrocarbon release. This type of analysis would produce risk rankings, discussed further in this Section, that would be unitless and reflect solely on the efficacy of the barrier element. However, in consultation with the workgroup, it was decided that additional consideration should be given to risks of potential hydrocarbon releases in terms of health and employee safety, the environment, and the community. An explanation of how this was handled is provided below.

The risks of the safety and integrity of equipment and barriers included in the Success Path were determined using the FMECA tailored for this project. This included the following evaluation elements:

- Identifying component failure modes for each major component;
- Determining the local consequence of each failure mode;
- Determining the consequence of failure modes on the impacted barrier(s);
- Identifying cause(s)/mechanism(s) of failure;
- Ranking the consequences of each failure mode in terms of:
    - Consequence ranking on barrier(s);
    - Consequence ranking on health and employee safety;
    - Consequence ranking on the environment; and
    - Consequence ranking on the community.
- Assigning an occurrence ranking for each failure mode, which was agreed to be based on average failure frequency in service as estimated by the experts based on their experiences in a quasi-quantitative manner. The failure occurrence data was distilled to that of post-setup and post-testing failures (not including shop or field testing failures), which would eliminate comparisons of dissimilar failure modes.
    - Notably, the occurrence ranking does not change based on evaluation terms, such as employee health and safety, environment, or community, so there is only one occurrence ranking.
- Calculating a risk ranking for each failure mode (which is the product of consequence- and occurrence ranking);
    - This was once again done in terms of barrier, health and employee safety, environment, and community.
- Identifying failure detection mechanisms; and
- Identifying failure prevention controls.

The consequence, occurrence, and risk ranking are described in more detail here to provide clarity on each term and how/if they were able to be determined.

Because barrier or pressure control device elements can compromise a wireline rig-up more than one way, the analyses took account of typical scenarios or equipment configurations and considered which would typically have additional elements installed. This was one of the largest factors influencing the FMECA and the consequence rankings, as described in the next section. Notably, as this report discusses further in Section 6, a lack of preliminary consensus on typical wireline unit configurations made the FMECA analysis more challenging.

4.3.2 Occurrence and Consequence Rankings

The ***occurrence ranking*** was scaled to a 1 to 5 ranking system, where a ranking of “5” represented the most frequent types of events and a ranking of “1” represented the least frequent events. In the original project planning, the actual frequency ranking was to be determined once representative data for the failure modes being considered in the FMECA were obtained. For events in which no data were available, the expectation was that expert judgment would be used to determine the occurrence ranking.

While conducting the FMECA, it became apparent that documented quantitative data to determine the occurrence ranking of each failure was unavailable. Due to the constraints in the available data, part of the analysis included achieving consensus among workgroup participants on quasi-quantitative occurrence rankings based on expert judgment. The agreed-upon rankings are presented in Table 1. FMECA evaluations were then performed using these rankings.

Table 1: Failure Occurrence Rankings.

Occurrence Rank	Occurrence Qualification	Occurrence Frequency
1	Very rare	1 in 100
2	Somewhat Rare	1 in 50
3	Somewhat Common	1 in 25
4	Common	1 in 10
5	Extremely Common	1 in 5

The ***consequence ranking*** used in the analysis is provided in Table 2 below. It ranges from a ranking of “1” in which the failure being evaluated has no direct impact on the functionality of the barrier, to a ranking of “6” in which the final barrier to the environment has been disabled. Each failure mode identified was assigned a value from 1 to 6 based on a consensus of the FMECA workgroup subject matter experts.

Table 2: Failure Consequence Rankings.

Consequence Rank	Consequence Description
1	System degraded but operational, no direct impact on barrier
2	System disabled, but alternative system available, no direct impact on barrier
2.5	System disabled/degraded with barrier degraded but operational
3	System disabled/degraded with barrier degraded, normal operations suspended
4	Barrier disabled, but two (2) alternative barrier(s) remain
5	Barrier disabled, but one (1) alternative barrier remains
6	Barrier(s) disabled, no barriers remaining

Notable items include the rankings of 2.5, 5, and 6. The ranking of 2.5 was introduced late in the project to accommodate cases where a failure leads to the barrier being degraded-but-operational but differs from a failure causing a barrier to be degraded-but-operational and necessitating suspension of normal operations. The ranking of 2.5 was assigned out of convenience to avoid changing already assigned rankings.

Rankings of 5 and 6 were differentiated due to noted differences regarding the common company policies or philosophies that require two pressure isolation elements[7] to be closed when performing maintenance or other business-as-usual operations (i.e., non-emergency operations) above the pressure control stack. Most commonly, two wireline rams are used for this purpose. However, these two elements may or may not be considered redundant barriers with respect to each other for emergency pressure control because they may share a single point of failure—e.g., a wireline that has bunched up in the bore precluding complete wireline valve seal. The concept of barrier redundancy is discussed later in this report. While both rankings of 5 and 6 were used, it may become appropriate to drop one in the future, depending on the final recommendation in API RP 16WL regarding whether two elements must be closed in non-emergency situations and possibly decoupling this from emergency pressure control.

To accommodate for consequences on specific groups, specifically health and employee safety, environment, and community, the authors and workgroup subject matter experts devised ***consequence multipliers*** which deflated or inflated the risk ranking based on the estimated severity of the consequence on each of these groups. The multipliers typically increased for each pressure category. These multipliers helped to contextualize the risk of a potential loss of pressure containment during wireline operations. The convention of multiplication was chosen out of convenience and as a practical way to put the risks associated with operations in different

[7] While BSEE regulations for wireline operations at 30 CFR §250.260 appear to require "at least one wireline valve", other regulations, for example the drilling operations regulations in Subpart G, call for "two independent barriers installed." From conversations with industry experts in the course of this study, many companies routinely carry the two-barrier requirement into their wireline operations company policies.

pressure categories into further perspective. Pressure Categories (PC) are explained in Section 5.3.

Table 3: Consequence Ranking Multipliers.

PC	Health and Employee Safety Consequence Ranking Multiplier	Environment Consequence Ranking Multiplier	Community / Sensitive Environment Consequence Ranking Multiplier
0	0.05	0.2	0.4
1	0.1	0.6	1.2
2	0.5	0.6	1.2
3	0.8	0.99	2
4	0.9	0.99	2
5	1	1	2

4.3.3 Risk Rankings

The ***risk ranking*** is the product of consequence and occurrence; i.e. a failure that occurs most frequently and has highest consequence in terms of barrier failure is calculated to have the highest risk ranking. Due to the consequence and occurrence ranking scales being calculated for barrier risk only, the risk ranking values ranged from 1 to 30 and the reference risk matrix is fairly compact. Table 4 below provides an example reference barrier risk ranking structure, where a decision can be made for classifying component failure risk as "Low", "Medium" or "High", indicated by color. Low ranking ranges from 1 to less than 6, Medium is greater than or equal to 6 to 12 inclusive, and High ranking is anything greater than 12.

Table 4: Example Failure Risk Ranking for Barrier Integrity.

Risk Ranking: Barrier Integrity						
		Occurrence Ranking				
		1	2	3	4	5
Consequence Ranking	1	1	2	3	4	5
	2	2	4	6	8	10
	2.5	2.5	5	7.5	10	12.5
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25
	6	6	12	18	24	30

Low	Medium	High

The reference risk matrix was further expanded to accommodate for the addition of consequence multipliers. In some cases, more granularity in multipliers, like in the case of health and employee safety, was warranted, causing the resulting reference risk matrix to still range from 1 to 30 but contain many more discrete values. This is shown in the Health and Employee Safety reference risk matrix in Table 5.

Table 5: Risk Ranking for Health and Employee Safety.

Risk Ranking: Health and Employee Safety						
		Occurrence Ranking				
		1	2	3	4	5
Consequence Ranking	0.05	0.05	0.1	0.15	0.2	0.25
	0.1	0.1	0.2	0.3	0.4	0.5
	0.125	0.125	0.25	0.375	0.5	0.625
	0.15	0.15	0.3	0.45	0.6	0.75
	0.2	0.2	0.4	0.6	0.8	1
	0.25	0.25	0.5	0.75	1	1.25
	0.3	0.3	0.6	0.9	1.2	1.5
	0.4	0.4	0.8	1.2	1.6	2
	0.5	0.5	1	1.5	2	2.5
	0.6	0.6	1.2	1.8	2.4	3
	0.8	0.8	1.6	2.4	3.2	4
	0.9	0.9	1.8	2.7	3.6	4.5
	1	1	2	3	4	5
	1.25	1.25	2.5	3.75	5	6.25
	1.5	1.5	3	4.5	6	7.5
	1.6	1.6	3.2	4.8	6.4	8
	1.8	1.8	3.6	5.4	7.2	9
	2	2	4	6	8	10
	2.25	2.25	4.5	6.75	9	11.25
	2.4	2.4	4.8	7.2	9.6	12
	2.5	2.5	5	7.5	10	12.5
	2.7	2.7	5.4	8.1	10.8	13.5
	3	3	6	9	12	15
	3.2	3.2	6.4	9.6	12.8	16
	3.6	3.6	7.2	10.8	14.4	18
	4	4	8	12	16	20
	4.5	4.5	9	13.5	18	22.5
	4.8	4.8	9.6	14.4	19.2	24
	5	5	10	15	20	25
	5.4	5.4	10.8	16.2	21.6	27
	6	6	12	18	24	30

In other cases, due to the existence of multiplier values greater than 1, the risk matrix range was sometimes larger, up to 60 (i.e., the product of the worst consequence, 6, by the worst occurrence, 5, times 2 in the case of community risks in high pressure category operations). This example is shown in Appendix B.

4.4 Wireline Pressure Control Configuration Diagrams

Pressure control configuration diagrams (or stack diagrams) are a helpful visual tool for communicating minimum requirements for pressure control barriers and operational barriers. The diagrams below represent some of the possible stack configurations for slickline and braided line wireline operations.

In most cases, the wireline pressure control units are encased in a single body, that is typically named after the number of ram or valve bodies that it includes. For example, the body in Figure 3 would be referred to as a "quad," wherein different types of actual valves or rams can be installed in it per the operation's requirements, but the number of the elements is the same: four. Other typical configurations can include triples, duals, or even have more than four elements. Majority of the diagrams in this section and in Appendix C show quad bodies, but the focus should be placed on the discussion of the correct number of pressure control elements making up a safe configuration.

The representation in this Section focuses on the detailed visual distinctions between the rams and other elements and the illustration of an outside view is shown in a smaller size off to the side. These diagrams, in their full scale for better legibility, are available in Appendix C.

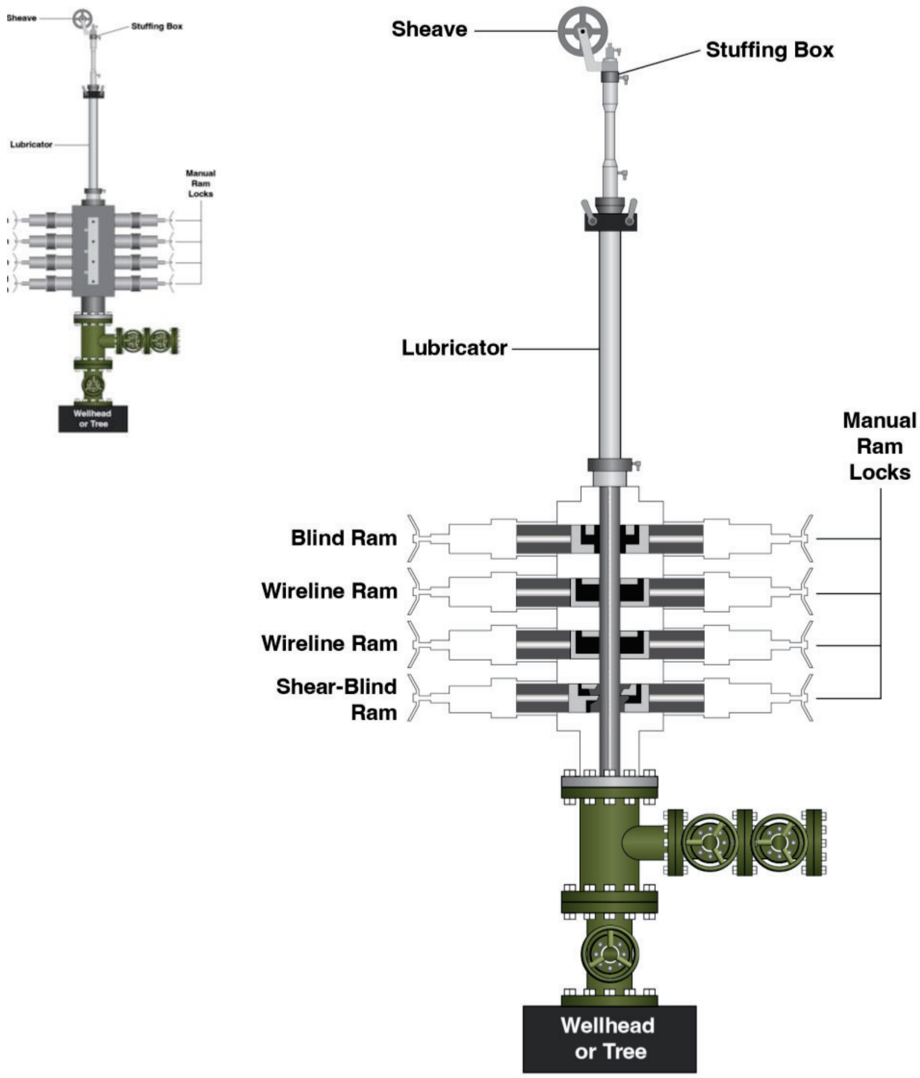


Figure 3: Typical Slickline Wireline Configuration with a Blind Ram and Two Standard Wireline Rams.

Figure 3 shows a typical configuration of slickline operations with a blind ram, two wireline rams, and one shear-blind ram encased in a "quad" body. The figures that follow show possible ram variations within the quad.

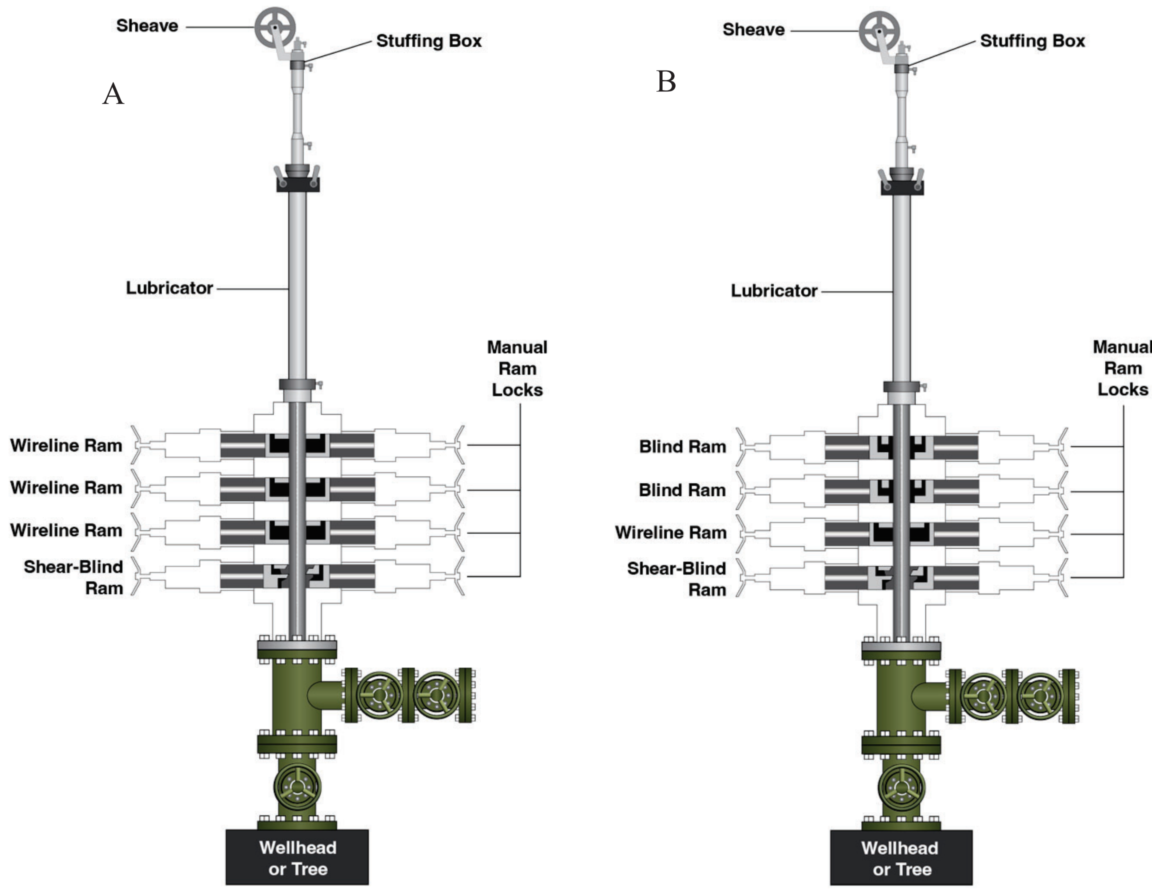


Figure 4: Alternative Slickline Wireline Ram Configurations-Three Wireline Rams on the Left (A) and One Wireline and Two Blind Rams on the Right (B).

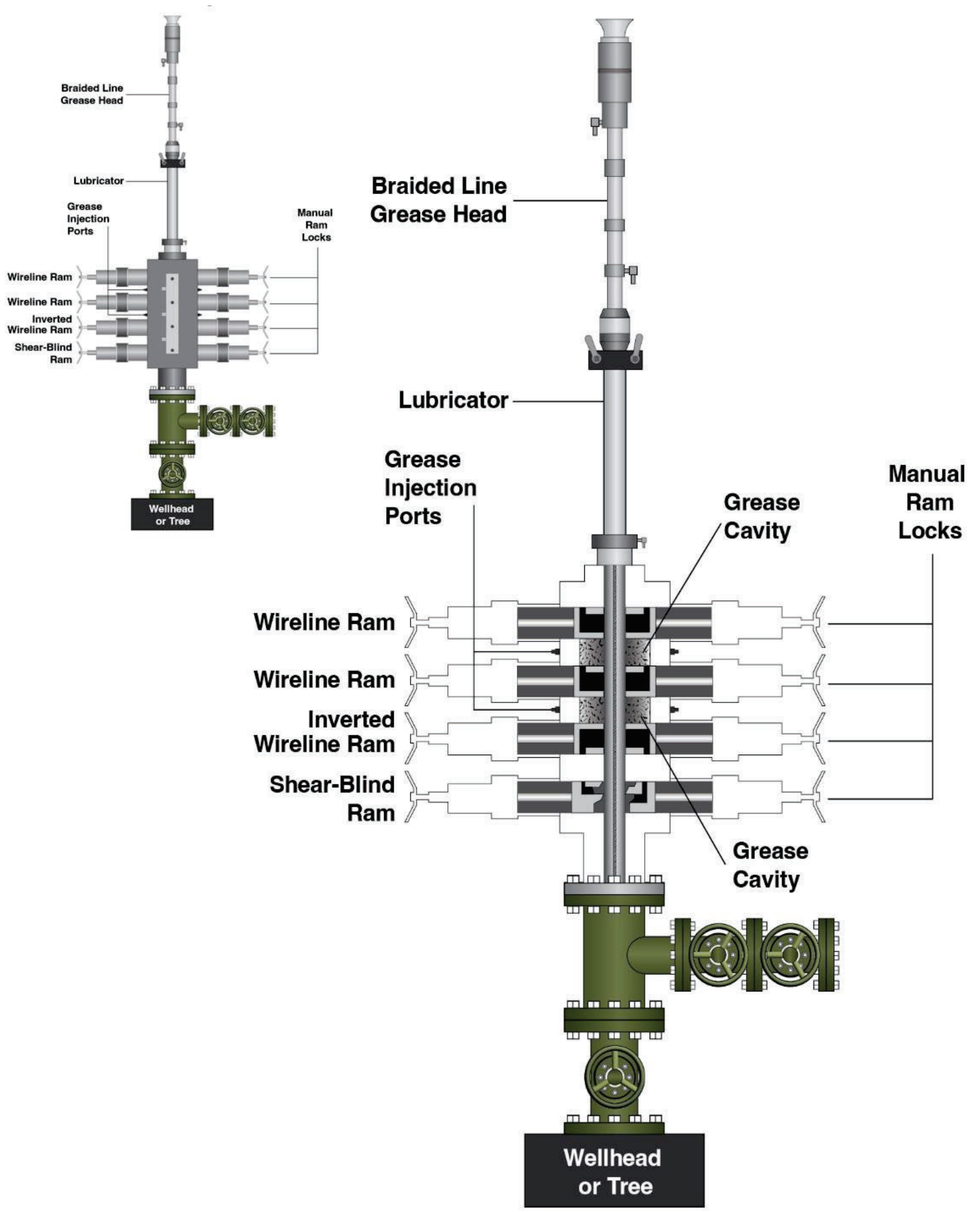


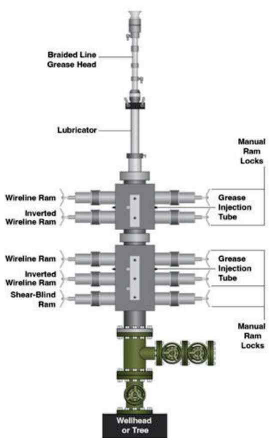
Figure 5: Typical Braided Line Wireline Configuration with Two Standard and One Inverted Wireline Ram.

Unlike configurations shown in Figure 3 and Figure 4 that illustrate slickline wireline operations, braided line wireline operations must include the addition of grease as a sealing element. Grease is to fill gaps (or "micro-annuli") between the elastomeric ram sealing element and the complex geometry of the braided wire. Additionally, because this grease needs to be encapsulated in a cavity that can hold the majority of its volume at a required pressure, a well pressure control function that would have been achieved with a single wireline ram in a slickline operation—has

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the view of the funding agency. Based on BSEE's review of the impact of the original report as not being at least influential, no peer review was commenced.

to instead involve a standard wireline ram and an inverted wireline ram (i.e., the grease cavity) in braided line wireline operations.

One such configuration is shown in Figure 5, which shows two standard rams and one inverted ram, which creates two grease cavities. An alternative configuration is shown in Figure 6, where two grease cavities are created by two sets of standard and inverted wireline rams. The philosophies regarding the numbers of standard and inverted rams are discussed further in Section 5.2.2.



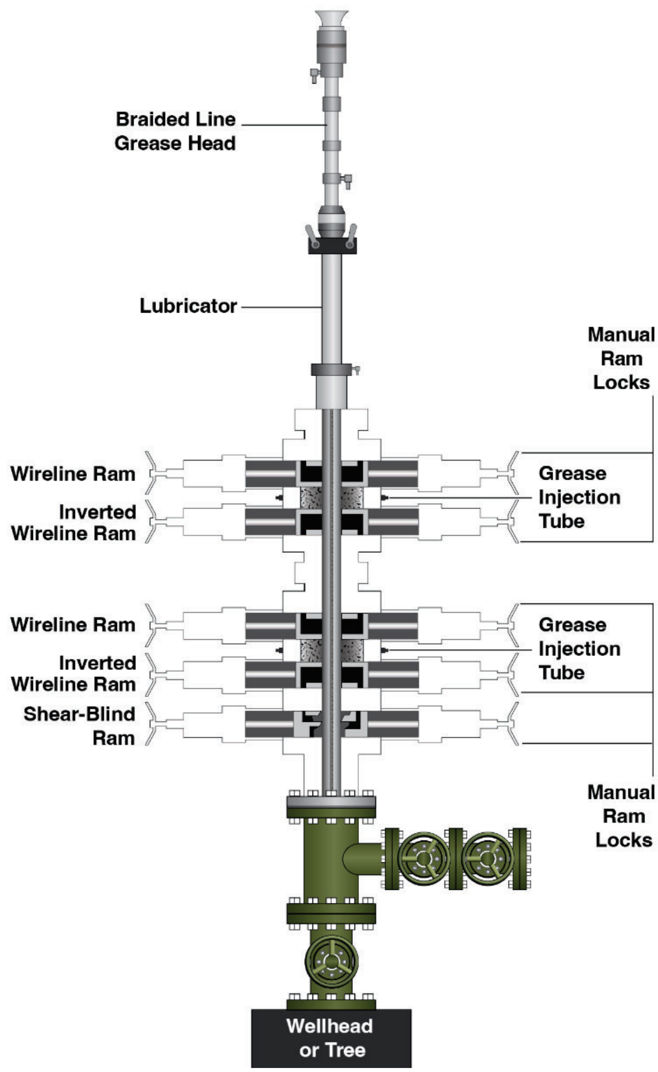


Figure 6: Braided Line Wireline Configuration Option with Two Standard and Two Inverted Wireline Rams.

