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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, supported the development of API Recommended Practice (RP) 16SB to strengthen governance of snubbing and hydraulic workover (HWO) well control systems. Although snubbing and HWO represent long-established intervention technologies, industry expertise has historically remained siloed, and no comprehensive API standards previously existed. To address this gap, BSEE engaged Argonne National Laboratory to conduct Success Path and Failure Modes, Effects, and Criticality Analysis (FMECA) evaluations of key barrier and pressure-control elements, providing a structured basis for assessing system robustness and identifying high-risk failure points. Through biweekly collaboration with API Subcommittee 16 subject matter experts, the study revealed challenges in achieving consensus on terminology, equipment configurations, and definitions of well-control concepts, underscoring the need for standardization. Despite these constraints, the analyses demonstrated broad industry agreement on the requirement for a minimum of two barriers during snubbing operations and highlighted areas where additional safety components may be warranted. The study concludes with recommendations to continue applying Success Path and FMECA methodologies, advance terminology harmonization, expand training, and pursue improved data collection and future research to support the evolving development of API RP 16SB.

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

Final Draft

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Argonne National Laboratory Technical Report no.: ANL-23/25

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About Argonne National Laboratory

Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Lemont, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

Snubbing 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

July, 2023

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List of Acronyms

API	American Petroleum Institute
Argonne	Argonne National Laboratory
BHA	Bottomhole Assembly
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulation
CT	Coiled Tubing
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
FMECA	Failure modes, effects, and criticality assessment
HWO	Hydraulic workover
MAOP	Maximum anticipated operating pressure
MASP	Maximum anticipated surface pressure
NRC	U.S. Nuclear Regulatory Commission
PRA	Probabilistic risk assessment
PC	Pressure Category
psi	Pound per square inch
RP	Recommended Practice
RWP	Rated working pressure
SB	Snubbing
SBR	Shear-blind ram
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 regulations. 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 contributed to the development of the American Petroleum Institute (API) Recommended Practice (RP) 16SB, covering Snubbing & Hydraulic Workover Well Control Equipment Systems.

The impetus of this study, and, at a higher level, of the development of API RP 16SB arose from the understanding that snubbing and hydraulic workover (HWO) operations comprise a very mature industry. However, a lot of the knowledge, experience, and expertise has become siloed within individual organizations or even individual subject matter experts within the organizations. Further, there are only a small number of BSEE regulations pertinent to snubbing, 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 snubbing and HWO is warranted.

Leveraging the experience gained through a previous similar effort of supporting the development of the second edition of another well intervention technology API Recommended Practice, API 16ST 2ed, *Coiled Tubing Well Control Equipment Systems* (API, 2022), BSEE enlisted the help of Argonne National Laboratory (Argonne) to assist the group of experts involved in the development of API RP 16SB by performing Success Path and FMECA analyses of the relevant physical barriers and pressure control systems. The Success Path and FMECA analyses were envisioned to help the experts in documenting and evaluating the current assumptions on the sufficient degree of safety that a certain equipment configuration provides. Additionally, these analyses are designed to help pinpoint areas in need of improvements, such as single points of failure or others that present a relatively high risk.

Argonne embarked on this work by establishing biweekly two-hour meetings with the select group of subject matter experts from the API Subcommittee 16 (SC16), tasked with the development of API RP 16SB. 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 the first edition of the document, for API RP 16SB, the discussions had to pivot to focusing on gaining consensus on these systems. A prominent example includes a lack of common definitions for terminology and nomenclature. Additionally, while it appeared that the snubbing operations had been taking place with the inherent 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 rigups.

As a result, the study was still able to accomplish Success Path and FMECA analyses for selected barriers and pressure control elements, but they were more fluid and supported working assumptions that were made in parallel. Additionally, the FMECA analyses was elevated to a higher level to capture more general failure modes and their effects. Specifically, rather than analyzing a subcomponent of an elastomeric seal on a blind ram or pipe ram, the analysis simply included a high-level assessment of sealing elements as one group. Sections 3 and 4 of this report provide more detail on the adjusted Success Path and FMECA approaches that were employed in this study.

This study also served to capture other observations, which led to conclusions and recommendations beyond 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. As another example, a better definition of the term “well control” and other relevant aspects of the operations need to be defined for snubbing and, ideally, complement similar terminology pertinent to other operations. If 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 snubbing 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 snubbing 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 API RP 16SB. 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 can continue to be used by the group of subject matter experts to continue to capture and evaluate the assumptions made while developing API RP 16SB.