5. Discussion

5.1 What Constitutes a Barrier Versus a Pressure Control Device?

5.1.1 Barrier Definition

Argonne's definition of process safety deals with making sure that the necessary equipment and systems are in place to prevent significant accidents. Policies and procedures that focus on the safety of the individual are referred to by the authors of this paper as *industrial safety*.

The word "barrier" in this definition of process safety means a physical object or device. Elements such as personnel availability and actions, training, procedures, and equipment (e.g., communication equipment) are important because they *support* the physical barriers. These elements are necessary to ensure the proper function of the physical barriers, but they in themselves are not in fact barriers. Furthermore, in process safety, the risk is directly related to barrier assurance because it is understood that if the barrier is breached, the consequences of the released fluid on the personnel, the environment, and facility and/or the surrounding community can be severe.

The basic idea behind this approach can be simply presented as follows:

Establish a robust physical barrier between people/environment and the hazardous materials

Establish a necessary number of robust backup barriers that will protect people and the environment from the hazardous material(s) if the first one fails

Ensure that necessary actions are taken for the barrier and the backup barriers to carry out their functions*

* These actions include automatic or human actions to actuate the barrier when it is needed as well as performing necessary testing, maintenance, and repairs to the component or system to ensure its proper function when needed.

The achievement of the above criteria—or the *safety goal*—is not always simple. Offshore oil and gas systems tend to be complex. The barriers may be exposed to substantial loads from fluid pressures (either from the hydrocarbon reservoir or from applied service pumping operations), and forces associated with stack configuration and operating conditions. So, one of the key ingredients to establishing and maintaining multiple physical barriers is to understand which elements form the primary barrier, and which elements need to be in place or established to form the secondary or backup barrier(s). For example, in coiled tubing, BSEE regulations and API RP 16ST 2nd Ed. determine the number and kinds of redundant barriers for specific pressure categories.

5.1.2 Active and Passive Barrier Characteristics

It is important to recognize that some physical barriers are naturally *passive* elements—ones that are expected to carry out their safety goal without human action or electronic signals. Passive barriers are further subdivided into *passively actuated barriers* and *purely passive barriers*.

Passively actuated barriers change their state to meet their safety function (e.g., from open to closed), however they do so without human intervention, such as pressing a button, or software actuation, and they typically rely on natural phenomena, such as the force of gravity or spring forces, among others.

On the other hand, purely passive barriers perform their safety function without a change in state. Examples of purely passive barriers are pipes or tubing, casing and cement. It is important to note, however, that despite no mechanical action being required to have purely passive barriers meet their safety functions, considerations of correct manufacturing, installation, and resistance to external factors and forces must still be present to ensure their success.

Other physical barriers are *active* barriers, which must change their state (open, close, cut and seal) to carry out their safety function, and this change of state is driven by an external action.

Thus, a safe multiple physical barrier system is one where the physical barriers, passive and active, can perform their safety function under *all* expected and anticipated conditions. The oil and gas industry uses specific conditions, often based on service pressure, to specify the design loads that may be placed on the physical barrier(s). Such conditions include the maximum anticipated surface pressure (MASP) and the rated working pressure (RWP).

The diagram in **Error! Reference source not found.** summarizes passive and active barrier attributes.

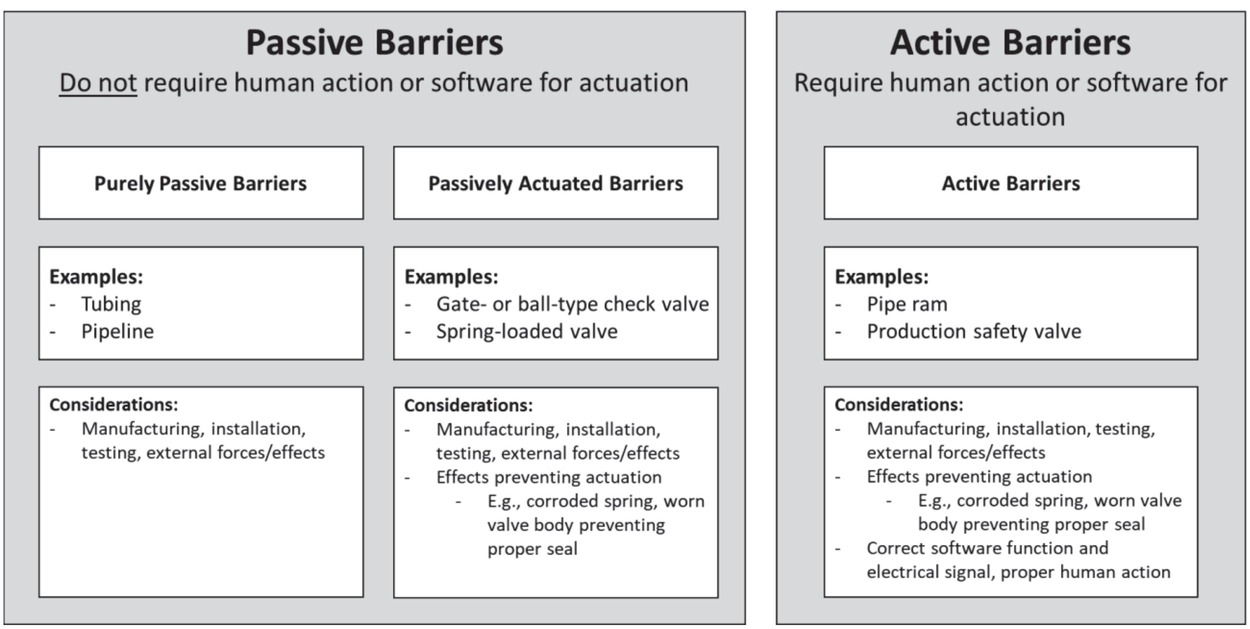


Figure 7: Summary of Active and Passive Barriers.

Aside from the design of the proposed equipment, it is also critical to consider the construction (or installation and testing) of the various components, the operation of these components, and the maintenance of these components. Argonne's Success Path approach embodies the multiple physical barriers philosophy and analyzes these actions in terms of four discrete phases—design, construction, operation, and maintenance—or DCOM.

Whether passive or active, the physical barriers are components of an overall system. Their safety function in oil and gas facilities is to form a barrier to the uncontrolled release of hydrocarbons or hazardous fluids capable of harming personnel, the environment, and facilities and/or surrounding communities. Contrary to the common misconception that a "barrier" is comprised of equipment that is relied upon only in an adverse situation (in the case of coiled tubing, it is the *well control stack*); the Success Path approach focuses on the integrity of the elements forming the hydrocarbon-sealing envelope at all times. This concept is widely accepted and is most commonly defined by the NORSOK D-010 standard (Standards Norway, 2021).

In wireline operations, the equipment components that form a barrier must be able to isolate the full cross-sectional area of the pressure control stack bore inner diameter. This area is typically defined as the area between the outer diameter of the wireline and bore of the pressure control stack (i.e., the annulus). In addition, the wireline itself must maintain its mechanical and pressure-containing integrity in order to allow rams and valves to properly seal around it or to shear it if necessary, to keep the hydrocarbons and hazardous fluids contained.

5.2 Pressure Control Barriers Versus Pressure Control Devices

In the course of this study, the workgroup subject matter experts determined that a further characterization of safety elements was necessary. Specifically, there are use cases that require a permanent seal to be formed that can function while unattended. On the other hand, there are situations where a seal that requires constant monitoring, verification, and maintenance is acceptable. For these reasons, the safety elements were further classified into *pressure control barriers* that are different from *pressure control devices.*

Pressure control devices are those that require active attendance and are not necessarily expected to provide a complete seal at all times. An example is a stuffing box or packoff.

On the other hand, pressure control barriers are those that can be closed and can remain closed and be able to provide pressure control without any further intervention. An example of such a barrier is a properly functioning shear-blind ram. Another example is the system of barrier elements comprised by the slickline wireline ram and the wireline itself, provided that the wireline is able to maintain integrity and it allows a proper and complete seal of the wireline ram around its outer diameter.

In the case of braided line wireline rams, this presents a more complex situation since, as mentioned previously and discussed in more detail in Section 5.2.2, the seal between the wireline ram and the braided wireline is completed through the injection and control of grease, which is an involved process and cannot be left unattended, thus contradicting the workgroup's working classification of barriers, as of this writing. This scenario continues to present a challenge to the industry and the group of experts involved in drafting of API RP 16WL.

5.2.1 Number of Barriers

As briefly mentioned before, the barrier requirements per BSEE regulations for wireline operations are limited compared to other BSEE regulations. Specifically, sub-paragraph (b) in 30 CFR § 250.620 *Wireline operations* states:

> . . . All wireline perforating operations and all other wireline operations where communication exists between the completed hydrocarbon-bearing zone(s) and the wellbore shall use a lubricator assembly containing ***at least one wireline valve*** [emphasis added by the authors].

At the same time, other regulations, for example, those in Subpart G—*Well Operations and Equipment*, have a requirement of "at least two barriers installed."

This has been recognized as a potential gap and there have been recommendations for additional safety elements. For example, a BSEE-commissioned study in 2017 contains a recommendation for revising this requirement by mandating one set of wireline rams and one additional device capable of cutting the wireline, such as a wireline shear ram or a shear-blind ram (BSEE, 2017).

Additionally, from communications with the industry subject matter experts in the course of this study, most companies have integrated the two-barrier requirement into their company safety policies for most workover operations, including wireline operations. While the timing of this writing is too far from being able to tell what the published recommendations of API RP 16WL will include, the majority of technical discussions that took place in the course of this study implied a requirement for two pressure control barriers.

5.2.2 Braided Wire Rams with Grease

By the nature of it, the braided wire has a complex geometry, and no elastomeric seal can be guaranteed to seal against it without creating micro-annuli, which can become a leak path. The industry recognizes this, and in the cases of braided wire operations, they create cavities with an inverted wire ram on the bottom (inverted means it provides a seal against fluids from above) and standard wire ram on top (standard means it provides a seal against fluids from below). The cavities are then pumped full of grease. The grease is a viscous fluid of predetermined characteristics, such as viscosity, chemical composition, thermal expansion, and others that are determined by the nature and environment of the operations. It is continuously injected into the cavity via injection ports and replenished to compensate for the losses of grease that is returned. Grease is typically injected at 120% of shut-in tree pressure. Finally, the pressure in grease cavities is equalized between the cavities, and managed through the equalizing valve. This concept is shown in Figure 8 below.

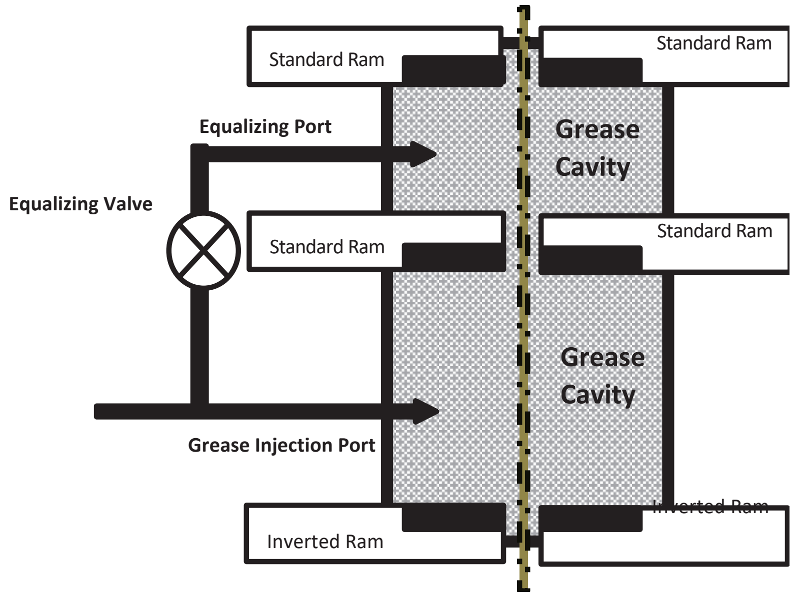


Figure 8: Braided Wire Grease Cavity Safety System

There are several issues that this system presents. First, the availability and quality of grease able to withstand often changing environmental factors (e.g., at a worksite where the ambient temperature changes significantly depending on the time of day, and to compensate, one may need either a very versatile type grease or two or more banks of different grease). This requires significant attention and was determined in the discussions to be an area of vulnerability. Second, even with the correct grease that is present in the correct amount, contamination is an easy pathway to system failure. Third, the injection ports each present a single point of failure, i.e., one injection port failing can lead to depressurization of the cavity. Fourth, there are typically redundant grease pumps ("dual pumps"); however, the power supply or grease supply for those pumps is most often common and may be a single point failure that can disable the system. There are many other vulnerabilities not listed here, but the above are the most prominent. For these reasons, the workgroup had decided to classify this system a *pressure control device* rather than *barrier*.

At the same time, this classification can lead to a gap in the braided wireline system's ability to meet a discussed/ potential requirement of having two *barriers*, as noted in Section 5.2.1. The only other barrier present in a typical configuration is the shear-blind ram. To close this gap, 16WL will most likely mandate additional barrier elements to meet the two-barrier requirement, which may be a second blind ram, shear blind, or a gate valve.

The system, as presented in Figure 8, is only one of several ways in which the industry currently achieves two operational pressure control devices. The philosophy behind the system shown above is that the presence of two standard rams and two grease filled cavities prevents fluid flow from below. There are other philosophies which disagree that the above truly represents two pressure control devices as they share the single inverted ram, which can be viewed as a single point of failure, thus claiming that the above is just one pressure control device. To address this concern, sometimes, two inverted rams may be used: each inverted ram paired with one standard ram. The sequence of the installed rams in this case is shown in

Figure 9. While this approach addresses the single point of failure concern with respect to the number of inverted rams, it may present other challenges, such as an inability to equalize the grease pressure in certain ram closure sequences or present a challenge to the good practice of minimizing stack height and complexity. This is another area where the expert workgroup will need to do a considerable amount of work on gaining consensus on the best practice.

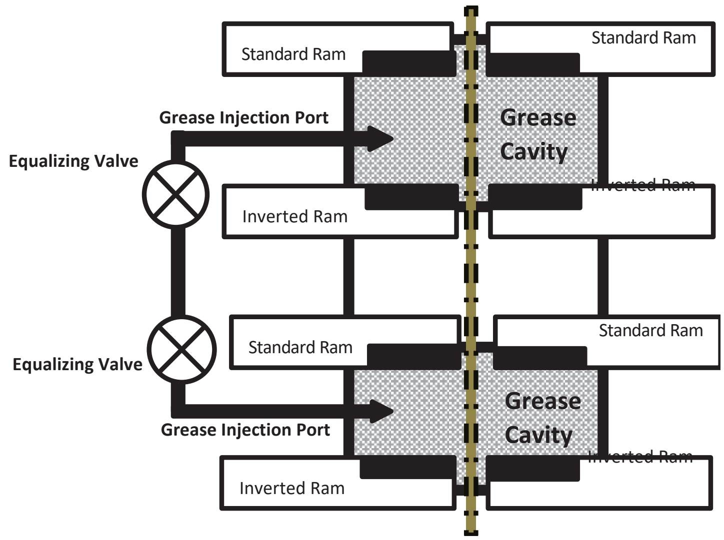


Figure 9: Alternative Braided Wire Grease Cavity Safety System.

5.3 Pressure Categories

Pressure categories are a helpful way to evaluate and compartmentalize any applicable operational risks. In a way, this is intuitive since higher pressure categories imply a greater amount of hydrocarbons released in case of a barrier failure. In this study, pressure category identification was driven by the maximum anticipated surface pressure (MASP) values, which then established equipment rated working pressure (RWP) requirements. The four pressure categories, plus "PC-0", for this study are shown below.

Table 6: Wireline Pressure Category and Barrier Requirement Information.

PC	MASP Range, psig	Minimum Stack Equipment RWP, psig	Min # of Pressure Control Equipment Barriers
PC-0	0	3,000	1
PC-1	1 – 4,166	5,000	2
PC-2	4,167 – 8,333	10,000	2
PC-3	8,334 – 10,416	12,500	2
PC-4	10,417 – 12,500	15,000	2

It is important to note that the current assumption for MASP of 0 implies the well's inherent inability to flow unassisted—i.e., it is "naturally" at 0 psi pressure at the surface. Following this logic, the MASP is not 0 psi if it is held that way via human intervention, such as deliberate addition of weighted fluid, etc.

The values in Table 6 were agreed upon during this study. Reduced MASP ranges relative to equipment RWP allow a 20% margin (i.e., 5,000 ÷ 1.2 = 4,166) for pressure drop across flow tube grease and other like devices used for well pressure control. These values may change when API RP 16WL is drafted or published.

6. Observations and Findings

6.1 Overall Observations

As stated previously, there was a significant gap in consensus in a number of areas concerning wireline operations. A full Success Path and FMECA process would logically conclude with clear recommendations or demonstrated advantages of a defined barrier configuration and even a possible barrier actuation sequence. While many of the FMECA areas assumed a redundancy, it was not always clear what the actual redundancy is. In contrast, the advantage that the research team had during the API RP 16ST 2nd Ed., or Coiled Tubing analysis task was a clear understanding of the barriers and other elements already outlined in the first edition. In that study, the Success Path and FMECA was a basis to improve or enhance the requirements in the first edition, whereas in the present study, these risk assessment methods merely tested working assumptions, often made in the course of the study and dialogues. Nevertheless, this study identified several important areas for the API RP 16WL workgroup to consider for the first edition of the document, as noted throughout the report and summarized in this section.

Additionally, irrespective of the baseline consensus on certain barrier, pressure control, and operational configurations and conditions, the time estimate to complete a Success Path and FMECA analysis proved to be a challenge, although having more underlying understanding would likely have helped to speed up the studies by eliminating the need for extensive discussion regarding existing redundancies or single points of failure. As mentioned previously more than twice as much time spent in regular working meetings than originally anticipated (A total of 22 meetings that took place over the course of 10 months).

6.2 Success Path an FMECA Results

6.2.1 Success Path Observations

The Success Path analysis was meant to model consensus-based systems, but also supported an exercise to build consensus on certain barrier and operational elements in addition to the intended purpose. For example, there was significant debate about typical power systems driving safety valves as there did not appear to be one standard practice for the kinds and the number of power systems (e.g., accumulators, manual hydraulic pumps and any associated redundancies, etc.). However, there seemed to be general consensus on the need for redundancy in safety systems in a conservative recommended practice document.

General observations and findings from the wireline Success Paths are below:

- Current practices do not appear to consistently require redundant power systems for wireline valves.
- Braided wire operations have multiple single point failures, many of which appear in the grease injection system.

- Braided wire operations do not presently appear to have two redundant and diverse barriers, making it a potentially higher risk operation.[8]

- There are elements that can disable an entire "leg" of a Success Path, for example, the sheave, if incorrectly sized or eroded, may deform the slick line, potentially precluding the wireline valve from properly sealing against the wireline outer diameter.

- In today's environment, powered actuators are often hydraulic and driven from either a motor- or engine-driven pump or by an accumulator bank. A manual pump can be substituted for hydraulic fluid rapidly discharging from an accumulator, but large actuators require considerable time to move when driven by a manual pump.

    - Time is an important contraindicating factor for fully manual barriers. Several times the workgroup subject matter experts mentioned that personnel sometime must climb scaffolding or structures for access. The sentiment from the workgroup seemed that fully remote operation can provide a short action time as well and eliminate the need for personnel to climb or be next to a system that may be experiencing other than planned operating conditions.

    - Note that the resulting Success Paths show accumulator- and manual hydraulic pumps with an OR gate, meaning they are both present and represent a redundancy to each other; however, as it was later discovered, it is often the case that either one or the other is available, but not both manual pump and accumulator. This may prompt a future revision to the Success Paths for ram and valve barrier elements to reflect current or recommended practices more accurately.

6.2.2 FMECA Results and Observations

FMECA helped to address specific risks related to certain barrier equipment, but because of the time overrun that the workgroup experienced, certain elements were deprioritized from analysis, and the wireline valves for braided wire, among other arguably important elements, were left out.

However, the FMECA did help to show areas of clear insufficiencies. Several examples include:

- Ram cylinder body leakage, which can result in hydrocarbon release, apparently happens somewhat commonly, with an occurrence ranking of 3. This is especially concerning

[8] Note that following the WIWC TG's decision to re-classify the braided wire ram with grease system as a pressure control device, rather than a barrier, to keep the focus of this study on prioritizing barrier element analyses, the effort to complete the FMECA for this system was suspended. However, considering that there are several single point failures in braided line wireline operations, this can be an intuitive hypothesis.

since this failure mode is also common to shear-blind rams, which are considered the "last resort" in terms of barrier reliance.

- Passive barriers, such as the tool trap, lubricator, wellhead adapter, and others, may also have areas of vulnerability, which may warrant further attention and possible recommendations in terms of proper maintenance and material selection, to prolong barrier life and increase associate safety margins.
- The hand pump and accumulator appear as very vulnerable parts of the system as often their failure leads to high consequence (often, consequence of 6 as unavailability of an actuation system can take out all ram or valve barriers). This means that an occurrence of 1 can classify the element as "Medium Risk" (orange color on the reference risk matrix), and an occurrence ranking of 2 (or the next one up), can make it "High Risk". There are several elements within each making them vulnerable, such as availability, flow capability, purity, and compatibility of the hydraulic fluid; availability of power and pumps to recharge accumulators (in systems where they are present), and so forth.

6.2.3 Further FMECA Development and Completion

Because all the FMECA analyses could not be completed in the available time, several components originally identified for analysis that were ultimately never analyzed. These include:

- Bleed ports
- Control console for accumulator
- Control fluid -partially addressed in the accumulators FMECA.
- Grease head including flow tubes/lines, which was started but abandoned mid-way.
- Grease pump, including hoses -partially started but abandoned after the workgroup made a decision to not include wireline valves for braided wire in the list of pressure control barriers.
- Hydraulic / Mechanical Latches
- Load Cell
- Hose couplings and connectors
- Sheave
- Slick/ Encapsulated Stuffing Box
- Wireline Ram for Slick Line- analysis started but abandoned mid-way through as there is still a gray area in referring to this element as a pressure control barrier.
- Wireline Unit Power Pack/ Prime Mover- partially addressed in the Accumulators FMECA sheet. It appears that the prime mover failure can be catastrophic to the entire operation—not just in terms of inability to quickly close the rams, but also possibly contributing to a lost ability to move the wire and attached tools in and out of the well.

6.3 Other Observations

Several observations came up in the discussions. This subsection represents some of the highlights. A brief but more complete list of these items is presented in Appendix E.

6.3.1 Consensus on What Constitutes a Barrier

Initially, the expert workgroup had vastly different definitions for what constituted a barrier. Through this exercise—and the workgroup's input and eventual consensus, as outlined in Section 5.2—the future efforts in writing the recommended practice document might better align around an agreed-upon barrier philosophy. Notably, per workgroup discussions, API does not currently require consistency in definitions across different documents. This can have both a favorable effect of providing the individual workgroups the freedom to come to consensus on the area of their shared expertise, but at the same time may perpetuate confusion across different oil and gas extraction operations.

6.3.2 Consensus on Nomenclature and Definitions

Through this exercise, the workgroup made significant breakthroughs on converging on consistent nomenclature. For example, there was a lack of clear definition for wireline rams, blind rams, shear rams, and shear-blind rams, and other elements, as these terms had been used inter-changeably in different ways in the companies' jargon. Another example is the term "slickline" versus "wireline". It should be understood that slickline is a subset of wirelines and braided- and other types of lines need to be called out as such. There are likely other such terms that the API RP 16WL workgroup will encounter and reconcile as they draft the RP that did not arise in this study.

Other terms lacking clear and consistent definition include (by category):

Major Components:

- Wire rams, pack off (stuffing box), grease head, shear blind, Shear ram (if applicable), braided wire, slickline, pump in sub (access port for killing well?), grease injector, E-line, lubricator, ball check, tool trap, tool catcher, sheeve, wire spool, load cell (if used).

Support Systems:

- Motive power for grease injection, motive power for hydraulics, electric power, and pneumatics.

Service classes:

- Pressure ranges, associated equipment rated working pressures, barrier requirement counts, or similar, pressure categorization philosophy based on MASP or MAOP (maximum anticipated operating pressure), recommended deratings because of grease head pressure drop.

Leaks:

- There was a discussion of major versus minor leaks; however, the workgroup did not come to a consensus as to where the differentiation is between the two.

6.3.3 Normative References

There was a number of references to other standards, specifications, and recommended practice documents brought up in discussions. Some of these are directly applicable while others only serve as example criteria that may or may not be applicable to wireline. While normative conformance was not a part of this study, the authors wished to document them in this report as an attempt to help the API RP 16WL workgroup in their future efforts of drafting the document. They are captured below.

The workgroup discussed concepts in:

- API RP 16ST 2ed, *Coiled Tubing Well Control Equipment Systems*, February 2021 for barrier and pressure control philosophy.
- API Spec 16A, *Specification for Drill-Through Equipment*, 4th Edition April 2017 (includes Errata 1 dated August 2017, Addendum 1 dated October 2017, Errata 2 dated November 2017, and Errata 3 dated April 2018).
- API Spec 6A, *Specification for Wellhead and Tree Equipment*-21st Edition, November 2018 (includes Errata 1 dated April 2019, Errata 2 dated June 2020, Addendum 1 dated July 2020, Errata 3 dated September 2020, Addendum 2 dated June 2021, Errata 4 dated September 2021, and Addendum 3 dated August 2022).
- API Std 16AR, *Standard for Repair and Remanufacture of Drill-Through Equipment*-1st Edition April 2017 includes Errata 1 dated August 2017 for COCs and COSs.
- API Spec 16D, *Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment*- 3rd edition November 2018.
- API Spec 16B, *Coiled Tubing, Wireline and Snubbing Well Control Stack Equipment* (Currently in letter-ballot)

Additionally, the authors found this reference helpful:

- API Spec Q2, *Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural gas Industries*, 2nd edition, July 2021.

There are likely other appropriate standards, specifications, or practices that may be relevant or useful but did not arise in the course of this study.

6.3.4 Barriers in Braided Wireline Operations

The definition of “barrier” versus “pressure control device” as presented in Section 5.2 of this report creates an issue with respect to barriers in braided wire and grease operations. It appears that there is currently only one way to address pressure control emergencies in braided wireline operations, and that is to actuate the shear-blind ram. The workgroup subject matter experts came to a conclusion that the system of wireline rams and grease would not be considered a barrier in

API RP 16WL, and will need to do a considerable amount of work to identify and require an additional option for pressure control in braided wireline operations.

6.3.5 Inverted Rams

Further, as discussed in Section 5.2.2 and shown in Figure 8 and

Figure 9, there is a lack of consensus on what constitutes two pressure control devices for normal, non-emergency braided line wireline operations. There are cases where one inverted ram in concert with two standard rams is used, and due to two standard rams and two cavities filled with grease, it is considered to comprise two pressure control devices, even though the single inverted ram can be considered a single point failure for both standard rams. Other schools of thought call for two sets of inverted and standard rams to guarantee the presence of two redundant pressure control devices (systems), but this also presents unique challenges. Notably, these two elements, albeit redundant, share several single points of failure, such as braided line integrity, grease characteristics/availability, and others.

6.3.6 Unique Issues Pertinent to Industrial Safety in Wireline Operations

While not a hydrocarbon release issue, a scenario of failed wire under excessive tension or other sudden separation modes can present a significant personnel hazard. This scenario arose briefly in the discussions and noted by the workgroup to be addressed in the future in API RP 16WL, and the workgroup subject matter experts' sentiment in the discussion pointed to a need to recommending preventive and mitigation approaches.

6.3.7 Independent Review Certificates and Other Manufacturer Certifications

Because many of the wireline operations aspects do not conform to an existing industry standard, the industry has adopted "Independent Review Certificates" or IRCs for certain equipment. From discussions with the workgroup, it was clear that the IRCs are a quality assurance mechanism between with equipment supplier/manufacturer and user.

6.3.8 Challenge with Non-Shearables

If a non-shearable object (e.g., a set of tools that the wireline is transporting or a section of the wireline has "birdnested") is present in the shear-blind ram (or any other barrier) upon a power failure affecting the wireline traveling in or out of a well, there is an open question as to how the non-shearable can be moved for pressure control or whether another device available. This may present a case for robust redundancy in power systems and/or a configuration that can sustain the ability to shear the wireline and seal across the wellbore.

6.3.9 Function Testing

Generally, mechanical ram locks are a standard feature on any ram assembly and are function-tested in the shop as part of repair or refurbishment. Once in the field, often there is no routine function testing. However, disassembly for repair could be needed. Testing if not already a common practice should be a consideration following any such disassembly.

6.3.10 Pressure Control Using Fluids

Weighted fluids can be present during some wireline operations. Some of the discussions with the workgroup touched on the weighted fluids' role in pressure control, but no clear consensus was reached.

7. Conclusions

The wireline operations industry is mature and complex. Considerable expertise exists within individual organizations or even subject matter experts within an organization that is invaluable. The safety and other best practices within the individual companies have evolved significantly and individual companies continue to consider and implement novel improvements. Operational flexibility is important to preserve capabilities but there are recommended practices that are largely common to all operations.

The industry should be commended for collaborating on the standardization and significant efforts to create a recommendation for best practices in this specialized yet complex and multi-faceted trade. From the discussions that took place as part of this analysis, it was clear that the industry's desire is to prioritize safety and the protection of the environment and the communities through well thought out recommendations. Namely, there appears to be general agreement regarding the need for redundant safety systems to combat the potential associated process safety hazards.

There are many areas that still need significant consensus to be reached by the subject matter experts. It was initially assumed that general agreement on the overall operations exists, but that assumption was disproven through the exercise of building the Success Paths and FMECA components of the study. In some cases, there was conflation in both Success Paths and FMECA regarding what was representative of the current practices versus what would the participants like to see in API RP 16WL when published and in future wireline operations.

Both Success Paths and FMECA helped to uncover areas of clear sufficiency in the safety systems, as well as areas of vulnerability to the system that the workgroup of experts will need to further consider and resolve in their efforts to develop API RP 16WL. Success Paths and FMECA are tools that can be used by the workgroup going forward as a way to document their assumptions and simply but effectively show potential ill effects of lacking conservatism in system designs. Success Paths easily point out single points of failure (of which there appeared to be many) while FMECA simply ranks the risk, in most cases, higher in the event that there are few or no alternative barriers available to support the primary barrier or safety system. It is hoped that this exercise and the potential future use of Success Paths and FMECA will help the industry experts to continue gaining consensus on critical wireline safety systems and to identify areas where more work is needed.

8. Recommendations

The authors of this report observed several areas potentially warranting recommendations, as summarized below.

One major recommendation is to encourage the workgroup to complete the remaining FMECAs identified in Section 6.2, such that all assumptions and recommendations are clearly documented.

A major component of this study and preceding studies that have utilized the Success Path Approach emphasize the need for a clear definition of the word “barrier.” As this definition continues to vary from operator to operator, it is recommended that BSEE and industry continue to work together to determine a common definition of a barrier.

Similarly, the workgroup subject matter experts discussed leaks and attempted to classify them as *major* and *minor* leaks. However, no definition emerged as to what constitutes a major or minor leak. The workgroup may consider further refining and quantifying this subject, which may help in the standardization of response recommendations as part of API RP 16WL.

Barrier assurance and the role that adding redundancy can play in a barrier’s reliability was brought up several times in the discussion. As noted in Section 6.2.2, the FMECA was able to show, in some instances, the elevated risks of systems with insufficient redundancy in power supply systems. It is recommended that the workgroup pay attention to findings related to sufficient diversity in redundancy as they continue to develop API RP 16WL.

Timing is another aspect of barrier assurance, as noted in Section 6.2.1, and it is recommended that the workgroup take into account barrier actuation timing requirements in their consideration of power systems as part of API RP 16WL recommendations.

There are additional areas of lack of consensus, which Success Paths and FMECA are not designed to capture. These include definitions and best practice requirements. It is recommended that the workgroup continue work on identifying minimum stack requirements to achieve safety. Additionally, it is recommended that the workgroup reach consensus and provide clear definitions for the terminology discussed in Section 6.3.2 of this report, with emphasis on defining the different types of wireline, such as slickline, braided line, e-line, and others, and make it clear that these are subsets of *wirelines*.

The workgroup may consider further expanding on the definitions as presented in Section 5.2 of this report to explicitly address the role of weighted fluids in pressure control (if any).

The industry has taken initiative in establishing the Independent Review Certificate or IRC mechanism to incorporate quality assurance in wireline operations. Apparently this not universal to all wireline components and systems. The workgroup might consider broadening applicability and incorporating IRC requirements or an equivalent program into the future API RP 16WL. Another possible route may be for the relevant stakeholders to consider incorporating applicable parts of the IRC or API Spec Q2, *Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural Gas Industries*.

From the workgroup discussions, ram lock function testing may not be a current requirement for some companies' wireline operation policies. If not already standard procedure, the workgroup may consider recommendations for function testing of the ram locks to become a requirement before placing back in service. Additionally, an ability to perform a visual check of the lock status may be desirable to ensure efficacy. If they do not already as of this writing, repair requirements may also need to include common sense measures such as correct parts, proper assembly, and competent technicians.

In possible future Success Path and FMECA analyses, it will be helpful if minimum stack configurations are already agreed upon or proposed configurations are hypothesized prior to analysis, such that the analysis can confirm or give basis to recommended modifications for certain safety features. Having this starting point can significantly speed progress toward completing FMECA analyses for all vital systems and components.

Because many aspects in wireline operations appear to have evolved independently, from company to company, training to accompany the publication or pre-publication to educate the many stakeholders may be warranted. This training should include a multitude of items, ranging from elementary aspects such as nomenclature and terminology to more nuanced, such as barrier definition and associated risks. As a precursor for this training, parts of the API RP 16WL would likely need to be finalized and go through yet-to-be-identified levels of approval to avoid potential confusion in training material.

As noted in Section 4.3.2, the occurrence rankings used in this study were quasi-quantitative and relied on expert judgment rather than on tracked data. To the Argonne team's knowledge, no statistical failure data exists that can be commonly leveraged by the stakeholders. It may be appropriate for the stakeholders, including BSEE and industry, to consider collaborating to establish a volunteer-based failure data collection mechanism, which can help uncover clear areas of vulnerability and potentially lead to their resolution. A precedent for this exists in the currently functioning SafeOCS system that tracks well control equipment, safety and pollution prevention equipment, and industry safety data (Bureau of Transportation Statistics, n.d.). SafeOCS reports are published annually and show anonymized statistical data.

While several observations were highlighted in the body of the report, a more comprehensive list of brief summaries of observations is provided in Appendix E. Once again, this list was designed to serve the purpose of documenting the observations gained throughout the study. One recommended way for BSEE to use this list is to reference the documented observations and note how these issues get addressed once API RP 16WL becomes published. This exercise may help BSEE in technical decision-making in potential future efforts of incorporating the RP by reference.

Additional recommendations included point to possible further research to gain sufficient understanding on these topics. They include:

- More detailed exploration of support systems, including more input from the manufacturers that are designing and building that equipment.

- Whether or not additional barriers (and how many) should be recommended for H_2S service.
- Further research may be needed to assist the workgroup's efforts in overcoming issues by potential single points of failures. The sheave was specifically noted in Section 6.2, but there may be other such components, too.
- If a non-shearable is present in the shear-blind during hydraulic power failure, there is an open question as to whether the non-shearable can be moved axially to enable shearing of the wireline or closure on the now-empty ram cavity. This depends on the control systems including whether the wireline spool hydraulic power is coming for a common source with the barrier and accumulator systems.
- The presence of (including the appropriate number of) inverted wireline rams will need to be further considered among the workgroup subject matter experts, to determine which configuration is ultimately able to provide safety to personnel.

9. References

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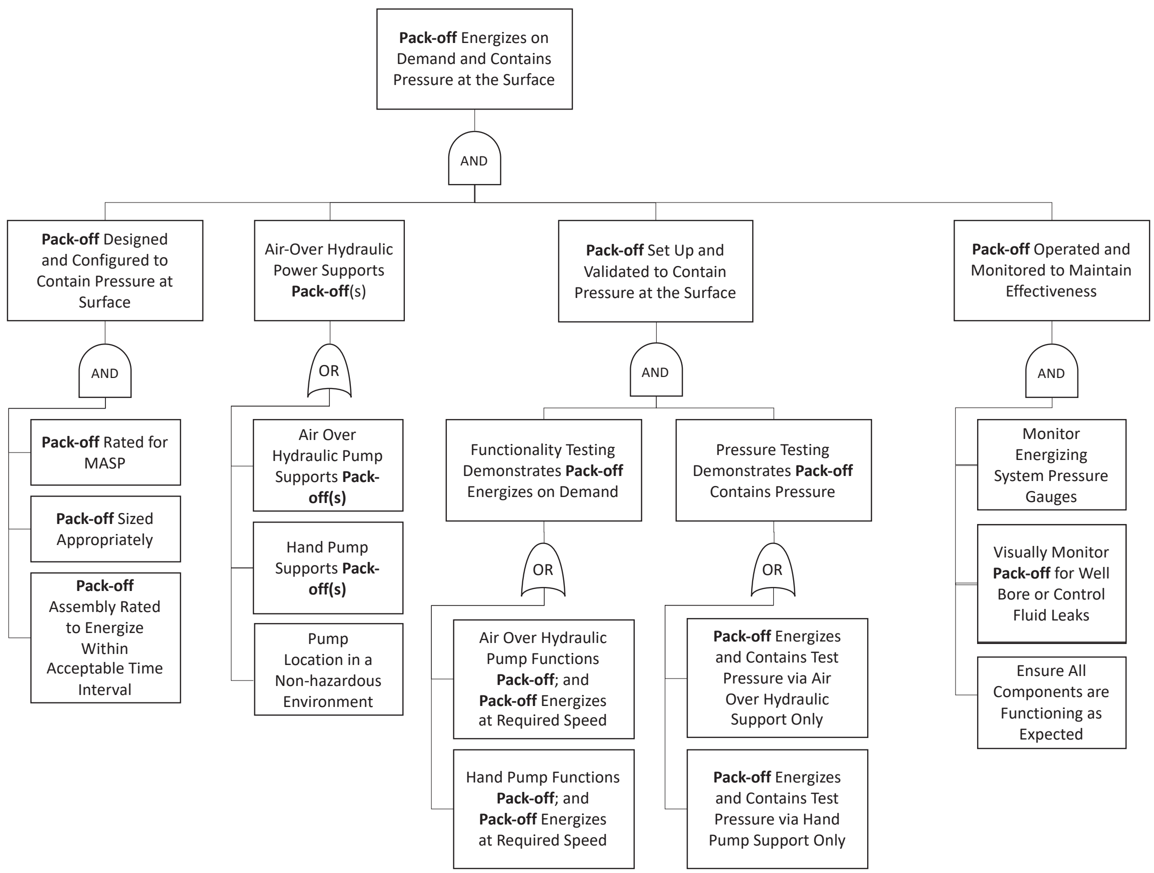
Appendix A. Wireline Operations Success Paths

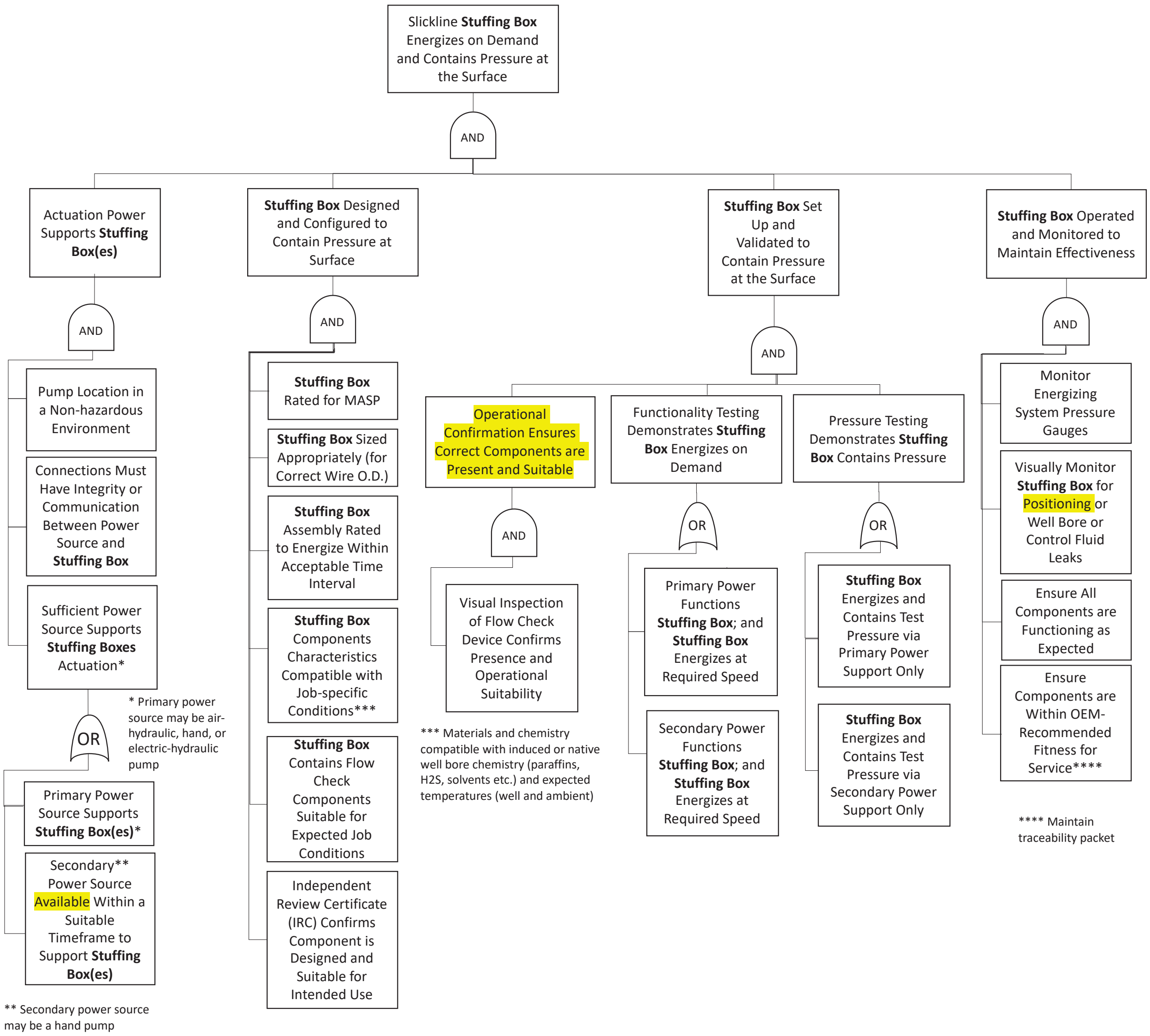
The completed set of Success Paths for wireline operations is presented below. Highlighted areas left intentionally for API RP 16WL workgroup subject matter experts to revisit.

Pressure Control Component: Pack-off, Hydraulically operated	
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram, Dual Pack-off)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Pack-off is constantly wearing during service. It should be anticipated to fail at any time.

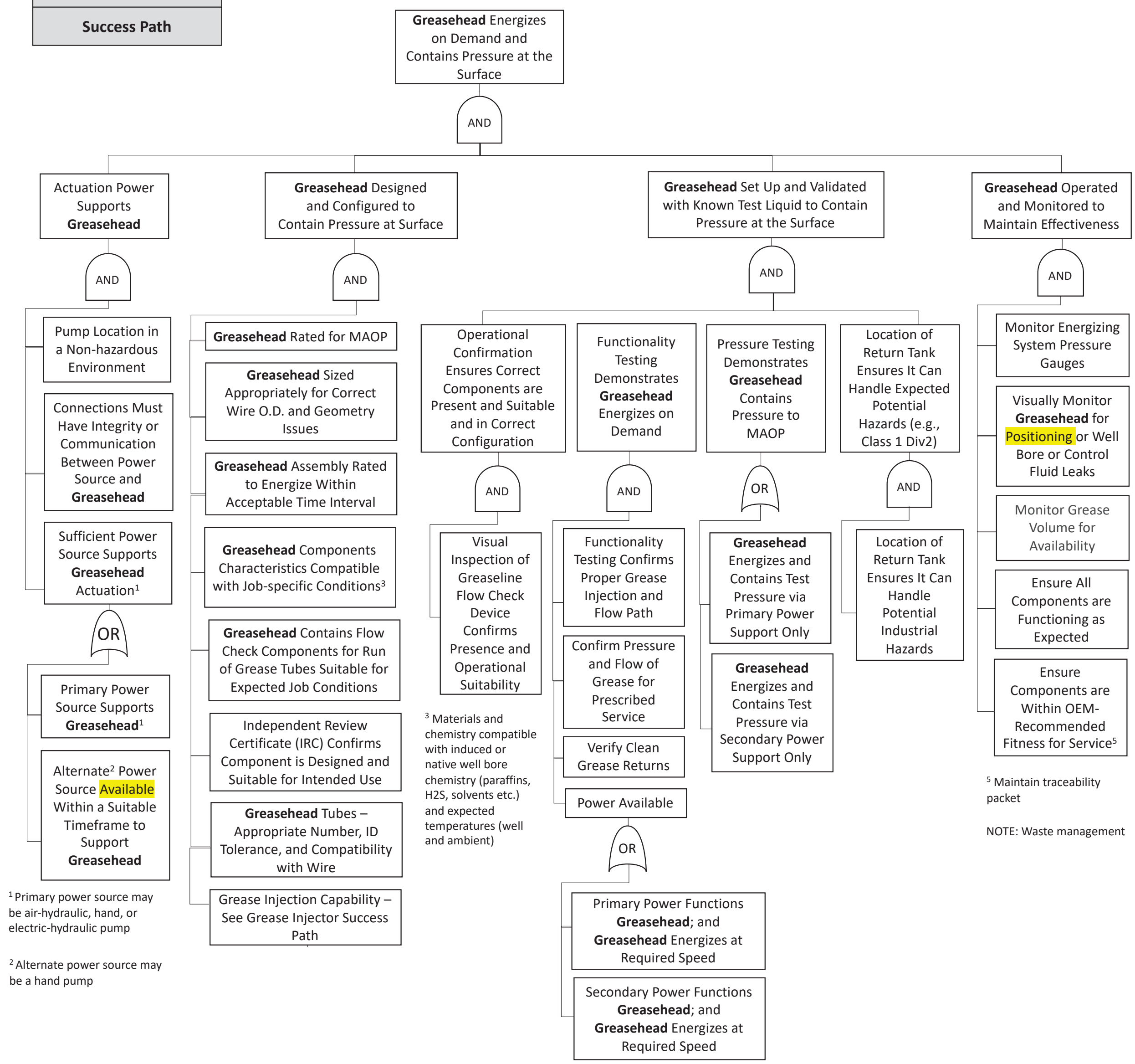
Pressure Control Component: Slickline Stuffing Box	
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console, Sheave configurations supports the operation,
Threat Scenarios	Stuffing Box is constantly wearing during service. It should be anticipated to fail at any time.