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

- The authors recommend that the group of subject matter experts continue the use of Success Paths and FMECA as tools to document, analyze, and justify the requirements as part of API RP 16SB development.
- There is clear benefit to gaining consensus on the terminology and nomenclature of the equipment, operations, and other details of snubbing and HWO activities, and the group of subject matter experts should continue work on this standardization as part of API RP 16SB development.
- To gain further stakeholder consensus and buy-in, training may be a beneficial way to communicate the requirements of API RP 16SB as they become published or considered in pre-publication.
- In possible future Success Path and FMECA analyses, beyond API RP 16SB, it will be beneficial if the work on configurations is completed to some degree prior to the

commencement of risk analysis. These configurations, regardless of status (final or proposed), should serve as inputs to the risk analysis.

- 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 lower-level or more detailed FMECA with input from manufacturers; assessment of barriers in H_2S services; and remedies to potential shear-blind ram and/or power supply issues with respect to non-shearables or scenarios where the workstring is 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, n.d.). BSEE's collective goals include instilling a stronger sense of safety and environmental responsibility among Operators while promoting compliance with regulations.

BSEE strives to expand its role as a world leader in offshore energy development, 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 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 snubbing (SB) operations. Argonne conducted Success Path and FMECA on the systems to be addressed in American Petroleum Institute Recommended Practice 16SB (Snubbing & Hydraulic Workover Well 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 snubbing and hydraulic workover (HWO) units to perform a subset of workover operations on oil and gas wells. BSEE regulates well control equipment systems under 30 CFR 250.700, Subpart G – Well Operations and Equipment. BSEE has a few specific snubbing operations requirements at 30 CFR 250.760. There are no specific regulatory requirements related to HWO operations on the Outer Continental Shelf (OCS). However, it is recognized that BSEE's regulations on these systems possibly could be improved, but there are currently no consensus standards to incorporate by reference[1].

Having recognized this gap, the API Subcommittee 16 (SC16) Well Intervention Well Control Task Group (WIWC-TG) is, as of this writing, developing Recommended Practice (RP) 16SB[2],

[1] The National Technology Transfer and Advancement Act of 1995 requires, "… all Federal agencies and departments shall use technical standards that are developed or adopted by voluntary consensus standards bodies, using such technical standards as a means to carry out policy objectives or activities determined by the agencies and departments."

[2] 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 pressure control equipment used for snubbing and HWO operations.

covering Snubbing & Hydraulic Workover Well Control Equipment Systems. Additionally, BSEE, through the involvement of Argonne, is supporting a parallel development of RP 16WL[3], *Wireline Pressure Control Operations and Equipment Systems*. A discussion of the observations and findings in that parallel effort is available through a separate document, ANL-23/33.

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.

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 the PRA and Success Path approach is that the PRA focuses on evaluating potential failures of systems and components, whereas Success Paths are effectively

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

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

the inverse of PRA, placing a focus on the minimum required system components for the system (or barrier) to succeed in performing its safety function. Argonne had performed a number of studies of individual offshore oil and gas operations and related safety systems for BSEE by using the 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 this study supporting the development of API RP 16SB 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 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 the FMECA on the 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 CT operations that was being proposed for APR RP 16ST 2nd Ed. was insufficient as there was no requirement for a redundant power system for the dedicated SBR. This means that the power system was potentially a single-point failure for all rams, including the dedicated SBR. As a result, the study recommended that API RP 16ST 2nd Ed. include considerations for separating and diversifying power sources such that the dedicated SBR could qualify as a truly redundant barrier.
  - The philosophy of barrier robustness and redundancy evaluation may be complementary to the development of API RP 16SB.

- 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 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 consumable and other non-barrier elements in snubbing and HWO operations, such as the stripping rams and possibly others may apply to the development of API RP 16SB.

These major discoveries with regard to coiled tubing operations that were made using this combined approach prompted the stakeholders to consider applying the same methodology of Success Path Based FMECA to the evaluation of critical systems in snubbing and HWO operations. Accordingly, BSEE elected to participate in the development of 16SB and sponsored

Argonne to lead the Success Path and FMECA analyses based on input from the API affiliated volunteer subject smatter experts.

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 encompass primarily process safety in snubbing and HWO operations, but also elements of personnel safety, environmental protection, and protection of facilities and assets—in emergency situations as well as normal maintenance and repair activities.

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 snubbing and HWO operations, both onshore and offshore. Although well intervention using snubbing and HWO has been the practice for decades, many nuances have yet to be fully 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 RP16SB, which is slated to set precedence over future safety practices applied to snubbing and HWO 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, 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.

Further, during this study, the focus on HWO was dropped completely due to time constraints. This choice was made based on the workgroup's assessment that HWO operations carried less hydrocarbon release risk as they apply to wells with no pressure at surface, unlike rig-assist or standalone snubbing operations, which involve constantly managing surface pressure.