Pressure Control Component: Greasehead

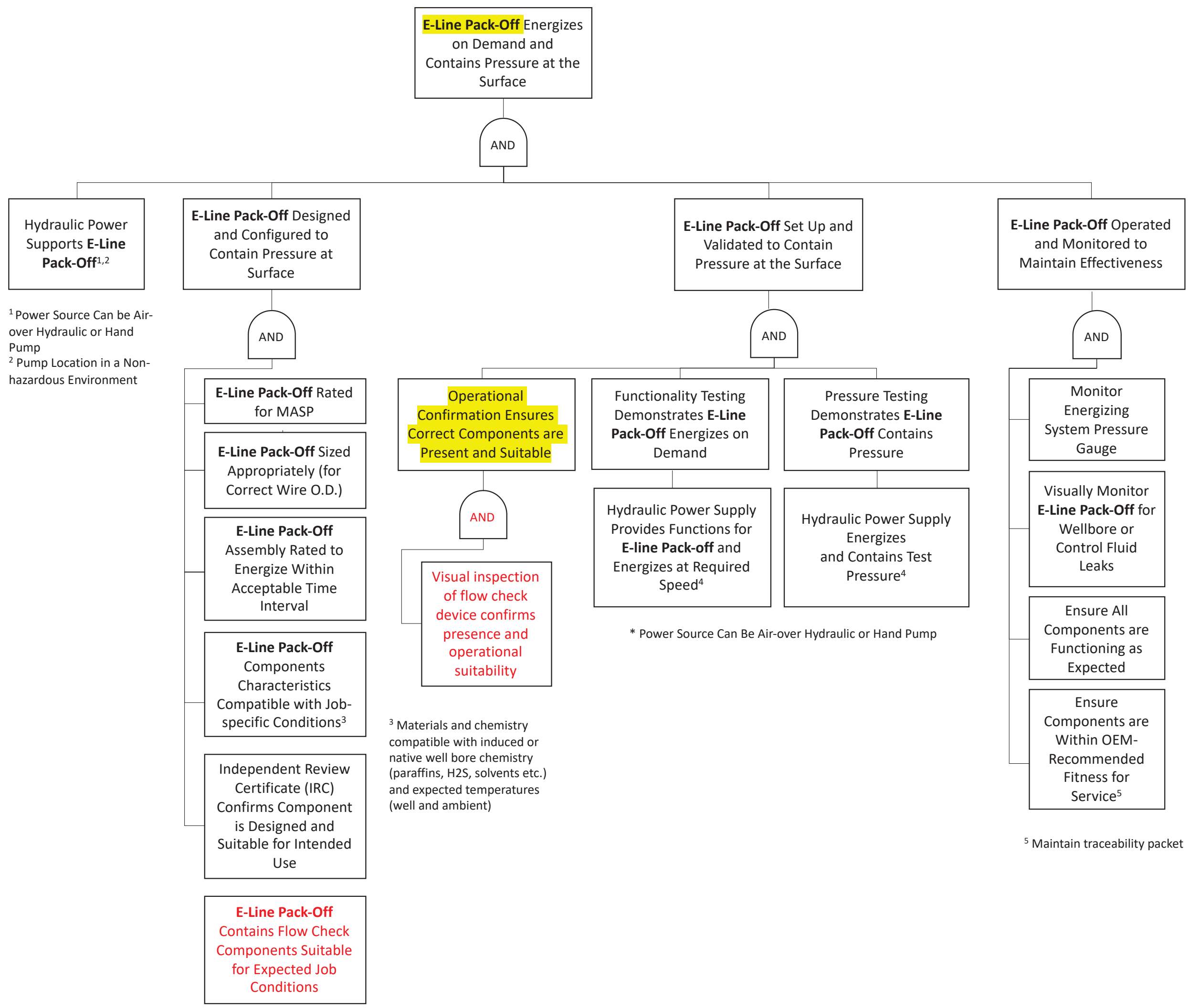
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console, Suspended Sheave configurations supports the operation,
Threat Scenarios	**Greasehead** is constantly wearing during service. It should be anticipated to be compromised at any time.

Pressure Control Component: Braided Line or E-Line Packoff

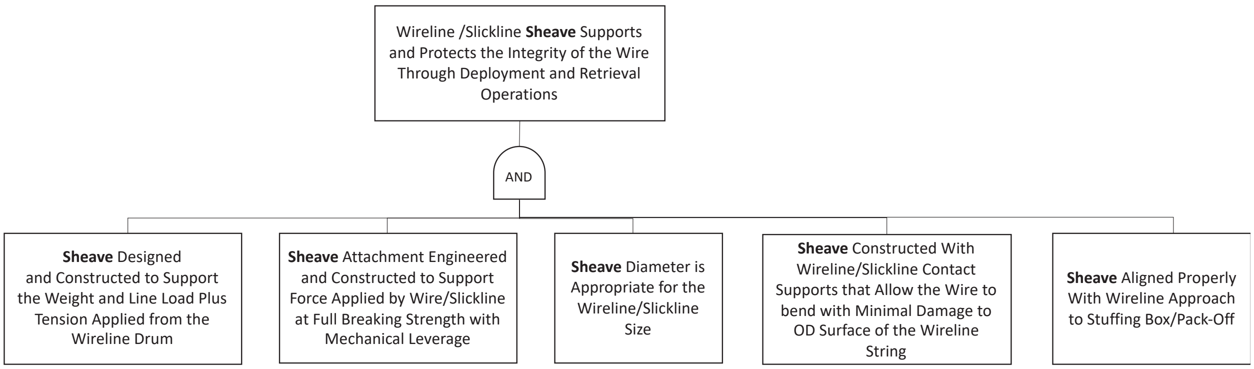
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Stuffing Box is constantly wearing during service. It should be anticipated to fail at any time.

Critical Support Element: Sheave

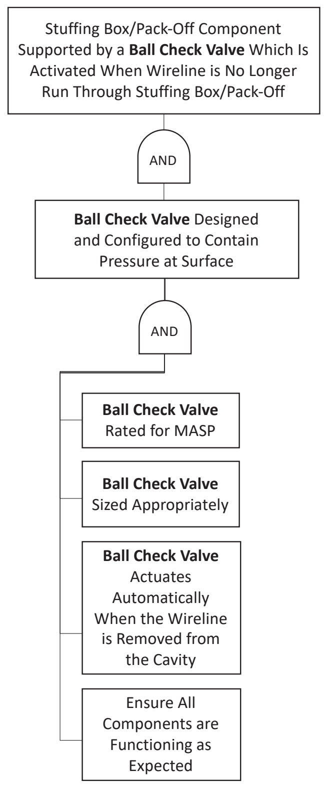
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Stuffing Box is constantly wearing during service. It should be anticipated to fail at any time.

Pressure Control Component: Ball Check Valve (Flow Check Device)

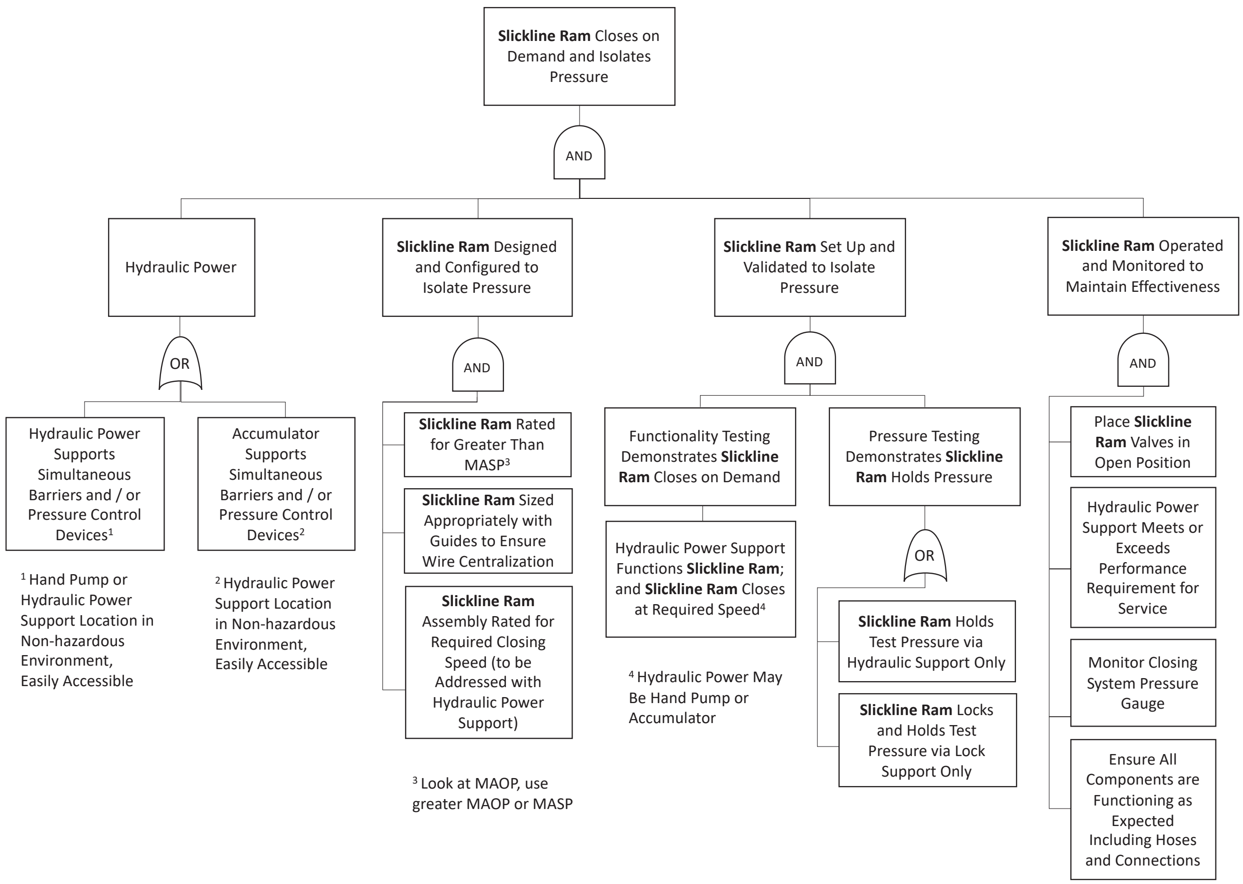
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Stuffing Box / Pack-Off Interface With Ball Check Mechanism
Threat Scenarios	Stuffing Box/Pack-Off is constantly wearing during service. It should be anticipated to fail at any time.

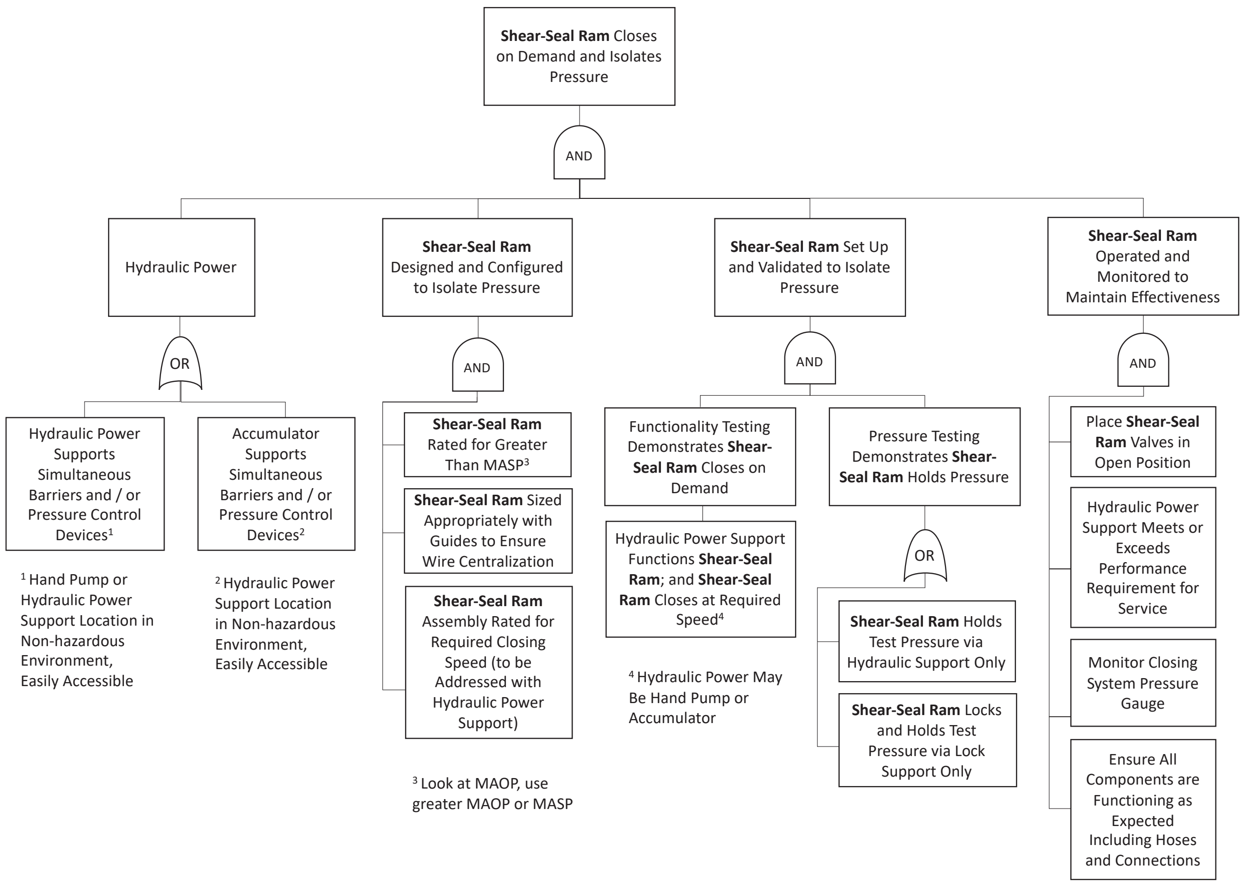
Physical Barrier Element: Slickline Ram (single strand & jacketed cable)

Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear-Blind Ram, Additional Wireline Ram(s), Inverted Wireline Ram
Critical Support Systems	Hydraulic Power, Wireline Grease Injection Pump
Threat Scenarios	Element wear or diametral wire wear or damage can be a factor.

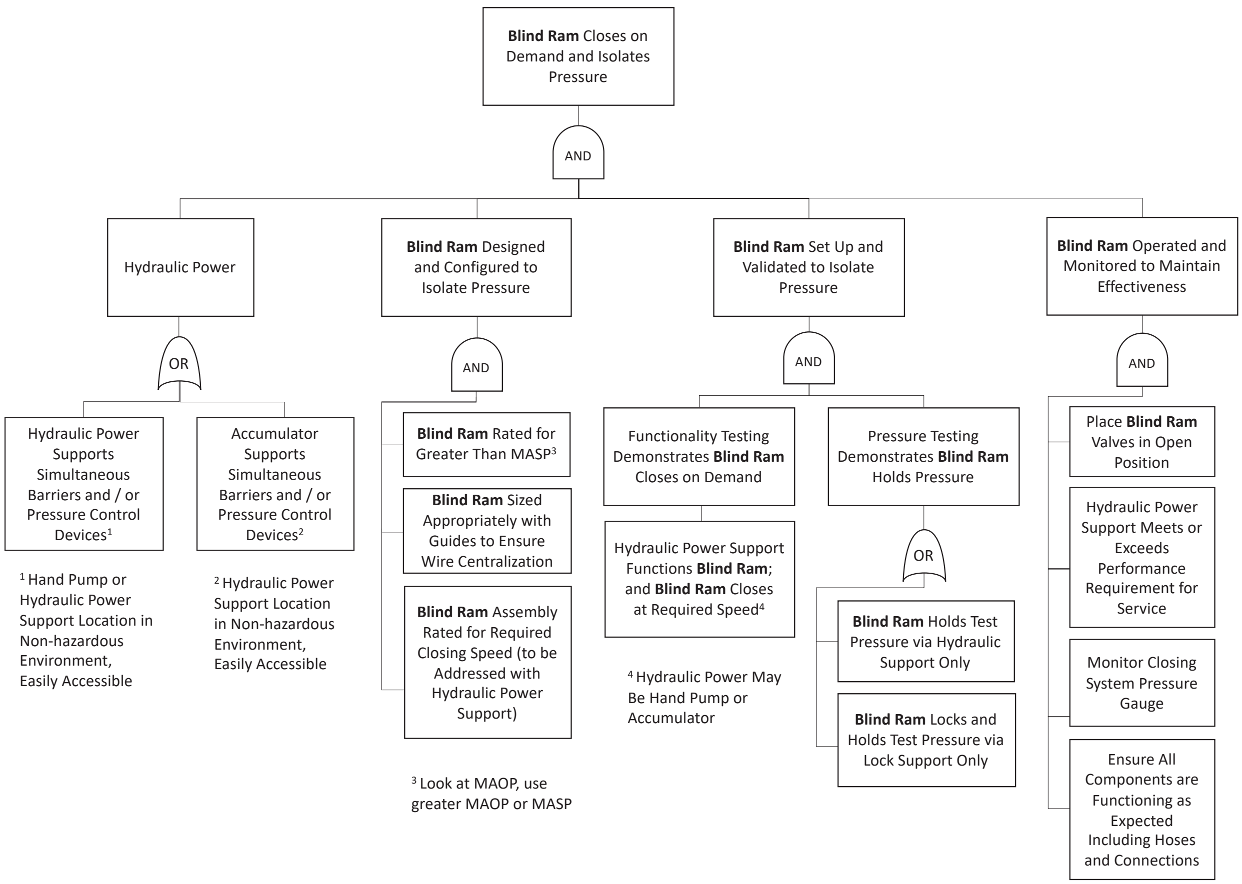
Physical Barrier Element: Shear-Seal Ram	
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear-Blind Ram, Additional Wireline Ram(s), Inverted Wireline Ram
Critical Support Systems	Hydraulic Power, Wireline Grease Injection Pump
Threat Scenarios	Element wear or diametral wire wear or damage can be a factor.

Physical Barrier Element: Blind Ram

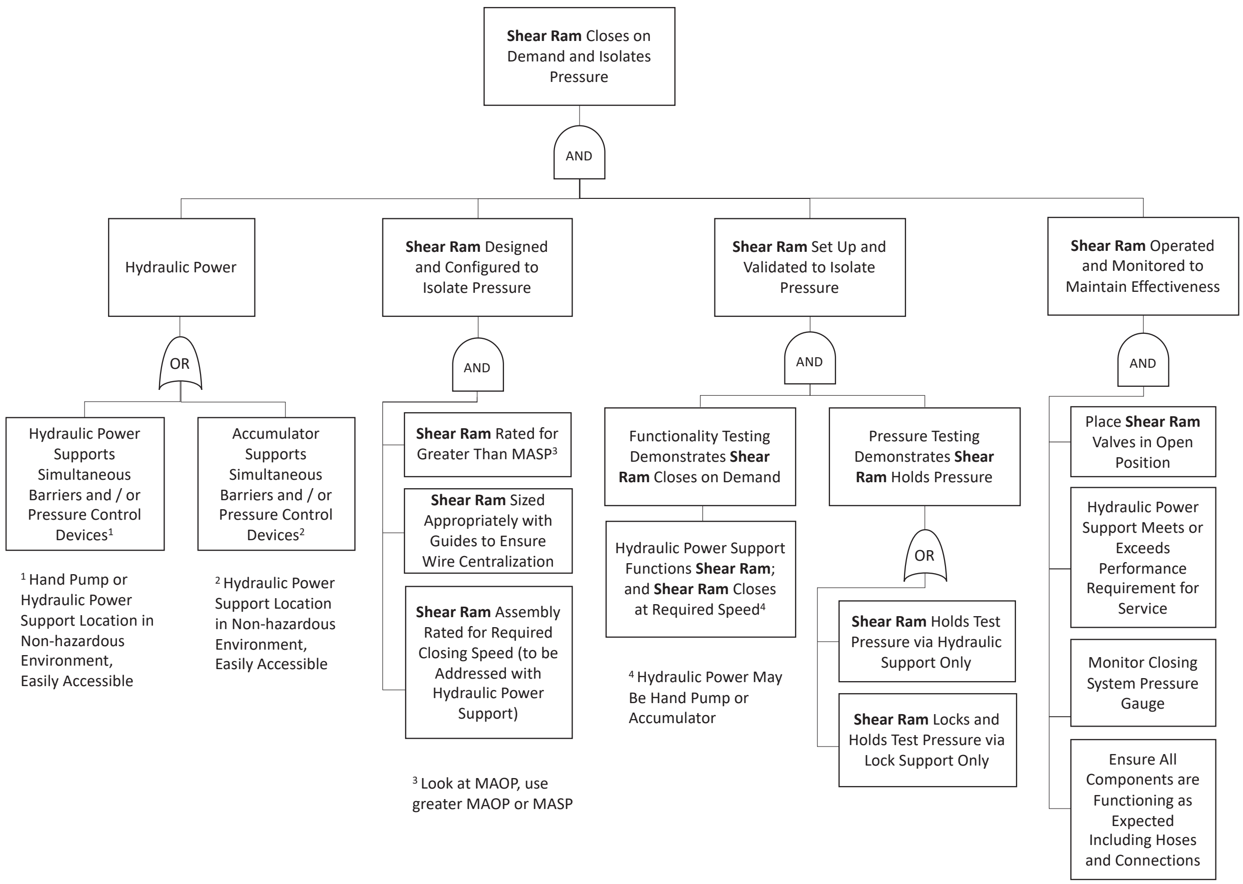
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear-Blind Ram, Additional Wireline Ram(s), Inverted Wireline Ram
Critical Support Systems	Hydraulic Power, Wireline Grease Injection Pump
Threat Scenarios	Element wear or diametral wire wear or damage can be a factor.

Physical Barrier Element: Shear Ram

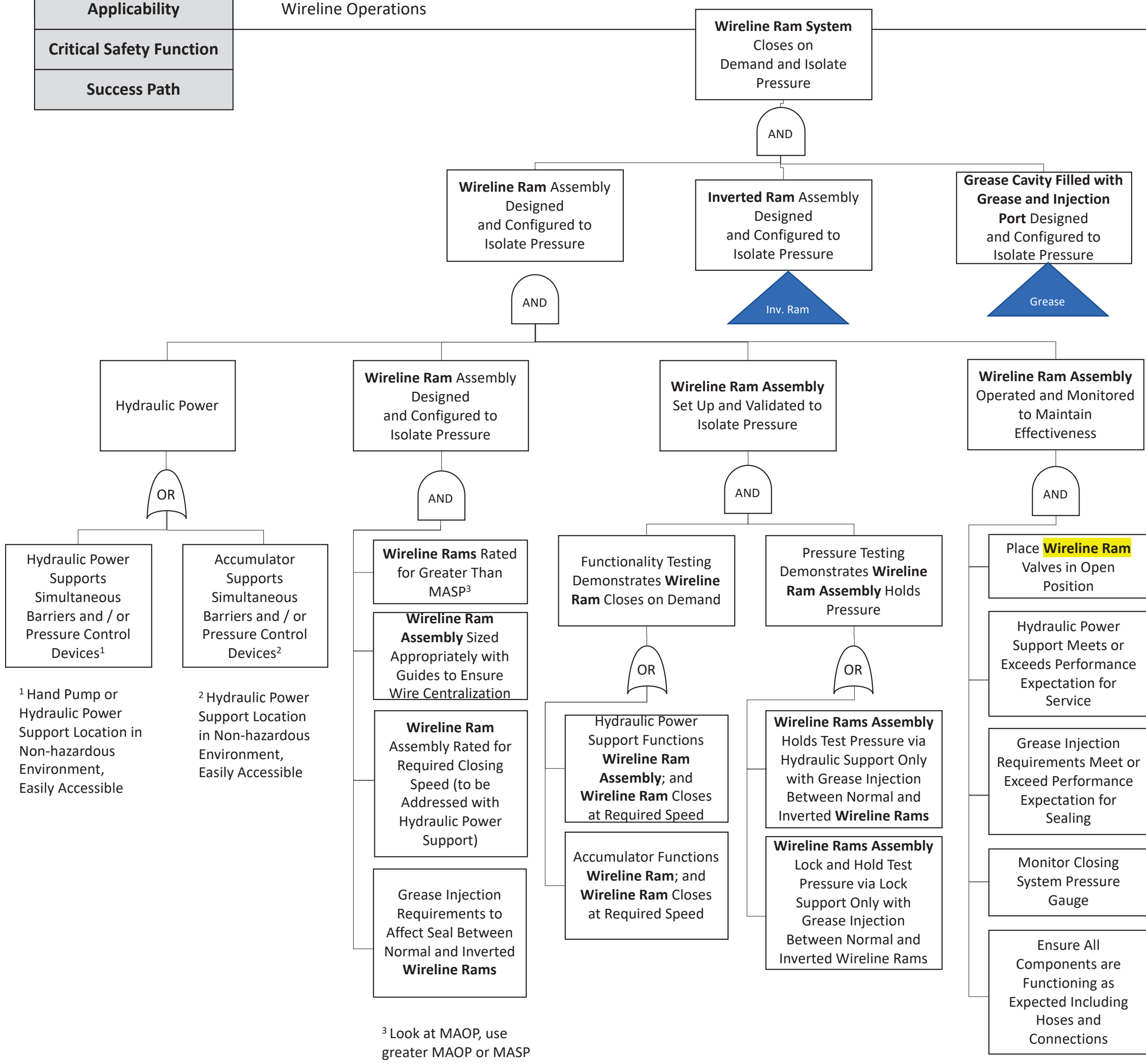
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear-Blind Ram, Additional Wireline Ram(s), Inverted Wireline Ram
Critical Support Systems	Hydraulic Power, Wireline Grease Injection Pump
Threat Scenarios	Element wear or diametral wire wear or damage can be a factor.

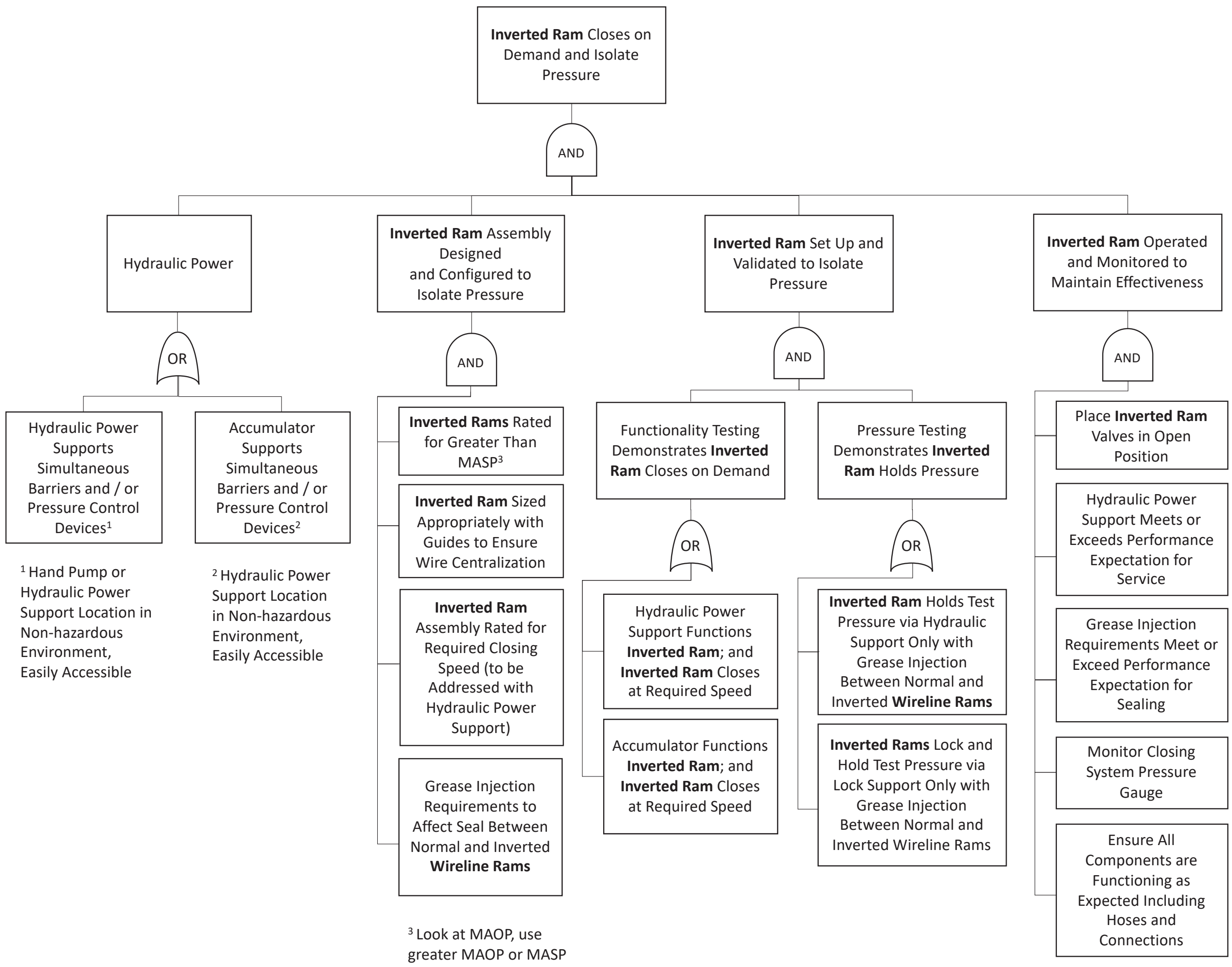
Physical Barrier Element: Wireline Ram Assembly (multi-strand & cable) NEW

Applicability	Wireline Operations
Critical Safety Function	
Success Path	



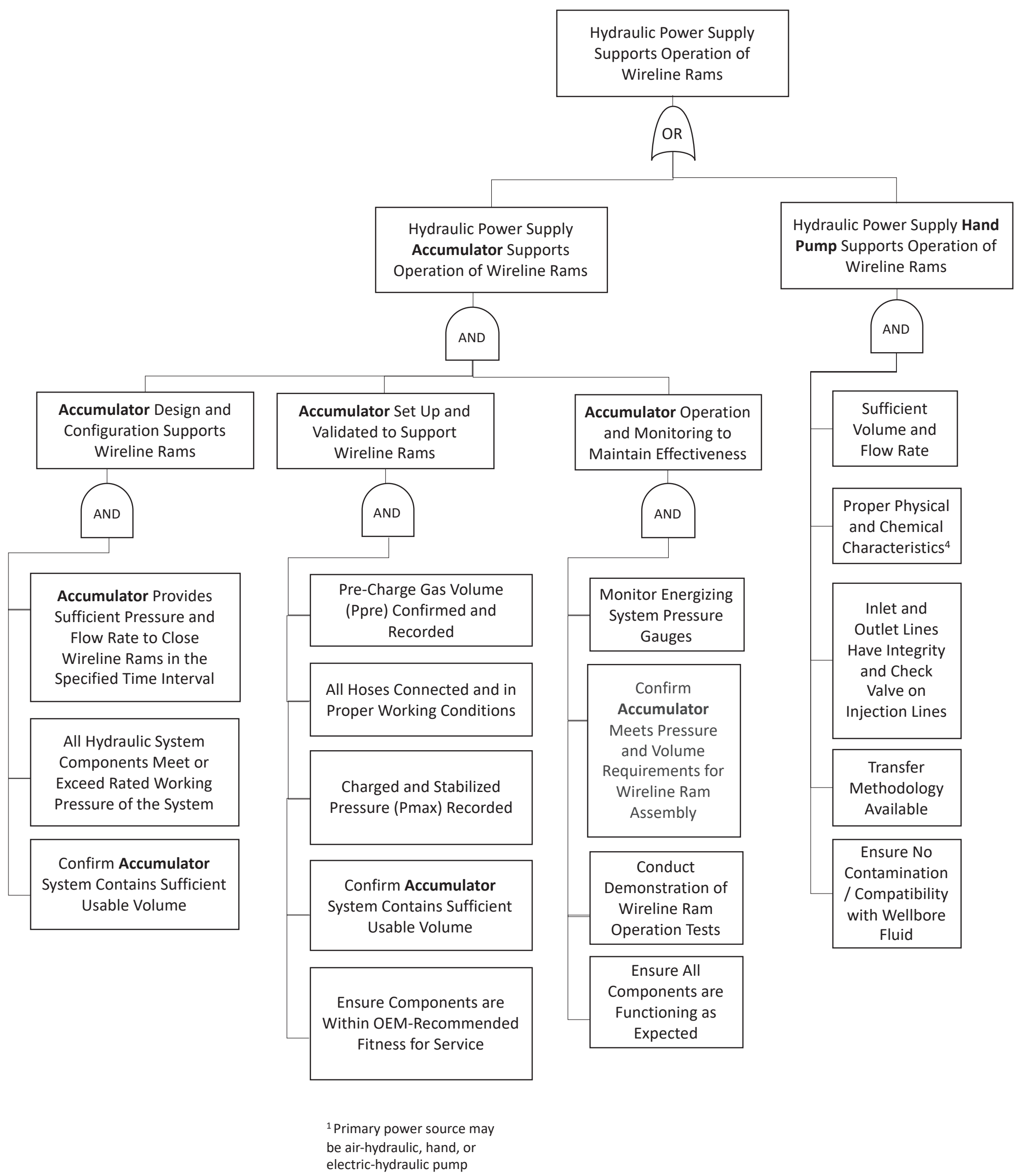
Alternate Success Path	Shear-Blind Ram, Additional Wireline Ram(s), Inverted Wireline Ram
Critical Support Systems	Hydraulic Power, Wireline Grease Injection Pump
Threat Scenarios	Element wear or diametral wire wear or damage can be a factor.

Physical Barrier Element: Inverted Ram As Part Of Wireline Ram Assembly (multi-strand & cable) NEW	
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear-Blind Ram, Additional Wireline Ram(s), Inverted Wireline Ram
Critical Support Systems	Normal Ram, Hydraulic Power, Wireline Grease Injection Pump
Threat Scenarios	Element wear or diametral wire wear or damage can be a factor.

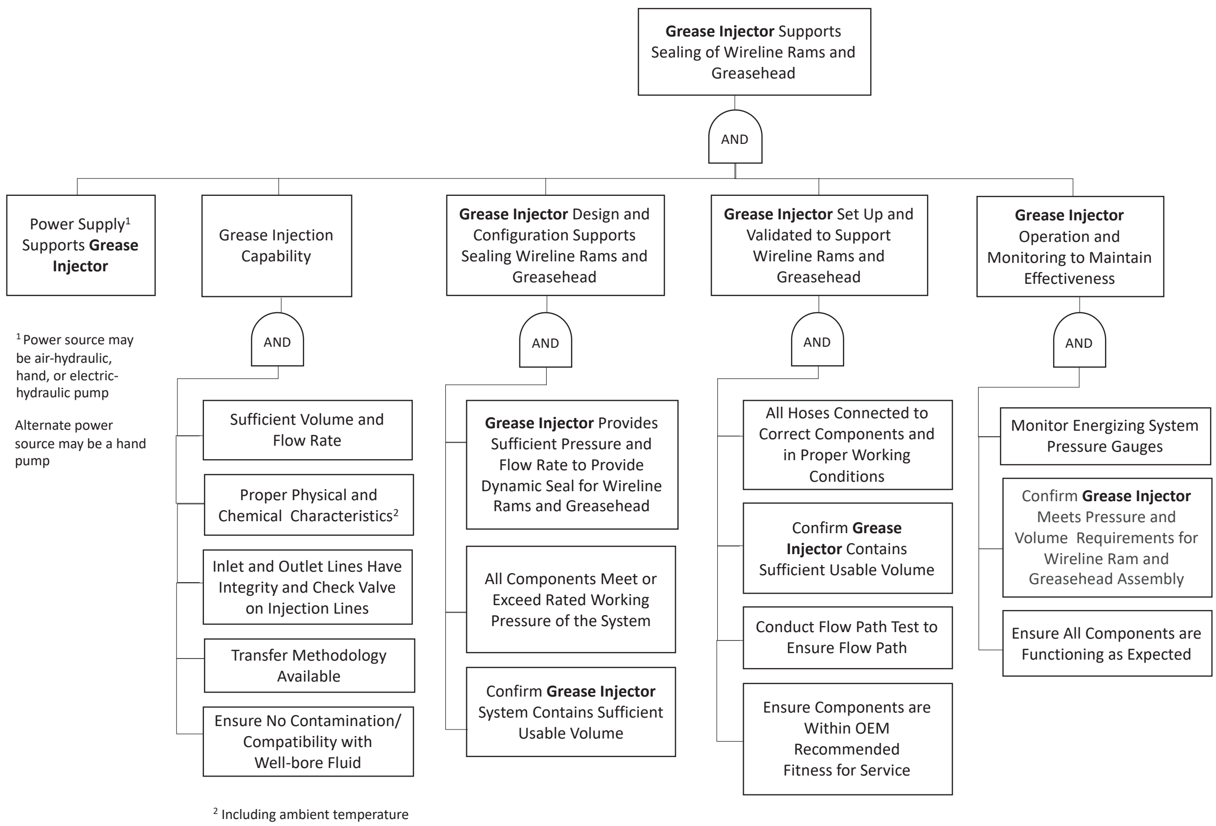
Pressure Control Component: Accumulator System	
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console, Suspended Sheave configurations supports the operation,
Threat Scenarios	**Greasehead** is constantly wearing during service. It should be anticipated to be compromised at any time.

Pressure Control Component: Grease Injector

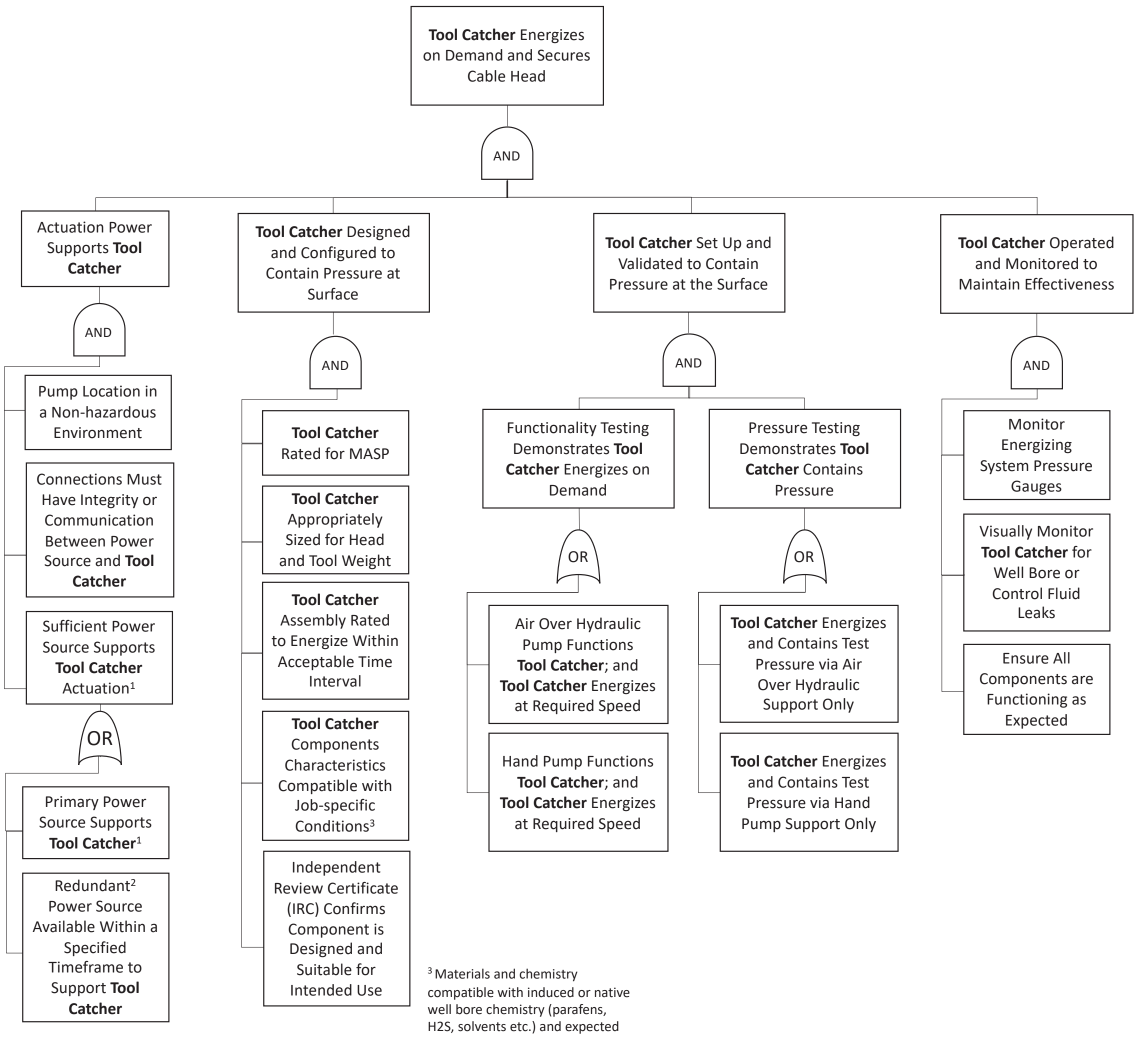
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console, Suspended Sheave configurations supports the operation,
Threat Scenarios	**Greasehead** is constantly wearing during service. It should be anticipated to be compromised at any time.

Barrier Support Component: Tool Catcher (if used)

Applicability	Wireline Operations
Critical Safety Function	
Success Path	



[3] Materials and chemistry compatible with induced or native well bore chemistry (parafens, H2S, solvents etc.) and expected temperatures (well and ambient)

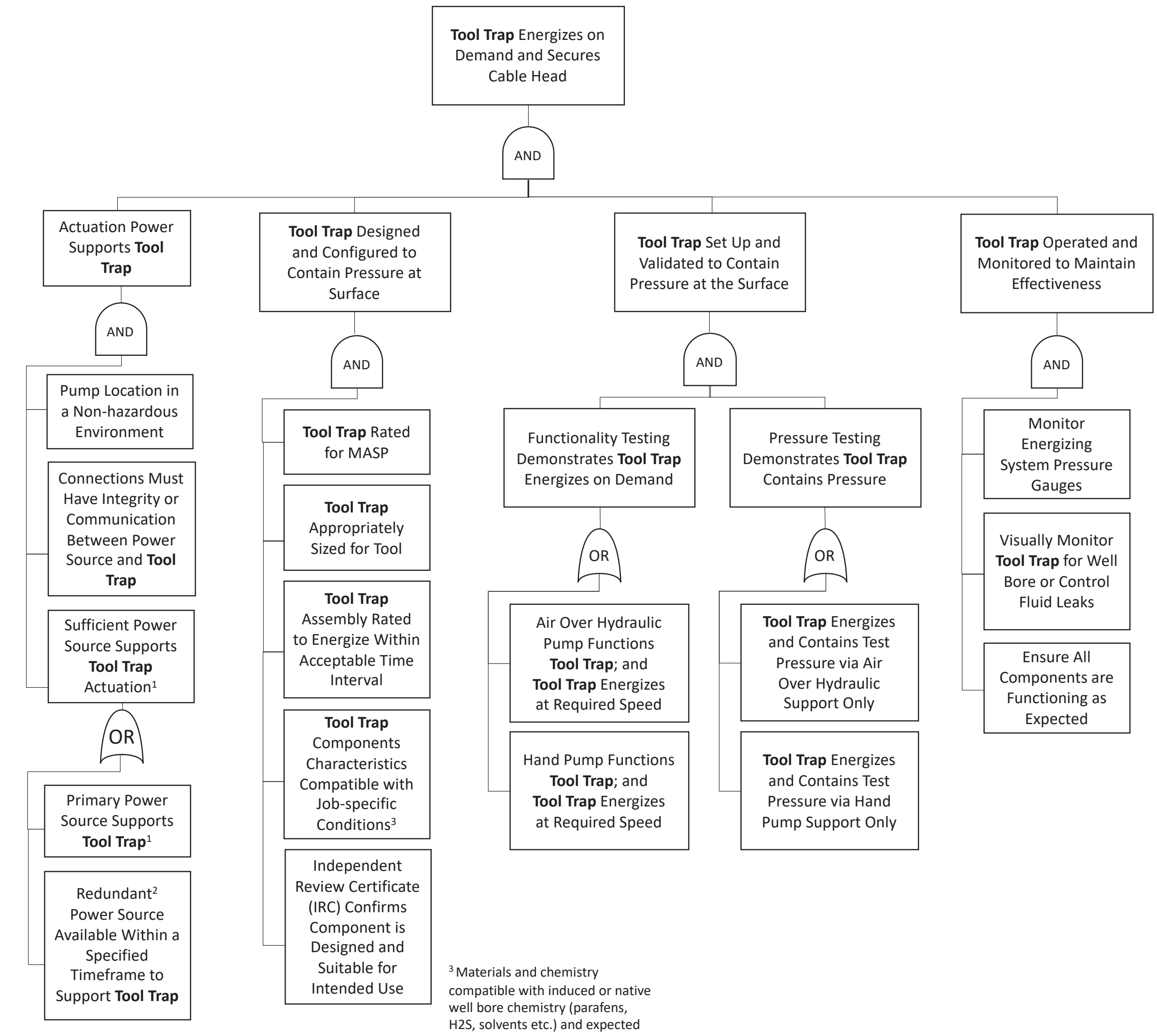
[1] Primary power source may be air-hydraulic, hand, or electric-hydraulic pump

[2] Redundant power source may be a hand pump

Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram, Second or Dual Pack-off)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Tool Catcher is constantly wearing during service. It should be anticipated to fail at any time.

Barrier Support Component: Tool Trap (if used)

Applicability	Wireline Operations
Critical Safety Function	
Success Path	



[3] Materials and chemistry compatible with induced or native well bore chemistry (parafens, H2S, solvents etc.) and expected temperatures (well and ambient)

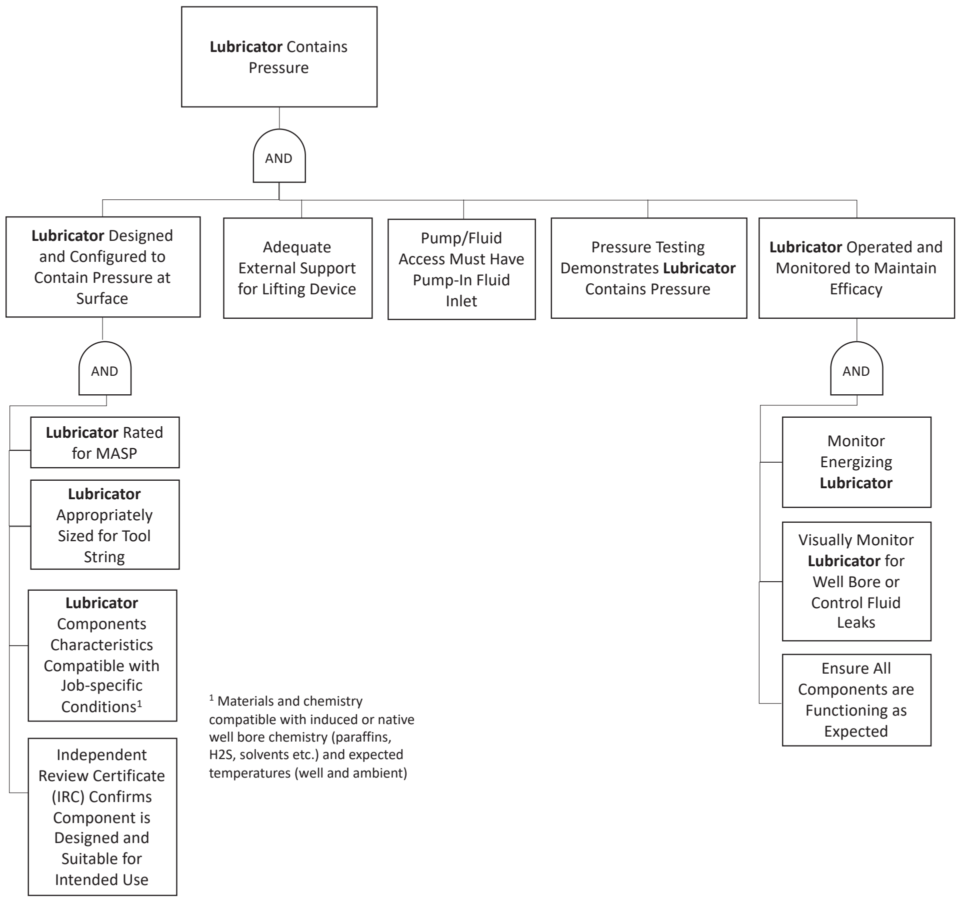
[1] Primary power source may be air-hydraulic, hand, or electric-hydraulic pump

[2] Redundant power source may be a hand pump

Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram, Second or Dual Pack-off)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Tool Trap is constantly wearing during service. It should be anticipated to fail at any time.