3.2 The Role of HWO and Snubbing Operations

Before moving further, it is important to outline the scope and role of snubbing operations. Snubbing and HWO are well intervention techniques used for a multitude of purposes, both in the onshore and offshore oil and gas operations. Snubbing operations are used for well intervention, often in live wells, in activities such as milling out plugs, frac ports or cement, running production tubing, retrieving tools or equipment (i.e., "fishing"). Generally, snubbing units are used in hydrostatically underbalanced wells, while HWO units are used in hydrostatically overbalanced wells.[5] Because of the amount of force snubbing units typically employ and the length of pipe joints, they are remarkably robust and tall components and structures.

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[5] The terms "underbalanced" and "overbalanced" refer to presence of pressure at surface.

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 workgroup 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 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 the full HWO and snubbing stack minimum requirement diagrams.
- Appendix D contains the API rules and policies that governed the group 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., whereby the workgroup, consisting of oil and gas volunteer subject matter experts in the API Well Intervention/ Well Control Task Group (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 as well as risk analysis experts. Argonne facilitated the information gathering through biweekly teleconferences with the larger group and additional literature search about snubbing operations to construct Success Path models of the system elements and to subsequently guide 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 several 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 reaching consensus among a group of volunteer subject matter experts in the field of snubbing and HWO 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 group's efforts. The chair of WIWC-TG selected a focused sub-group from within the API Subcommittee 16 (SC-16) who would be available for biweekly discussions led by Argonne to gain consensus on critical safety components and their features, which make them effective well 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 Application

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

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

- Annular
- Blind ram
- Pipe handling system
- Safety pipe ram
- Shear-blind ram

[6] The distinction between pressure control barriers and pressure control devices was made as part of the workgroup meetings and is discussed in Section 5.3.

- Stripping pipe ram
- Workstring

The approach to constructing the barrier or non-barrier pressure control element Success Paths, in most cases, involved applying consistent 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 was included. An example resulting Success Path for a safety pipe ram barrier element 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.

Importantly, the OR gate is not to be treated as a list or "menu" of options for components that *could* be installed. In other words, if a component is shown 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.