Pressure Control Component: Lubricator (includes Crossovers, Bleed Subs, Pump-In Subs)

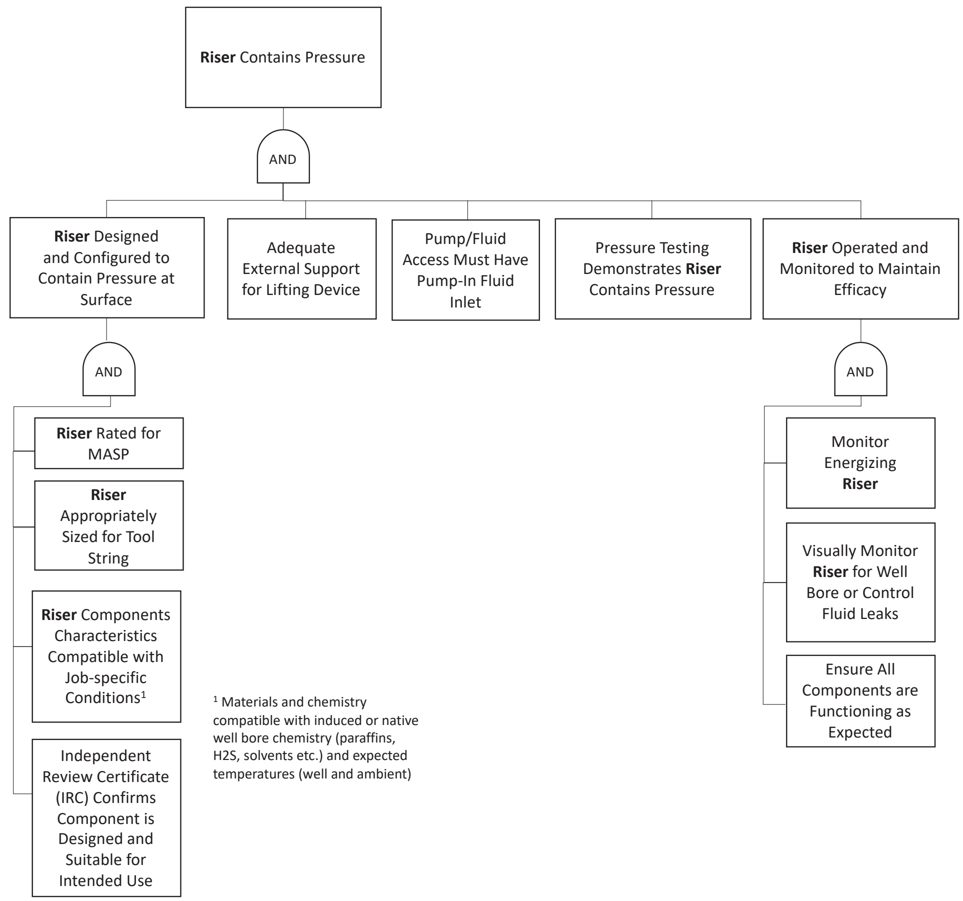
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



[1] Materials and chemistry compatible with induced or native well bore chemistry (paraffins, H_2S, solvents etc.) and expected temperatures (well and ambient)

Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram, Second or Dual Pack-off)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Lubricator is constantly wearing during service. It should be anticipated to fail at any time.

Pressure Control Component: Riser	
Applicability	Wireline Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Wireline Ram; Other Barriers (e.g., Shear and Blind Ram, Second or Dual Pack-off)
Critical Support Systems	Hydraulic Power for Controls and Wireline Console
Threat Scenarios	Lubricator is constantly wearing during service. It should be anticipated to fail at any time.

Appendix B. FMECA References and Example

FMECA Reference items are presented below.

Consequence Ranking	
Rank	**Description**
1	System degraded but operational, no direct impact on barrier
2	System disabled, but alternative system available, no direct impact on barrier
2.5	System disabled/degraded with barrier degraded but operational
3	System disabled/degraded with barrier degraded, normal operations suspended
4	Barrier disabled, but two (2) alternative barrier(s) remain
5	Barrier disabled, but one (1) alternative barrier remains
6	Barrier(s) disabled, no barriers remaining

System = component or device being assessed

Occurrence Ranking		
Rank	**Qualification**	**Frequency**
1	Very rare	1 in 100
2	Somewhat Rare	1 in 50
3	Somewhat Common	1 in 25
4	Common	1 in 10
5	Extremely Common	1 in 5

Consequence Ranking Multipliers			
PC	**Health and Employee Safety**	**Environment**	**Community / Sensitive Environment**
0	0.05	0.2	0.4
1	0.1	0.6	1.2
2	0.5	0.6	1.2
3	0.8	0.99	2
4	0.9	0.99	2
5	1	1	2

Pressure Category and Barrier Requirement Information			
PC	**MASP Range, psig***	**Minimum Stack RWP, psig**	**Min # of PCE Barriers**
PC-0	0	3000	1
PC-1	1 – 4,166	5000	2
PC-2	4,167 – 8,333	10000	2
PC-3	8,334 – 10,416	12500	2
PC-4	10,417 – 12,500	15000	2

* These values were agreed upon during this study. Reduced MASP ranges relative to equipment RWP allow a 20% margin (i.e., 5,000 ÷ 1.2 = 4,166) for pressure drop across flow tube grease and other like devices used for well pressure control. The values may change when API RP 16WL is drafted or published.

The rules dictating the risk rankings are shown below.

Formatting rules:	Lower Bound	Upper Bound	Example
>0 - <6	0.0000001	5.999999	1
>=6 - <12	6	11.99999	10
12+	12	1000000	12

Below are the reference risk ranking tables.

Risk Ranking: Barriers						
		Occurrence Ranking				
		1	2	3	4	5
Consequence Ranking	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Low	Medium	High

Risk Ranking: Health and Employee Safety

		Occurrence Ranking				
		1	2	3	4	5
Consequence Ranking	0.05	0.05	0.1	0.15	0.2	0.25
	0.1	0.1	0.2	0.3	0.4	0.5
	0.125	0.125	0.25	0.375	0.5	0.625
	0.15	0.15	0.3	0.45	0.6	0.75
	0.2	0.2	0.4	0.6	0.8	1
	0.25	0.25	0.5	0.75	1	1.25
	0.3	0.3	0.6	0.9	1.2	1.5
	0.4	0.4	0.8	1.2	1.6	2
	0.5	0.5	1	1.5	2	2.5
	0.6	0.6	1.2	1.8	2.4	3
	0.8	0.8	1.6	2.4	3.2	4
	0.9	0.9	1.8	2.7	3.6	4.5
	1	1	2	3	4	5
	1.25	1.25	2.5	3.75	5	6.25
	1.5	1.5	3	4.5	6	7.5
	1.6	1.6	3.2	4.8	6.4	8
	1.8	1.8	3.6	5.4	7.2	9
	2	2	4	6	8	10
	2.25	2.25	4.5	6.75	9	11.25
	2.4	2.4	4.8	7.2	9.6	12
	2.5	2.5	5	7.5	10	12.5
	2.7	2.7	5.4	8.1	10.8	13.5
	3	3	6	9	12	15
	3.2	3.2	6.4	9.6	12.8	16
	3.6	3.6	7.2	10.8	14.4	18
	4	4	8	12	16	20
	4.5	4.5	9	13.5	18	22.5
	4.8	4.8	9.6	14.4	19.2	24
	5	5	10	15	20	25
	5.4	5.4	10.8	16.2	21.6	27
	6	6	12	18	24	30

Risk Ranking: Environment

Consequence Ranking	Occurrence Ranking				
	1	2	3	4	5
0.2	0.2	0.4	0.6	0.8	1
0.4	0.4	0.8	1.2	1.6	2
0.5	0.5	1	1.5	2	2.5
0.6	0.6	1.2	1.8	2.4	3
0.6	0.6	1.2	1.8	2.4	3
0.8	0.8	1.6	2.4	3.2	4
0.99	0.99	1.98	2.97	3.96	4.95
1	1	2	3	4	5
1.2	1.2	2.4	3.6	4.8	6
1.2	1.2	2.4	3.6	4.8	6
1.5	1.5	3	4.5	6	7.5
1.8	1.8	3.6	5.4	7.2	9
1.98	1.98	3.96	5.94	7.92	9.9
2	2	4	6	8	10
2.4	2.4	4.8	7.2	9.6	12
2.475	2.475	4.95	7.425	9.9	12.375
2.5	2.5	5	7.5	10	12.5
2.97	2.97	5.94	8.91	11.88	14.85
3	3	6	9	12	15
3.6	3.6	7.2	10.8	14.4	18
3.96	3.96	7.92	11.88	15.84	19.8
4	4	8	12	16	20
4.95	4.95	9.9	14.85	19.8	24.75
5	5	10	15	20	25
5.94	5.94	11.88	17.82	23.76	29.7
6	6	12	18	24	30

Risk Ranking: Community

		Occurrence Ranking				
		1	2	3	4	5
Consequence Ranking	0.4	0.4	0.8	1.2	1.6	2
	0.8	0.8	1.6	2.4	3.2	4
	1	1	2	3	4	5
	1.2	1.2	2.4	3.6	4.8	6
	1.2	1.2	2.4	3.6	4.8	6
	1.6	1.6	3.2	4.8	6.4	8
	2	2	4	6	8	10
	2.4	2.4	4.8	7.2	9.6	12
	2.4	2.4	4.8	7.2	9.6	12
	3	3	6	9	12	15
	3.6	3.6	7.2	10.8	14.4	18
	4	4	8	12	16	20
	4.8	4.8	9.6	14.4	19.2	24
	5	5	10	15	20	25
	6	6	12	18	24	30
	7.2	7.2	14.4	21.6	28.8	36
	8	8	16	24	32	40
	10	10	20	30	40	50
	12	12	24	36	48	60

An example FMECA sheet for the analysis of Blind Ram components is below.

Barrier/Pressure Control element	Component	Component Function	Failure Mode	Local Consequence of Failure	Consequence of Failure on Barrier(s)	Cause(s)/ Mechanism(s) of Failure	Pressure Category No.	Consequence Ranking (Barrier)	Consequence Ranking (Health & Empl Safety)	Consequence Ranking (Environment)	Consequence Ranking (Community)	Occurrence Ranking	Risk Ranking (Barrier)	Risk Ranking (Health & Employee Safety)	Risk Ranking (Environment)	Risk Ranking (Community)	Consequence Notes	Occurrence Notes	Detection Mechanisms	Prevention Controls	Other Notes
Blind Ram	Outer (rear) seal	Works together with inner seal and ram body to form complete barrier	Leak path across outer seal	cannot provide seal between ram body and ram bore	blind ram ineffective	wear and tear/ damage of seal. Incompatibility. Seal bore area damage/ corrosion. Rapid Gas Decompression (RGD)	PC: 0	5	0.25	1	2	na	NA	NA	NA	NA	Blind ram not present	Outer seal continuously exposed to wellbore fluids and conditions; subjecto wear when operated. Failures occur without preventative maintenance and inpsection schedule	Pressure passes closed blind ram	Pre-job pressure test. Scheduled preventative maintenance and inspection	General note: In PC0, which currently requires one barrier, it is rare that the barrier is a blind ram. Therefore, PC0 C./O. numbers are present purely for the analysis sake.
							PC: 1	4	0.4	2.4	4.8	1	4	0.4	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	1	4	2	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	1	4	3.2	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 4	4	3.6	3.96	8	1	4	3.6	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	1	4	4	4	8	Blind ram disabled, but wireline rams are present'				
Blind Ram	Inner (front) seal/blind element	Works together with outer seal and ram body to form complete barrier	leak path across inner seal	cannot isolate wellbore pressure	blind ram ineffective	wear and tear/damage of seal. Incompatibility. Seal bore area damage/corrosion. Rapid Gas Decompression (RGD). Inadequate or loss of hydraulic operating pressure. Wireline or debris across blind ram. Hydrate.	PC: 0	5	0.25	1	2	na	NA	NA	NA	NA	Blind ram not present	Inner seal continuously exposed to wellbore fluids and conditions; subject to extrusion when operated. Failures occur without preventative maintenance and inpsection schedule	Pressure passes closed blind ram	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	4	0.4	2.4	4.8	1	4	0.4	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	1	4	2	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	1	4	3.2	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 4	4	3.6	3.96	8	1	4	3.6	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	1	4	4	4	8	Blind ram disabled, but wireline rams are present'				
Blind Ram	Ram Body	Works together with inner and outer seal to form complete barrier	Leak path across ram body	outer seal do not seal against ram body	blind ram ineffective	Corrosion, wear and tear, mechanical damage	PC: 0	5	0.25	1	2	na	NA	NA	NA	NA	Blind ram not present	Ram body exposed to well bore fluids and force could deform or damage body over time	Pressure passes closed blind ram	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	4	0.4	2.4	4.8	1	4	0.4	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	1	4	2	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	1	4	3.2	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 4	4	3.6	3.96	8	1	4	3.6	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	1	4	4	4	8	Blind ram disabled, but wireline rams are present'				
Blind Ram	Inner seal retaining mechanism	Keeps inner seal in position in ram body	does not retain inner seal	inner seal lodges in ram bore or falls into well	cannot isolate well bore pressure, wireline tools unable to travel passed ram in either direction.	Mechanical damage	PC: 0	5	0.25	1	2	na	NA	NA	NA	NA	Blind ram not present	excluding human error, extremley unlikely to fail	Pressure passes closed blind ram	pre-job funtion test. Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	4	0.4	2.4	4.8	1	4	0.4	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	1	4	2	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	1	4	3.2	3.96	8	Blind ram disabled, but wireline rams are present'				

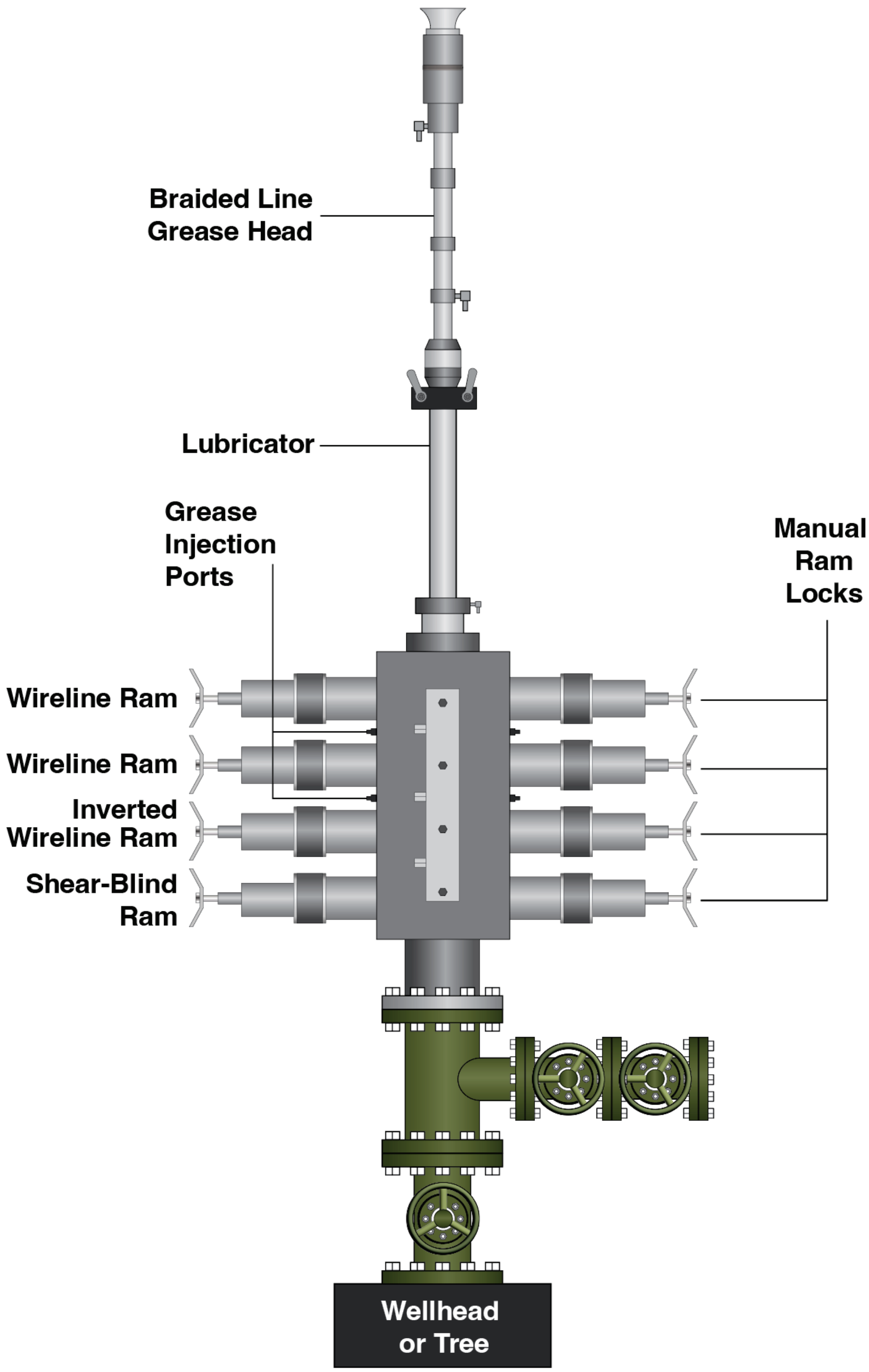
Barrier/Pressure Control element	Component	Component Function	Failure Mode	Local Consequence of Failure	Consequence of Failure on Barrier(s)	Cause(s)/ Mechanism(s) of Failure	Pressure Category No.	Consequence Ranking (Barrier)	Consequence Ranking (Health & Empl Safety)	Consequence Ranking (Environment)	Consequence Ranking (Community)	Occurrence Ranking	Risk Ranking (Barrier)	Risk Ranking (Health & Employee Safety)	Risk Ranking (Environment)	Risk Ranking (Community)	Consequence Notes	Occurrence Notes	Detection Mechanisms	Prevention Controls	Other Notes
							PC: 4	4	3.6	3.96	8	1	4	3.6	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	1	4	4	4	8	Blind ram disabled, but wireline rams are present'				
Blind Ram	piston rod seal (well bore side)	allows piston to move ram body in and out of bore ID while isolating ram cylinder from well bore pressure	leakage	wellbore leakage to atmosphere through weep hole	blind ram ineffective and unable to shear wireline	wear and tear/damage of seal. Incopmpatibility. Seal bore area damage/corrosion. Rapid Gas Decompression (RGD)	PC: 0	5	0.25	1	2	na	NA	NA	NA	NA	Blind ram not present	wear and tear from functioning piston mulitple times, but would take an excessive amount of functioning.	visible leakage through weep hole	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	5	0.5	3	6	1	5	0.5	3	6	Blind ram disabled, but wireline rams are present'				
							PC: 2	5	2.5	3	6	1	5	2.5	3	6	Blind ram disabled, but wireline rams are present'				
							PC: 3	5	4	4.95	10	1	5	4	4.95	10	Blind ram disabled, but wireline rams are present'				
							PC: 4	5	4.5	4.95	10	1	5	4.5	4.95	10	Blind ram disabled, but wireline rams are present'				
							PC: 5	5	5	5	10	1	5	5	5	10	Blind ram disabled, but wireline rams are present'				
Blind Ram	Bonnet o-ring	seals ram cylinder bonnet and contains well bore pressure	leakage	wellbore leakage to atompsphere	blind ram ineffective	damage during assemlby, corrosion or damage of seal face, degradation	PC: 0	5	0.25	1	2	na	NA	NA	NA	NA	Blind ram not present	should typically be identifiied during pressure test	visible leakage to atmosphere	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	5	0.5	3	6	1	5	0.5	3	6	Blind ram disabled, but wireline rams are present'				
							PC: 2	5	2.5	3	6	1	5	2.5	3	6	Blind ram disabled, but wireline rams are present'				
							PC: 3	5	4	4.95	10	1	5	4	4.95	10	Blind ram disabled, but wireline rams are present'				
							PC: 4	5	4.5	4.95	10	1	5	4.5	4.95	10	Blind ram disabled, but wireline rams are present'				
							PC: 5	5	5	5	10	1	5	5	5	10	Blind ram disabled, but wireline rams are present'				
Blind Ram	equalizing valve	allows user to equalize pressure above and below blind ram after closing and prior to opening	leakage	wellbore communication above and below ram	blind ram ineffective	damage during assemlby, corrosion or damage of seal face, degradation	PC: 0	5	0.25	1	2	2	10	0.5	2	4	Blind ram not present	will typically wear out over time through excessive use	Pressure passes closed blind ram	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	4	0.4	2.4	4.8	2	8	0.8	4.8	9.6	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	2	8	4	4.8	9.6	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	2	8	6.4	7.92	16	Blind ram disabled, but wireline rams are present'				
							PC: 4	4	3.6	3.96	8	2	8	7.2	7.92	16	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	2	8	8	8	16	Blind ram disabled, but wireline rams are present'				
Blind Ram	cylinder body	contains mechanism to open and close ram component	internal hydraulic leak	ram will not actuate	blind ram ineffective and unable to shear wireline	wear/tear damage of piston and piston rod, and wear/tear damage of piston and piston rod seals	PC: 0	5	0.25	1	2	1	5	0.25	1	2	Blind ram not present	internal failure of seal(s) render cylinder inoperable (hysrulic pressure balacaned across piston)	indicator rod does not travel. Visible leak of hydraulic fluid through weep hole	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	4	0.4	2.4	4.8	1	4	0.4	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	1	4	2	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	1	4	3.2	3.96	8	Blind ram disabled, but wireline rams are present'				