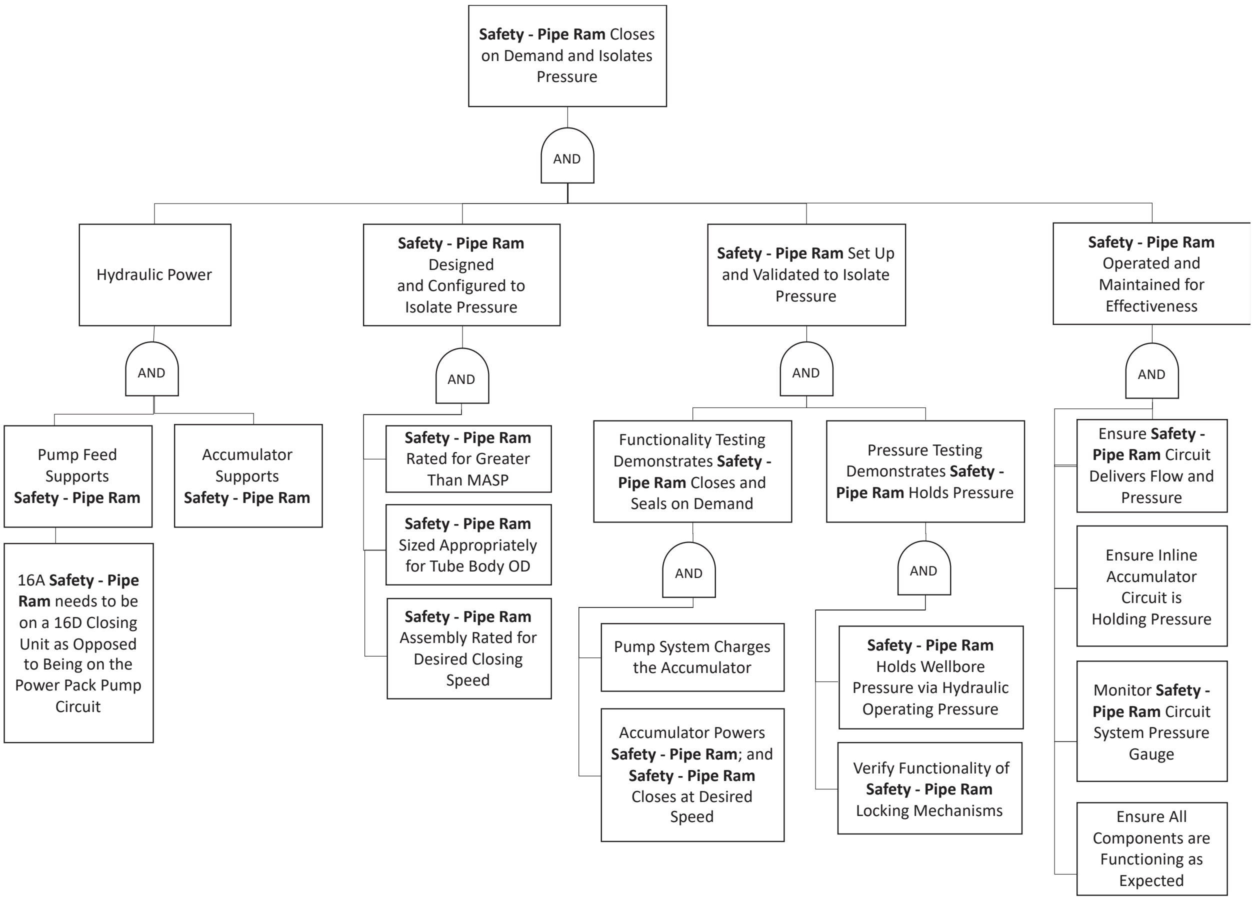

Figure 1: Example Success Path for the Safety Pipe Ram

A complete set of finished Success Paths for snubbing operations 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 to *"Ensure that all relevant components are functioning as expected"* in each 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 element to succeed. Examples of the linking of the FMECA to the success paths are provided in Figure 2.

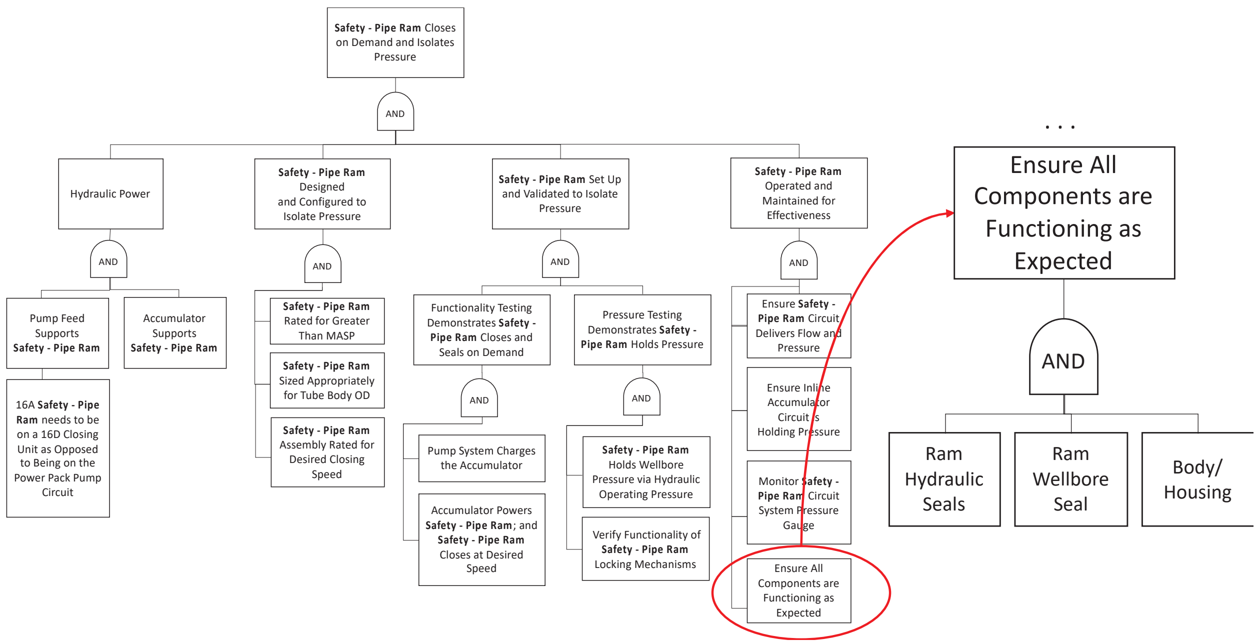

Figure 2: An Example of the Relationship Between a Barrier Success Path and Barrier Components Evaluated in the FMECA.

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 in the next section.

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 the group encountered while adjusting the course and the level of granularity of this study as discussed in Section 3.1 of this report, the group simply ran out of time to complete additional FMECA sheets together with Argonne's involvement. However, it is expected that this tool will continue to be used by the WIWC TG (i.e., API SC16 Task Group 5) as needed for further documentation of assumptions and recommendations as they continue to work on developing API RP 16SB.

4.3 FMECA Application

4.3.1 Structure

Argonne supported the API SC16 WIWC TG, which is tasked with developing API RP 16SB. This was to be based on evaluating the robustness of the safety elements from the perspective of the subject matter expert group 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 snubbing 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. In other words, clearly indicate the failure effect and other consequences in terms of potentially compromising the physical barriers that protect from release of hydrocarbons. This type of analysis produces risk rankings, discussed further in this Section, that are unitless and reflect solely on the efficacy of the barrier element. However, in consultation with the working group, 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 assets or facility/structure. An explanation of how this was handled is provided further in this section.

The risks in terms of the safety and integrity of equipment and barriers included in the Success Path were determined using the FMECA that was structured for this project and included the following evaluation elements:

- Identifying failure modes for each major component;
- Determining the local consequence of each failure mode;
- Determining the consequence of failure modes on the effected barrier(s);
- Identifying cause(s)/mechanism(s) of failure;
- Ranking the consequences of each failure mode:
  - Consequence on barrier(s),
  - Consequence on health and employee safety,
  - Consequence on the environment; and
  - Consequence on the assets or structure.
- Assigning an occurrence ranking for each failure mode, which was agreed to be based on average failure frequency 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, 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 the assets or structure.
- Identifying failure detection mechanisms; and
- Identifying failure prevention controls.

Further, having encountered the time delay, the scope of the FMECAs that were completed was elevated to a higher level to generalize and group certain failure modes. For rams, the failure modes were considered as groups, rather than in-depth, subcomponent-level analysis. These groups were:

- Ram hydraulic seals, i.e., elastomeric sealing elements of hydraulic power supply,
- Ram body seals, i.e., elastomeric sealing elements designed for controlling well pressures,
- Ram body, and
- Shearing elements (where applicable).

Because of the different contexts that the barrier elements can comprise in a snubbing unit configuration, the FMECA was further broken down by operation, rig-assist or standalone, and configuration name that corresponds to configurations as shown by the configuration (or "stackup") diagrams in Section 4.4.

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.

4.3.2 Occurrence and Consequence Rankings

The ***occurrence ranking*** was scaled to a 1 to 4 ranking system, where a ranking of "4" represented the most frequent types of events and a ranking of "1" represented the least frequent events. The actual frequency of each 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 by individuals with substantial snubbing experience. 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
1	Very rare
2	Somewhat Rare
3	Somewhat Common
4	Common

The ***consequence ranking*** that was 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 "5" in which the final barrier to the environment has been disabled. Each failure mode identified was assigned a value from 1 to 5 based on a consensus of the FMECA group members.

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
3	System disabled, no direct impact on barrier, normal operations suspended
3.5	System disabled/degraded with barrier degraded but operational
4	Barrier disabled, but alternative barrier remains
5	Barrier(s) disabled, no barriers remaining

The ranking of 3.5 was introduced late in the project to accommodate for cases where a failure leads to the barrier being degraded-but-operational, but should be discerned from a failure causing a barrier to be degraded-but-operational and normal operations must be suspended. The ranking of 3.5 was assigned out of convenience to not change the rest of the already assigned rankings.

To accommodate for consequences on specific groups, specifically health and employee safety, environment, and assets or facilities/structures, the team devised “multipliers” which deflated or inflated the risk ranking based on the estimated severity of the consequence on each of these groups based on pressure category (PC) which is discussed in Section 5.2. The multipliers typically increased for each pressure category. These multipliers helped to contextualize the risk of a potential loss of pressure containment during snubbing operations. The convention of multiplication was chosen out of convenience and as a sensible way to put the risks associated with operations in different pressure categories into further perspective.

Table 3: Consequence Ranking Multipliers

PC	Health and Employee Safety Consequence Ranking Multiplier	Environment	Assets/Facility 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

* PC0 was ultimately dropped from consideration together with the consideration of HWO operations within the updated focus of this study.

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 20 and the reference risk matrix is 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 from greater than or equals 6 to 12 inclusive, and High is anything greater than 12.

Importantly, the risk rankings of systems and components in this and any other relevant studies are presented relative to each other and not as a pre-determined risk number or threshold.