Barrier/Pressure Control element	Component	Component Function	Failure Mode	Local Consequence of Failure	Consequence of Failure on Barrier(s)	Cause(s)/ Mechanism(s) of Failure	Pressure Category No.	Consequence Ranking (Barrier)	Consequence Ranking (Health & Empl Safety)	Consequence Ranking (Environment)	Consequence Ranking (Community)	Occurrence Ranking	Risk Ranking (Barrier)	Risk Ranking (Health & Employee Safety)	Risk Ranking (Environment)	Risk Ranking (Community)	Consequence Notes	Occurrence Notes	Detection Mechanisms	Prevention Controls	Other Notes
							PC: 4	4	3.6	3.96	8	1	4	3.6	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	1	4	4	4	8	Blind ram disabled, but wireline rams are present'				
Blind Ram	cylinder body	contains mechanism to open and close ram component	failure of cylinder body elastom er leading to external hydrauli c leak.	ram will not actuate	blind ram ineffective and unable to hold well pressure	wear and tear/damage of cylinder body seals	PC: 0	5	0.25	1	2	1	5	0.25	1	2	Blind ram not present	cylinder dependent on hydraulic power to close ram	visible leakage of hydraulic fluid to atmosphere	Pre-job pressure test. Scheduled preventative maintenance and inspection	If there is a remote panel, there are other hoses/ supply lines presenting their own risks. Eliminate hoses. Ext failure from elastomer failure, separate from fitting/port damage on cylinder body.
							PC: 1	4	0.4	2.4	4.8	1	4	0.4	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 2	4	2	2.4	4.8	1	4	2	2.4	4.8	Blind ram disabled, but wireline rams are present'				
							PC: 3	4	3.2	3.96	8	1	4	3.2	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 4	4	3.6	3.96	8	1	4	3.6	3.96	8	Blind ram disabled, but wireline rams are present'				
							PC: 5	4	4	4	8	1	4	4	4	8	Blind ram disabled, but wireline rams are present'				
Blind Ram	ram lock	engages to ensure closure of ram for an undefined time period	failure to screw closed to lock ram closed	cannot maintain ram closure	shear/blind ram needs will need constant monitoring and hydraulic power to maintain seal	seized mechanical damage, sleeve nut thread damage	PC: 0	3.5	0.175	0.7	1.4	1	3.5	0.175	0.7	1.4	Blind ram not present	shear/blind will be unaffected as long as hydraulic power is available	resistance to operate	Pre-job pressure test. Scheduled preventative maintenance and inspection	
							PC: 1	3.5	0.35	2.1	4.2	1	3.5	0.35	2.1	4.2	Blind still functions but must be constantly monitored				
							PC: 2	3.5	1.75	2.1	4.2	1	3.5	1.75	2.1	4.2	Blind still functions but must be constantly monitored				
							PC: 3	3.5	2.8	3.465	7	1	3.5	2.8	3.465	7	Blind still functions but must be constantly monitored				
							PC: 4	3.5	3.15	3.465	7	1	3.5	3.15	3.465	7	Blind still functions but must be constantly monitored				
							PC: 5	3.5	3.5	3.5	7	1	3.5	3.5	3.5	7	Blind still functions but must be constantly monitored				
Blind Ram	cylinder body	connects fitting into cylinder body to allow to attach hydraulic hoses	failure of cylinder body hydrauli c ports during normal operatio n	external leak	blind ram ineffective and unable to hold well pressure	wear/ tear; mechanical damage fittings and/or thread damage/ impact damage	PC: 0	5	0.25	1	2	3	15	0.75	3	6	Blind ram disabled, no other ram present	This failure mode is common as experienced by the experts.	visible leak of hydraulic fluid to atmosphere	Pre-job pressure test. Scheduled preventative maintenance and inspection. Physical protection device (or "guard") may prolong ports' life.	Note regarding manual closing mechanism typically present in wireline rams/valves: they tend to be unreliable depending on the situation/environment, so no credit is given to them in this analysis. *Possibly address in the 16WL text or elsewhere.*
							PC: 1	4	0.4	2.4	4.8	3	12	1.2	7.2	14.4	Blind ram disabled, but one other barrier available				
							PC: 2	4	2	2.4	4.8	3	12	6	7.2	14.4	Blind ram disabled, but one other barrier available				
							PC: 3	4	3.2	3.96	8	3	12	9.6	11.88	24	Blind ram disabled, but one other barrier available				
							PC: 4	4	3.6	3.96	8	3	12	10.8	11.88	24	Blind ram disabled, but one other barrier available				
							PC: 5	4	4	4	8	3	12	12	12	24	Blind ram disabled, but one other barrier available				

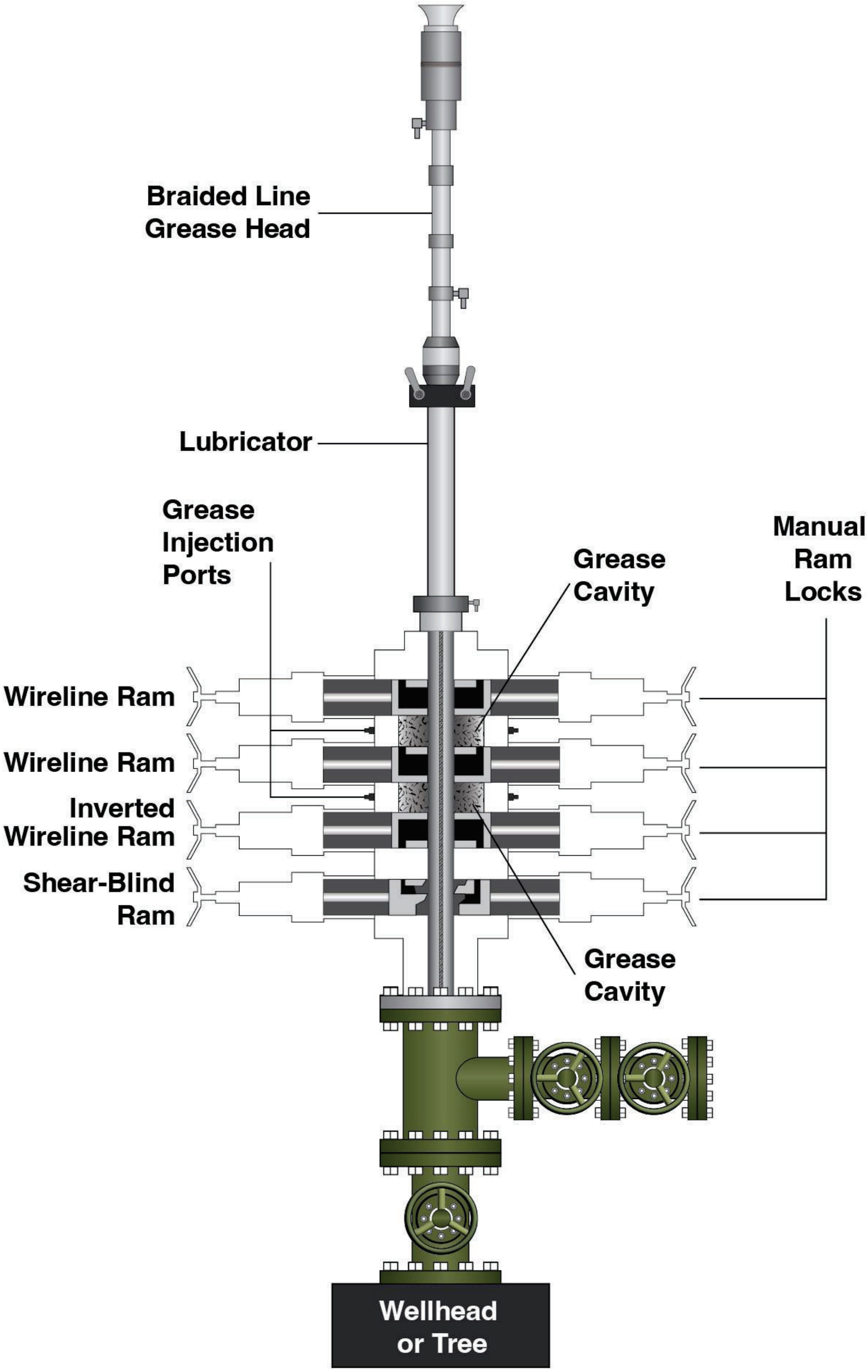
Appendix C. Detailed Wireline Safety Configuration Diagrams

Below are larger typical wireline configuration diagrams.