Table 4: Example Failure Risk Ranking

Risk Ranking					
		Occurrence Ranking			
		1	2	3	4
Consequence Ranking	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	3.5	3.5	7	10.5	14
	4	4	8	12	16
	5	5	10	15	20

Low	Medium	High

The reference risk matrix was further expanded to accommodate for the addition of consequence multipliers as explained in Section 4.3.2. In some cases, where there was more granularity in multipliers, like in the case of health and employee safety, the resulting reference risk matrix would span slightly different values and 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			
Consequence Ranking		1	2	3	4
	0.1	0.1	0.2	0.3	0.4
	0.2	0.2	0.4	0.6	0.8
	0.3	0.3	0.6	0.9	1.2
	0.35	0.35	0.7	1.05	1.4
	0.4	0.4	0.8	1.2	1.6
	0.5	0.5	1	1.5	2
	0.8	0.8	1.6	2.4	3.2
	1	1	2	3	4
	1.5	1.5	3	4.5	6
	1.6	1.6	3.2	4.8	6.4
	1.75	1.75	3.5	5.25	7
	2	2	4	6	8
	2.4	2.4	4.8	7.2	9.6
	2.5	2.5	5	7.5	10
	2.8	2.8	5.6	8.4	11.2
	3.2	3.2	6.4	9.6	12.8
	4	4	8	12	16

In other cases, due to the existence of multiplier values greater than 1, the risk matrix range was sometimes larger, up to 40 (i.e., the product of the worst consequence, 5, by the worst occurrence, 4, times 2 in the case of asset/facility risks in high pressure category operations). This example is shown in Appendix B.

4.4 Minimum Stack Requirement Representation

Stack diagrams are a helpful visual tool of minimum requirements for well control barriers and operational pressure control devices. The minimum stack requirements shown in the figures below are representative of the typical operations and are the authors', in consultation with the workgroup subject matter experts, best attempt to capture the minimum requirements for a handful of representative examples. They are presented here for the purposes of illustration of barrier elements comprising the barrier envelope, but it should be noted that there are many more configurations presently applied in snubbing operations that are determined by specific operational objectives. The snubbing stack typically includes an equalizing bleed-off loop, which is applicable in snubbing but not in HWO operations. The representation in this Section focuses on the detailed visual distinction between the rams and other elements and the illustration of a side-view is shown in a smaller size off to the right. These diagrams, in their full size, are shown in Appendix C for better legibility.

4.4.1 HWO Minimum Stack

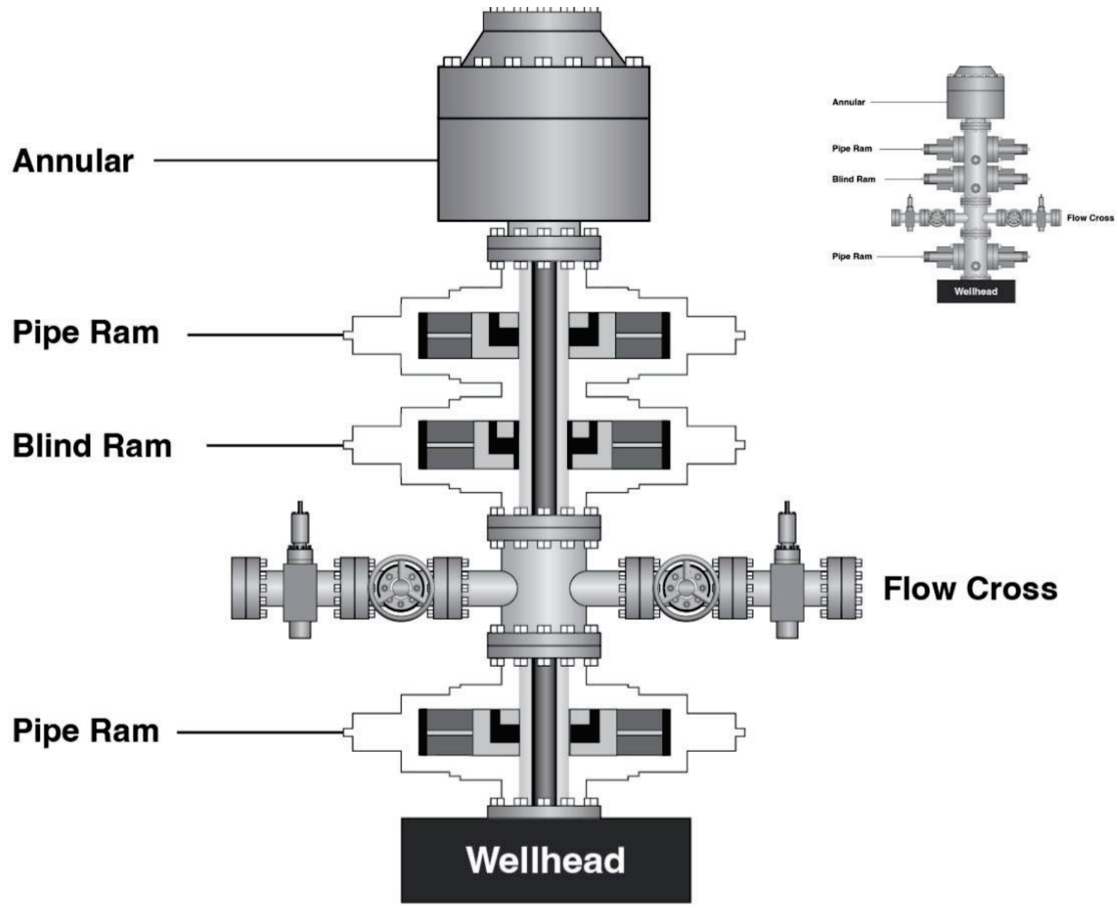

Figure 3: Typical HWO Stackup.

Figure 3 shows a minimum stackup diagram possible in HWO operations. Note that in pressures of 10,000psi and more, the pipe ram below the flow cross (closest to the wellhead) is typically paired with a with a shear-blind ram.

4.4.2 Snubbing Stack Diagrams

Figure 4 through Figure 7 shows typical rig-assist snubbing operation stackups, while Figure 8 represents a typical stand-alone snubbing operation stackup. In these diagrams, the equalization loop (often called the "snubbing loop") is shown in its side view. The rams other than the ones labeled "stripper rams" can be considered barrier elements. Note that a distinction of a typical actuation sequence for barrier elements in an emergency has not been made by the API RP 16SB workgroup subject matter experts as of this writing but would potentially be a beneficial next step in the development of the RP.

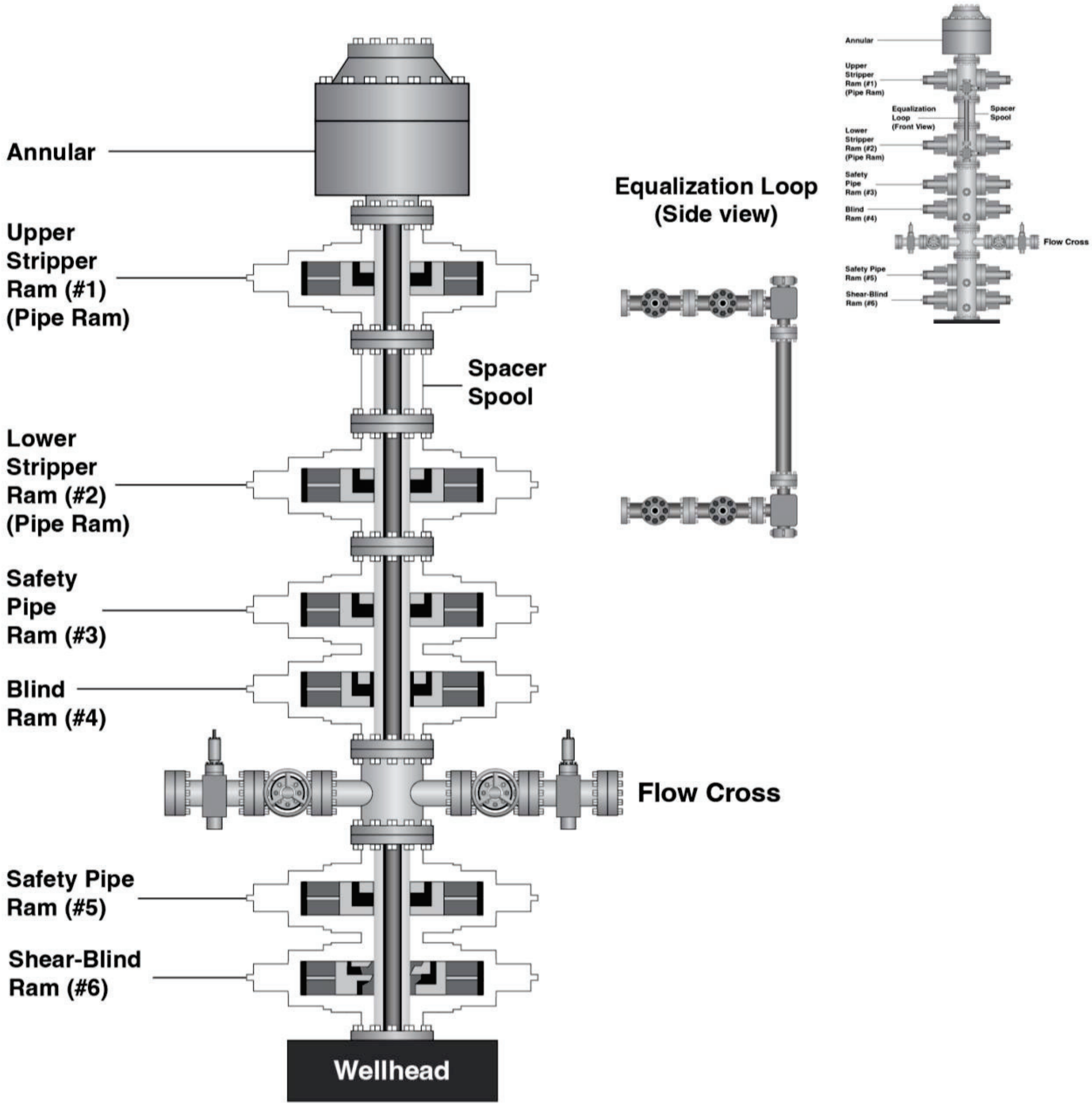

Figure 4: A Rig-assist Setup with Six Ram Design for Simple BHA.