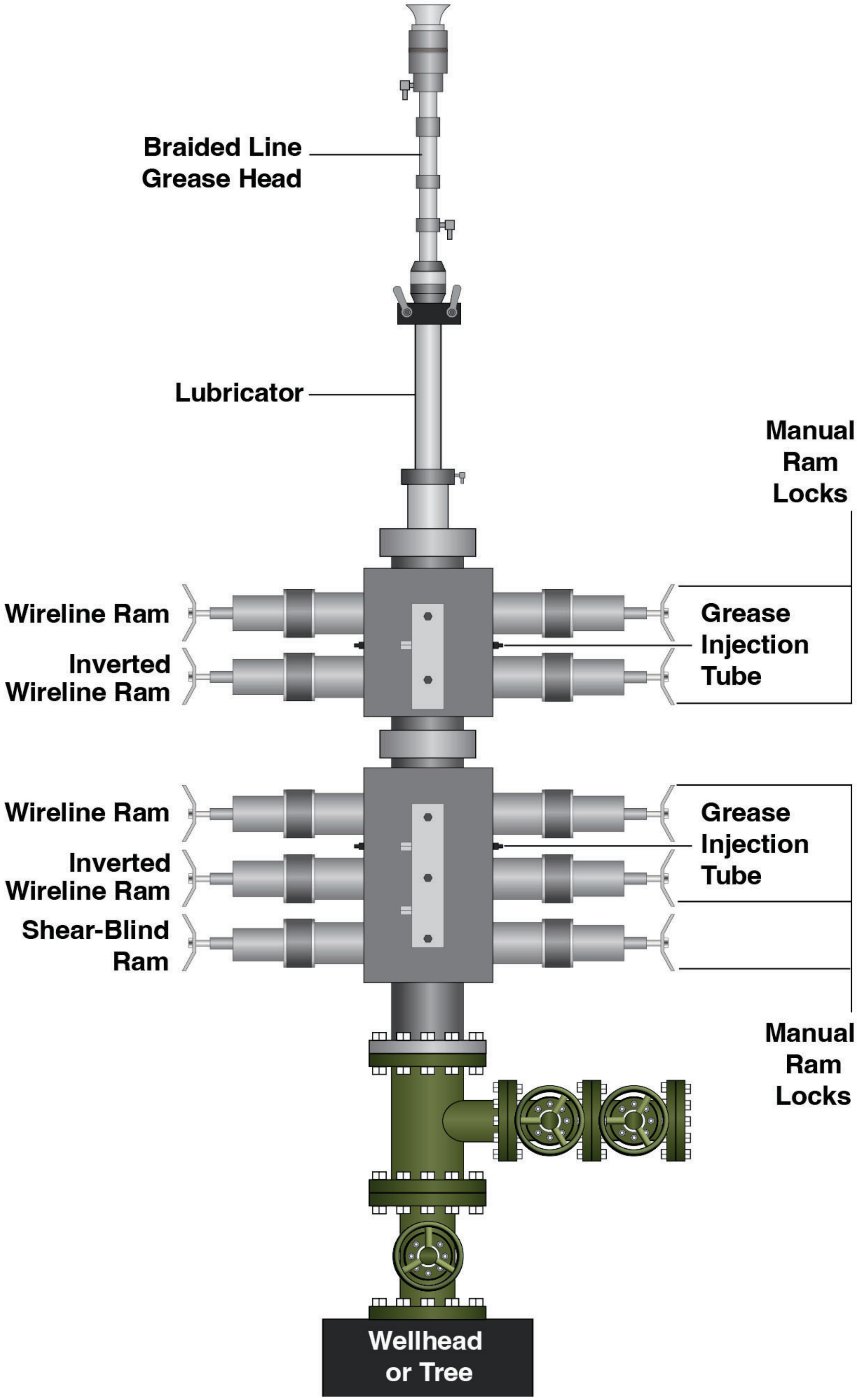
Braided Wireline - Figure 1



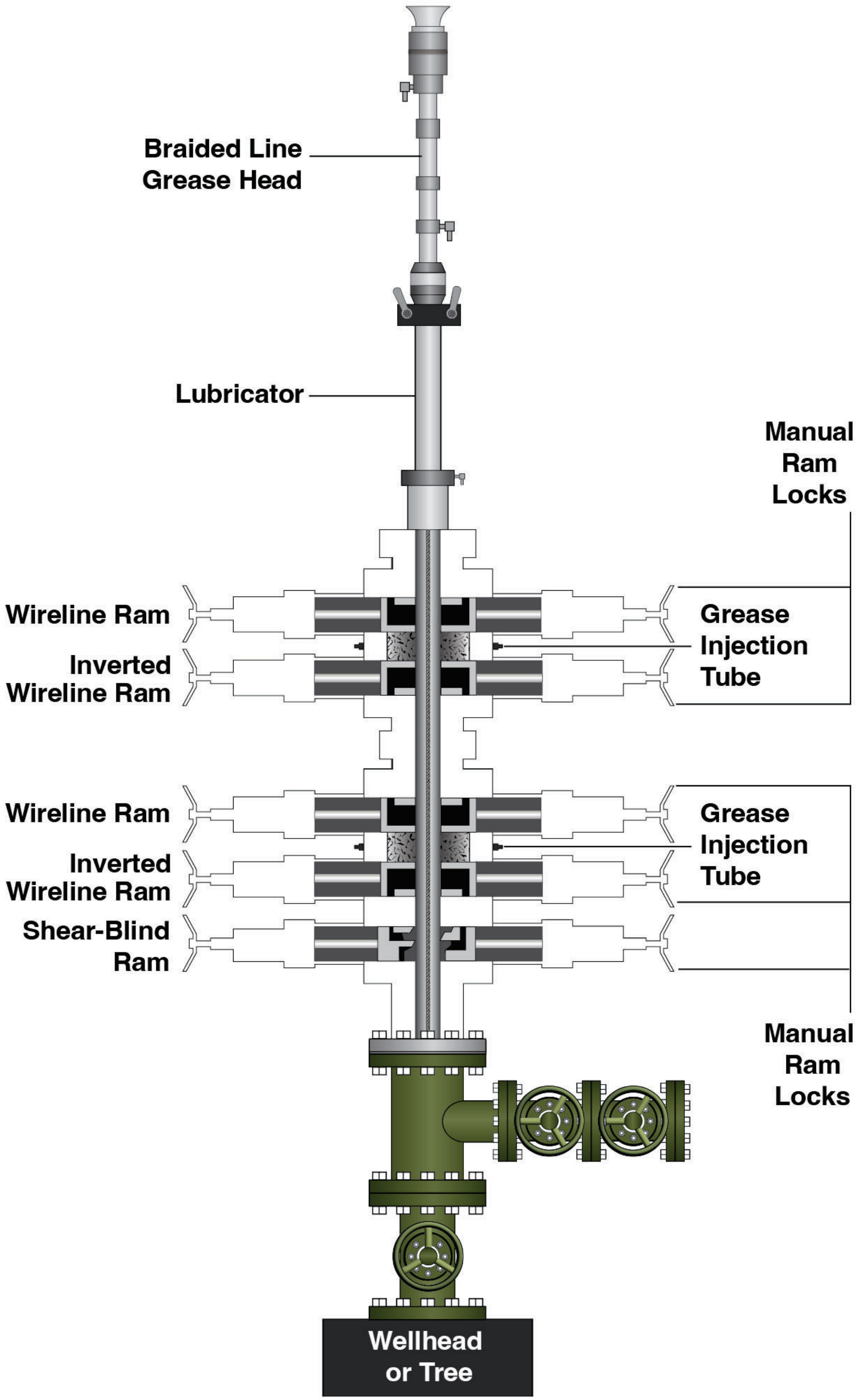
Braided Wireline - Figure 1



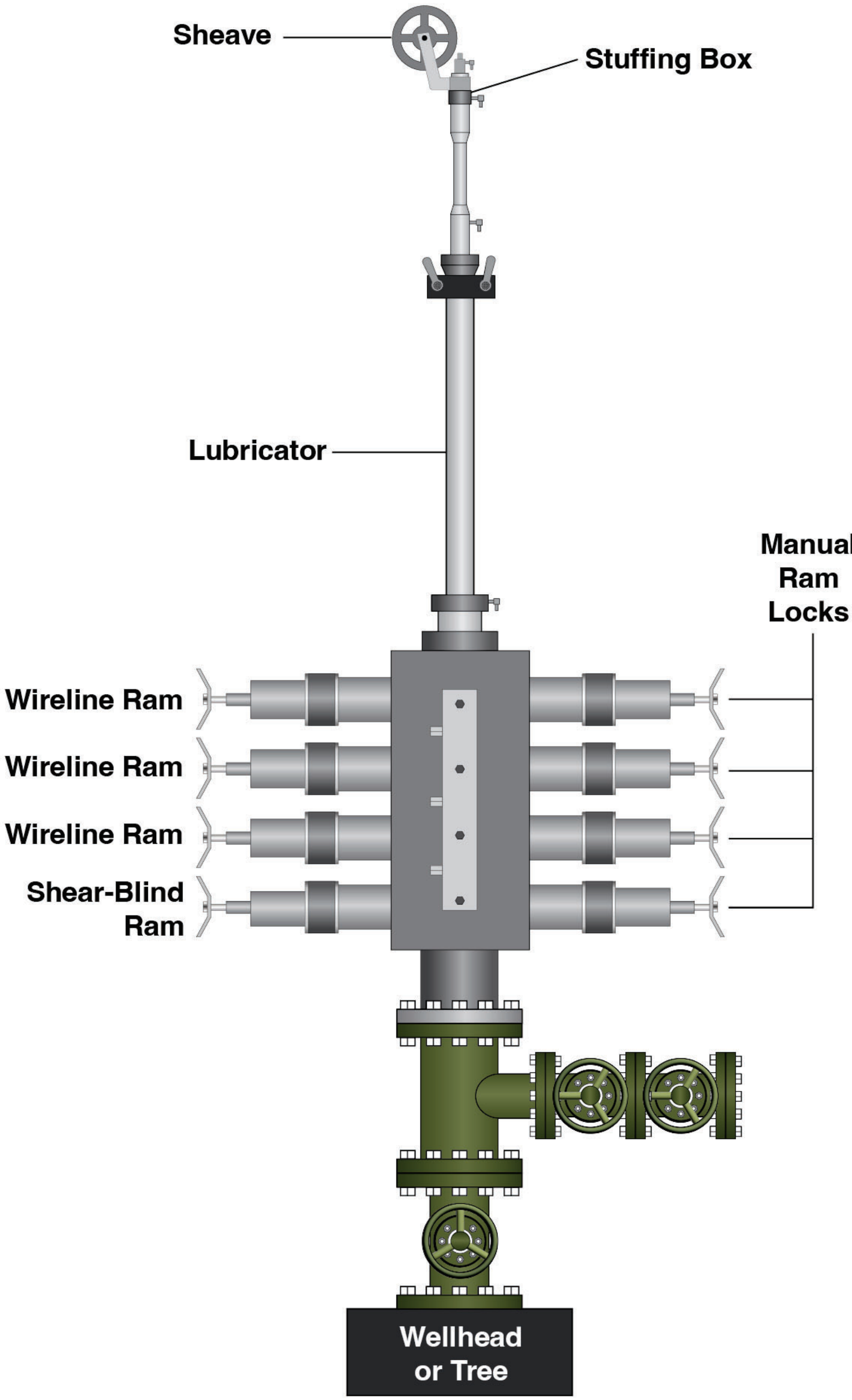
Braided Wireline - Figure 2

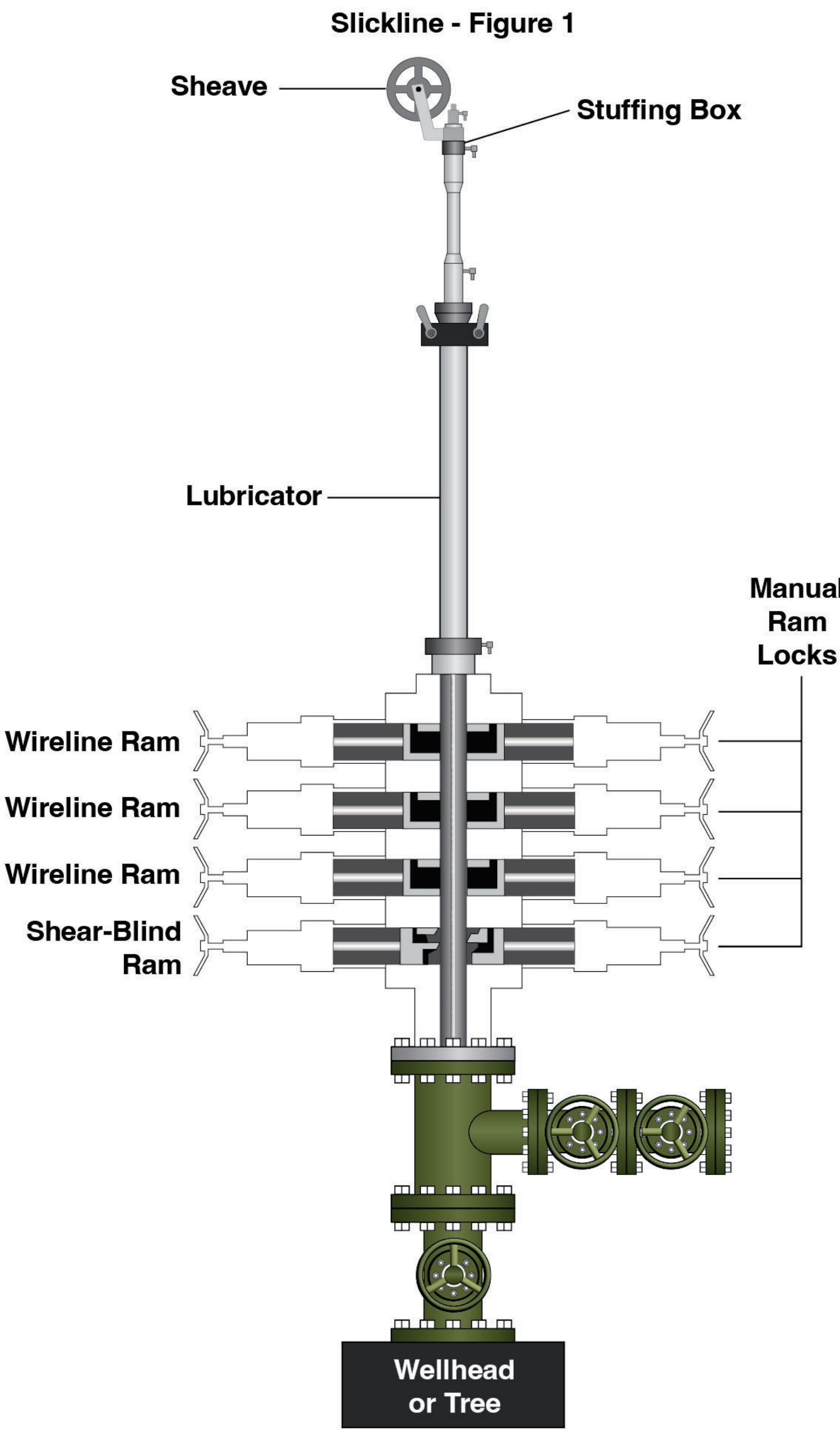


Braided Wireline - Figure 2

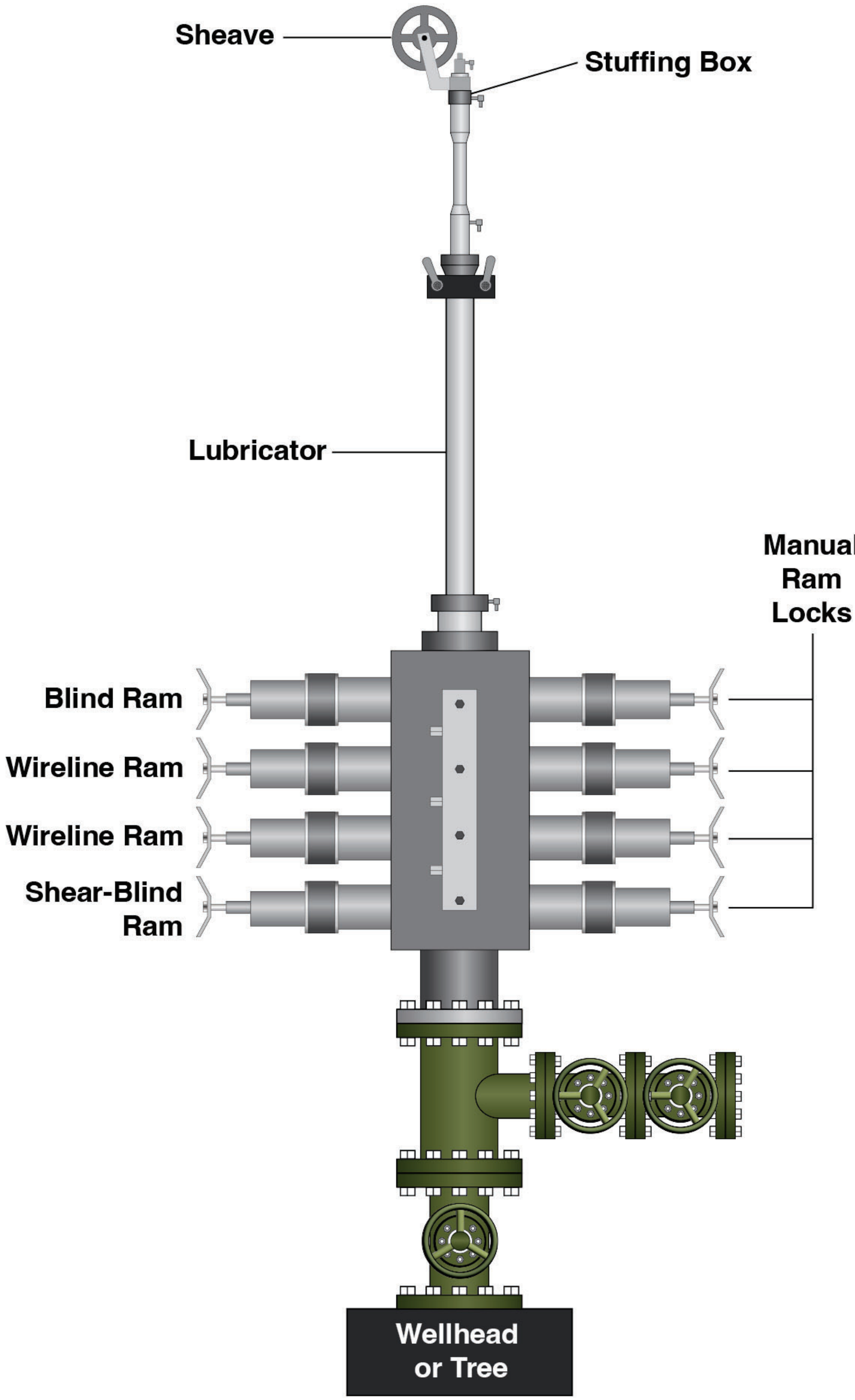


Slickline - Figure 1

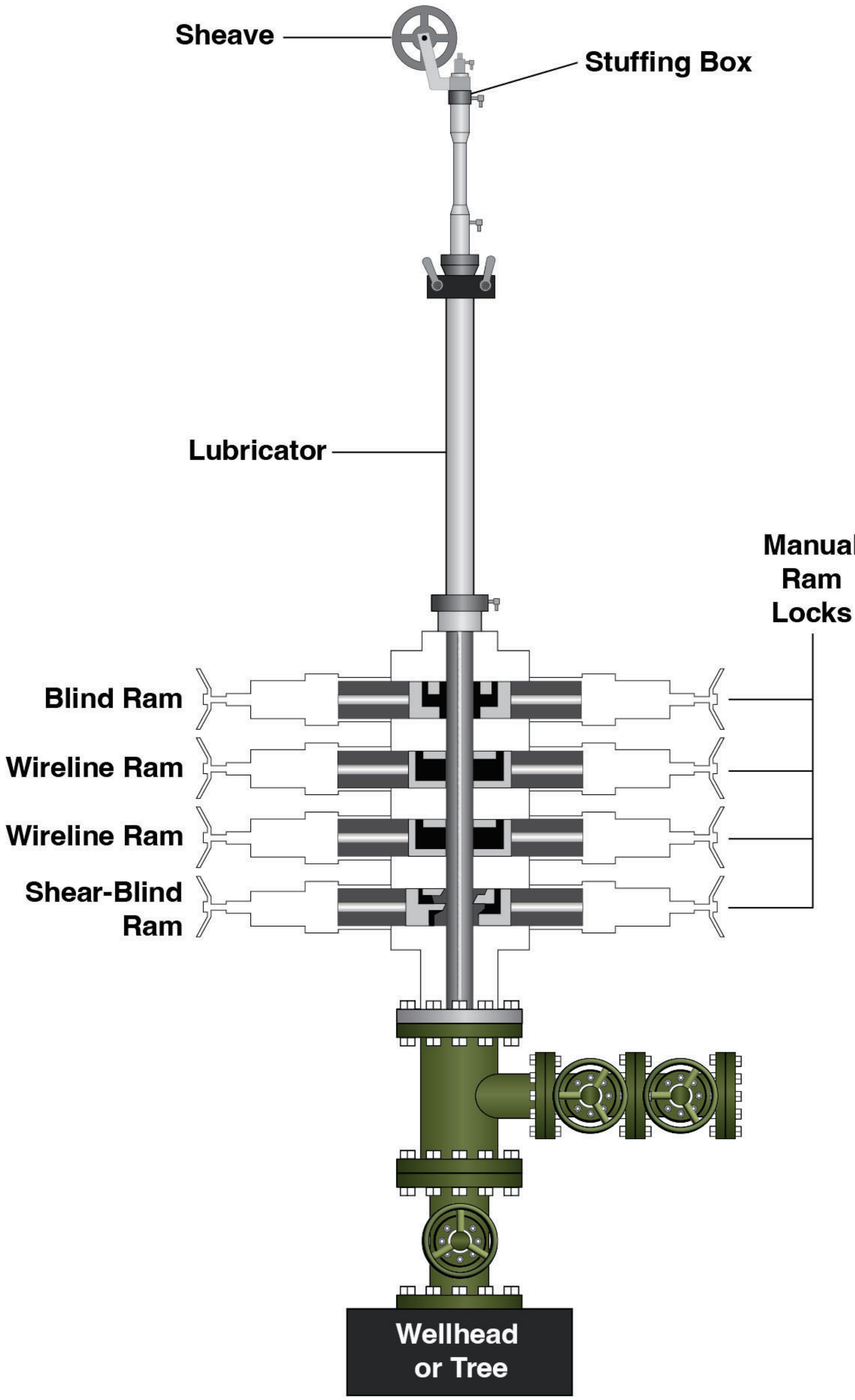



Slickline - Figure 1
Sheave
Stuffing Box
Lubricator
Manual
Ram
Locks
Wireline Ram
Wireline Ram
Wireline Ram
Shear-Blind
Ram
Wellhead
or Tree

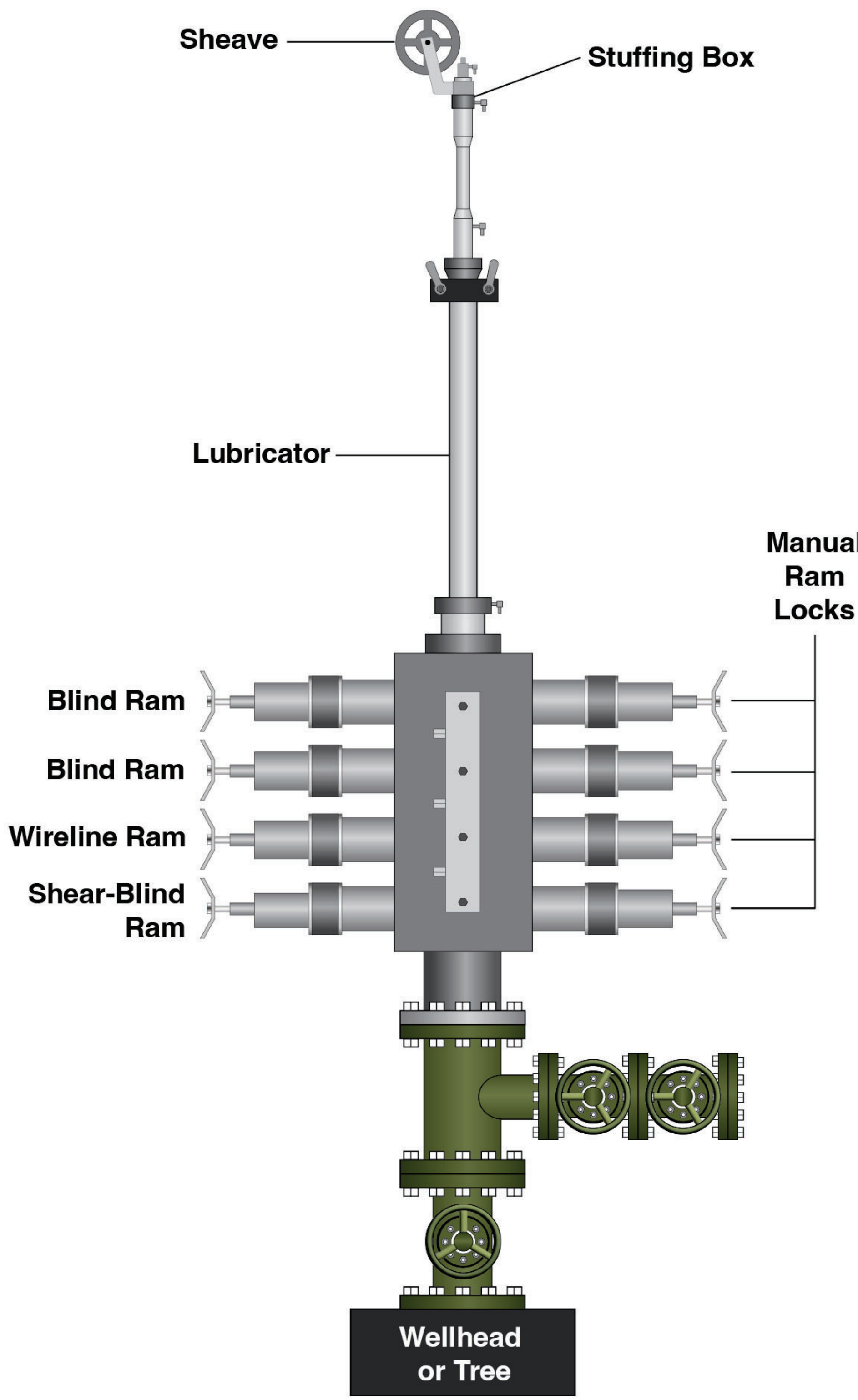
Slickline - Figure 2



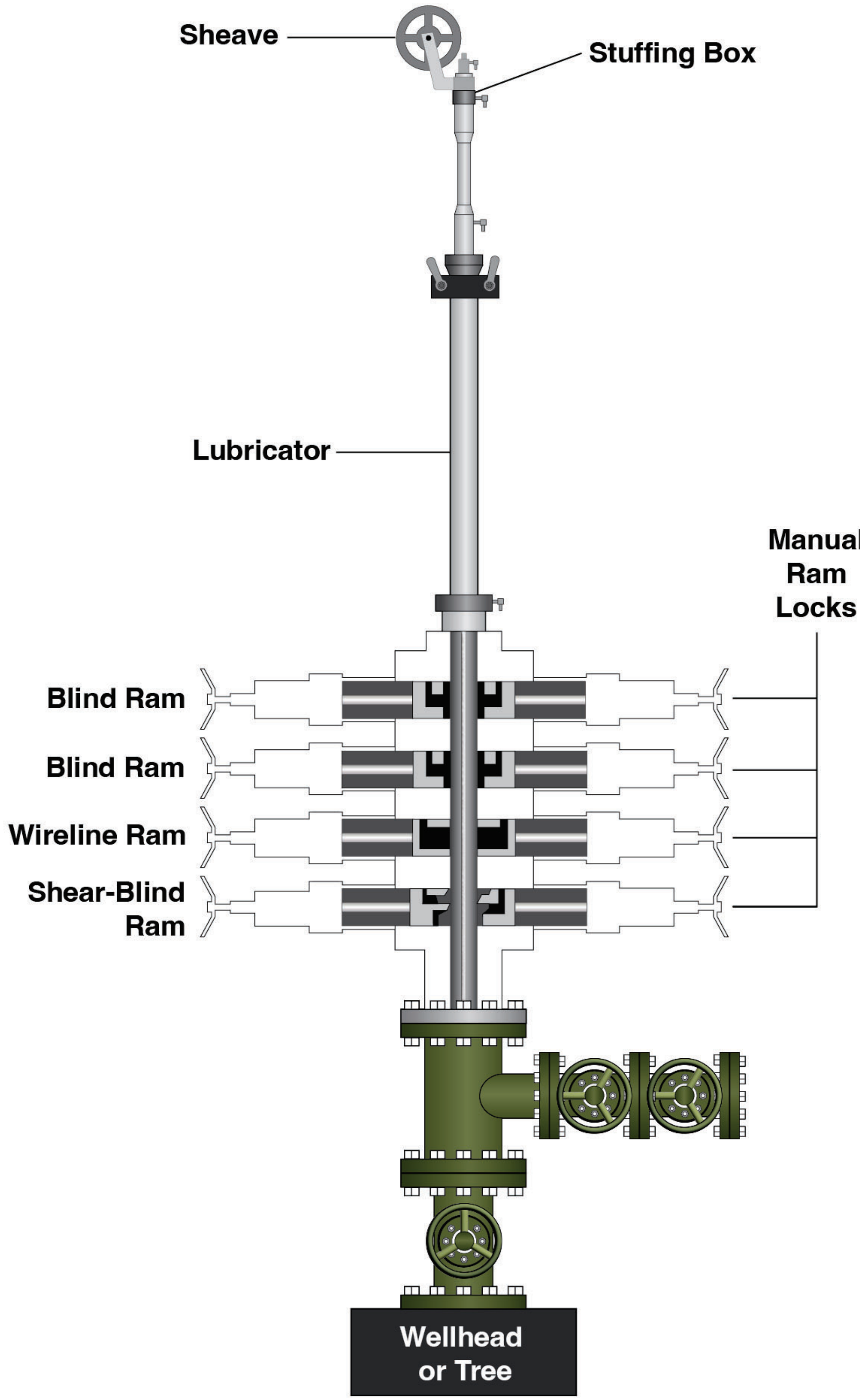
Slickline - Figure 2



Slickline - Figure 3



Slickline - Figure 3



Appendix D. API Rules of Conduct

The wireline success path and FMECA workgroup discussions conformed to the rules of API Antitrust Guidelines and Standards Meetings. These rules were applicable at the time when the meetings took place and may change in the future.

Content below is courtesy of API.

API Antitrust Guidelines

It is API's policy to comply with the antitrust laws. API staff and API committee participants should observe the following guidance:

- No discussion or forecasting of prices for goods or services provided by or received by a company.
- No sharing or discussing any company's confidential or proprietary information.
- No discussion of a company's specific purchasing plans; merger/divestment plans, production information, inventories or costs.
- No sharing or discussion of specific company compliance cost, unless publicly available.
- No agreement or discussion regarding the purchase or sale of goods or services (such decisions are independent company
- decisions).
- No discussion of how individual companies intend to respond to potential market/economic scenarios or government action;
- discussion limited to generalities.
- No disparaging remarks and no promotional remarks regarding specific vendors, products or services.
- If a discussion presents an antitrust issue, raise your concern immediately. If the discussion continues, announce that you are leaving the meeting
- because you have an antitrust concern, and immediately report your concern to API's Office of the Chief Legal Officer and to your company's own
- counsel. This Reference is not a comprehensive summary of antitrust issues, nor is it a substitute for legal advice. Antitrust issues should be raised with
- API's Office of the Chief Legal Officer and/or the member company's own antitrust counsel.

API Standards Meetings

API standards meetings, or others, are open to all interested parties. By participating in these meetings, and the standardization

process, you agree:

1) to fully comply with API's policies and procedures governing standards and antitrust concerns,

2) that once balloted and approved by API, API shall have a non-exclusive, perpetual, royalty-free worldwide license to use any

materials submitted by the participant for use in the standard, including creation of any derivative works that will be solely owned by API,
3) you will NOT provide any material that will violate the rights of any third parties, including, but not limited to, patents, copyrights, trade secrets, and trademarks,
4) NOT to provide any technical information or other materials that would violate U.S. export control laws,
5) to disclose the existence of any patented technologies in the material that you provide, including on-line submissions,
6) you will NOT make audio, video recordings, or take screen shots of API meetings and content without the express written consent of all persons who will be presenting their content, and
7) you must act professionally and comply with your company's code of conduct at all times.

Appendix E. Brief List of Expert Workgroup Discussion Topics

The following table lists subjects that arose in expert's discussions while developing wireline Success Paths and FMECAs. Some may not be appropriate for an API wireline document but serve as example criteria. Also, this list should not be construed as complete and comprehensive.

Type	Topic	Text Considerations (not in any order of precedence or importance):
Scope:		
	Workover system	▪ Extent of what is and is not covered by document.
	Nonservice provider components and systems	▪ Satisfactory performance of all equipment involved in wireline workovers. ▪ Enumerate good practices for well control and personnel safety independent of the entity providing that equipment.
References		
	API RPs and Standards: Adopting portions of, or concepts in:	▪ API Std 53, Well Control Equipment Systems for Drilling Wells-5th Edition December 2018, ▪ API Spec 6A, Specification for Wellhead and Tree Equipment-21st Edition, November 2018 includes Errata 1 dated April 2019, Errata 2 dated June 2020, Addendum 1 dated July 2020, Errata 3 dated September 2020, Addendum 2 dated June 2021, Errata 4 dated September 2021, and Addendum 3 dated August 2022, ▪ API Spec 16A, Specification for Drill-Through Equipment, 4th Edition April 2017 includes Errata 1 dated August 2017, Addendum 1 dated October 2017, Errata 2 dated November 2017, and Errata 3; April 2018 ▪ Std 16AR, Standard for Repair and Remanufacture of Drill-Through Equipment-1st Edition April 2017 includes Errata 1 dated August 2017 ▪ API Spec 16D, Control Systems for Drilling Well Control Equipment and Control ▪ Systems for Diverter Equipment, 3rd Ed., Nov. 2018.

Type	Topic	Text Considerations (not in any order of precedence or importance):
	API RPs and Standards Consider also:	▪ API Spec Q1. Specification for Quality Management System Requirements for Manufacturing Organization for the Petroleum and Natural Gas Industry, 9th edition, June 2013, includes Errata 1 dated February 2014, Errata 2 dated March 2014, Addendum 1 dated June 2016, Addendum 2 dated June 2018, and Errata 3 dated November 2019, and ▪ API Spec Q2, Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural gas Industries, 2nd edition, July 2021.
	Other	▪ Other appropriate standards, specifications, or practices.
Definitions		
	Terminology	▪ Distinguish between full barriers, pressure control, and operational barriers What is or is not any of these for purposes of document. ▪ Active or passive states? ▪ Define components and commonly acceptable synonyms.
	Major Components	▪ Wire rams, pack off (stuffing box), grease head, shear blind, Shear ram (if applicable), braided wire, slickline, pump in sub (access port for killing well?), grease injector, Eline, lubricator, unions, ball check, tool trap, tool catcher, sheeve, wire spool, load cell (if used)
	Support systems	▪ Motive power for grease injection ▪ Motive power for hydraulics. ▪ Electric power
	Service Classes	▪ Pressure ranges, associated equipment rated working pressures, ▪ Barrier requirement counts, or similar. ▪ Based on MASP/MAOP. ▪ Recommended deratings because of grease head pressure drop.
	Leaks	▪ Major versus minor?

Type	Topic	Text Considerations (not in any order of precedence or importance):
General:		
	Barrier philosophy	▪ Two tested barriers available during all operations. ▪ Rams locked when unattended?
	Pressure Control philosophy	▪ Two pressure control barriers available at all times and between personnel and well bore when performing maintenance. ▪ Pressure control status required constant personnel attendance.
	Common Mode Vulnerabilities	▪ When and when not to suspend operation because of a common mode failure…this could be hydraulic hose failure, pump failure, or loss of prime mover power.
	Field Pressure Tests	▪ Criteria and extent of systems tested. ▪ Use of components other than barriers for test purposes (inverted ram?).
	Shop Tests	▪ Pressure and function tests to be performed after refurbishing or repairing components or systems. ▪ Documentation package content
	H_2S Service	▪ Additional requirements for H_2S service (Number of barriers and pressure control devices).
	Lighting	▪ Night or low light operations. ▪ Battery backup
	Well Bore Access	▪ Provisions for well bore access below wireline equipment.
	Wire shearing	▪ Use of tree gate valve. ▪ Land or offshore? ▪ Certificate of capability. ▪ Minimum time requirement.
	Spare and replacement parts	▪ Minimum requirements.
	Wire Shearing	▪ Certification of capability from OEM. ▪ Centering device necessary?

Type	Topic	Text Considerations (not in any order of precedence or importance):
	Remote Operation	▪ When and where is remote operation recommended or required?
	Elastomer compatibility	▪ Compatibility with well bore fluids anticipated during job.
	Metal compatibility	▪ Compatibility with well bore fluids anticipated during job.
	Fishing for broken wire	▪ Requirements and safe practices for recovering broken or purposely sheared wire.
	Manually operated barriers	▪ Criteria on use, when and where.
	Manufacturer Certifications	▪ Independent Review Certification (IRC). ▪ Expansion of practice? ▪ Package minimums: tests, inspections, materials certification, quality program, parts, sources, etc.
	Remanufacturing and Repairs	▪ Component recertification for major repairs ▪ Replacement parts source (OEM?) ▪ Equivalent parts ▪ OEM vendor approvals.
	Technician Certification	▪ Requirements
	Pre job shop inspection process	▪ Identify components and processes. ▪ Checklist
	Effluent management	▪ Environment protection measures.
	Pressure Testing	▪ Liquid only? ▪ Exceptions when gas may be used?
	Tree Valve credit	▪ Part of or not part of barrier or pressure control envelope.
	Frac valve credit	▪ Part of or not part of barrier or pressure control envelope.
	Equipment ratings below stuffing box	▪ Equipment can or cannot be lesser rating than stiffing box.

Type	Topic	Text Considerations (not in any order of precedence or importance):
	Startup	▪ Confirmation of hydraulic or grease hose connections. ▪ Checklist
	Emergency control panels	▪ Placement ▪ Number ▪ Authority to use
	Independent Third-Party (I3P) Review	▪ When and where recommended/required. ▪ Credentials (PE?) ▪ Records
Systems:		
	Control	▪ Backup power (electrical) if needed for barrier or pressure control implementation.
	Accumulators	▪ Barrier and pressure control operation ▪ Capabilities ▪ Location ▪ Initial charging, testing, etc. ▪ When and where accumulators should be dedicated. ▪ Closing time and volume requirements. ▪ Redundant charging pumps? ▪ Pressure gauge placement and calibration. ▪ Compensation for adiabatic discharge. ▪ Fluid discharge limitations, if any.
	Grease Supply	▪ General capability ▪ Number of pumps ▪ Reservoir sizing ▪ Reservoir monitoring ▪ Location ▪ Returns ▪ Pressure control
	Hydraulic power	▪ General capability ▪ Number of pumps

Type	Topic	Text Considerations (not in any order of precedence or importance):
		▪ Reservoir sizing ▪ Reservoir monitoring ▪ Location ▪ Returns ▪ Pressure control
	Rams	▪ Ram locks: manual, status visible? ▪ Ram lock testing in shop. ▪ Added requirement for bonnet seal because of potential environmental impacts of leakage?
	Air/Hydraulic	▪ Acceptable application
Components:	Hydraulic Hose	▪ Routing criteria
	Shear blind rams	▪ Wire centering device ▪ Pressure test in field. ▪ Alternate ram actuation technologies (electric, explosive, pneumatic, etc)
	Ball check	▪ Cleaning requirements
	Wire	▪ Wire type ▪ Grades ▪ Certifications ▪ Documentation
	Load cell	▪ Load measuring system to control wire tension.
	Wire rams	▪ Seal with or without wire in bore ▪ Leak rate allowance?
	Blowout plug	▪ Used or not used. ▪ Testing criteria.
	Stuffing box	▪ Independent grease supply? ▪ Self-energizing with pressure? ▪ Pressure control function?
	Grease head	▪ Drift checks for tube diameters

Type	Topic	Text Considerations (not in any order of precedence or importance):
	Line wiper	▪ Dedicated component needed?
	Braided wire	▪ Preconditioning ▪ Pre job torque testing
	Quick Unions	▪ Requirements
	Coated wire	▪ Integrity criteria (No pressure leakage to interior?)
	Diverter	▪ Required?
	Hydraulic Hose Connectors	▪ Internal sealing (Check valves to contain hydraulic fluid when disconnected). ▪ No internal blockage when connections made. ▪ Sensitive to side loads?
	Slickline	▪ Pre job Eddy current testing. ▪ Cleaning inspection between jobs?

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