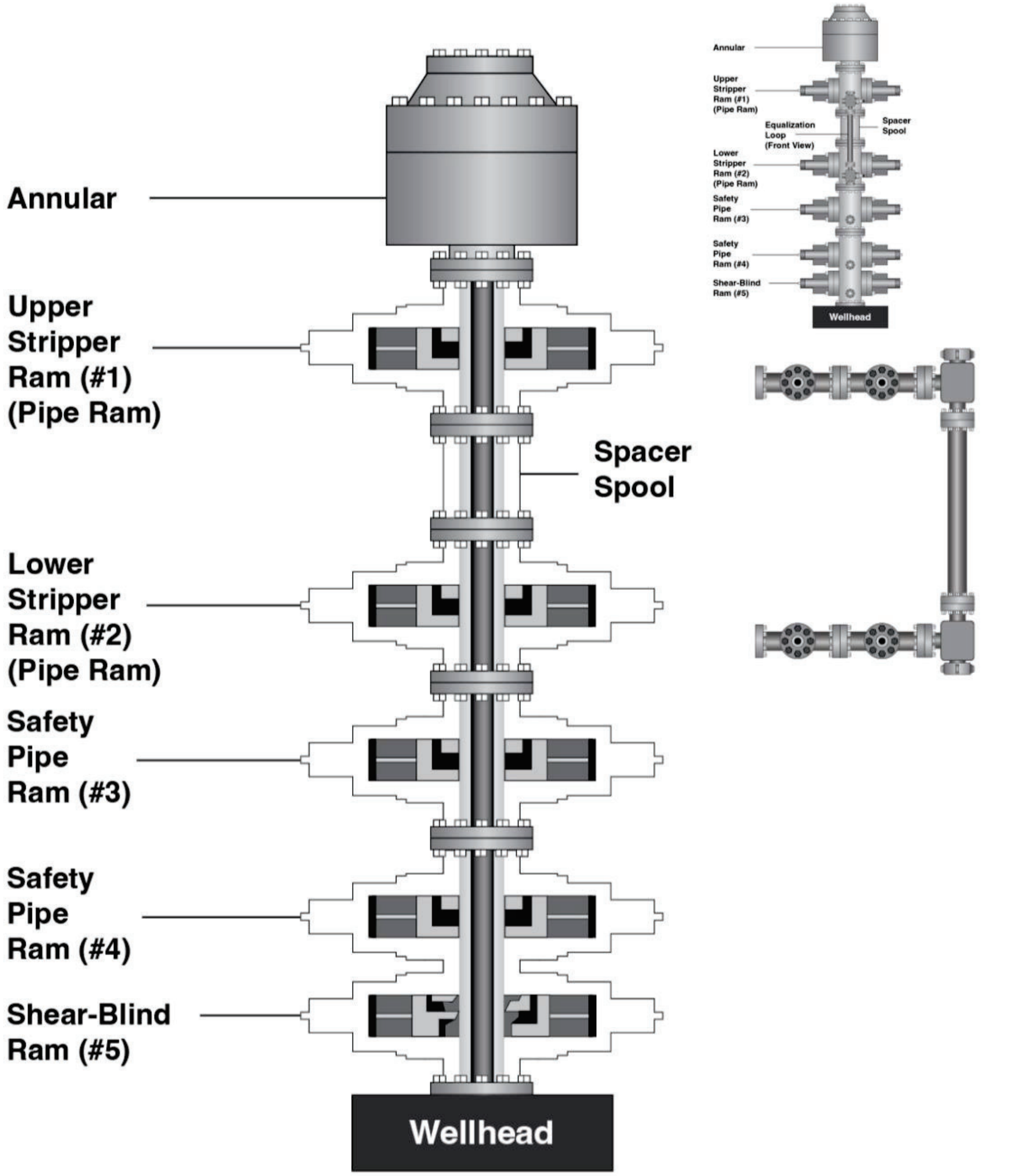

Figure 5: Rig-assist Setup with Five Ram Design for a Simple BHA or "Mini" Unit.

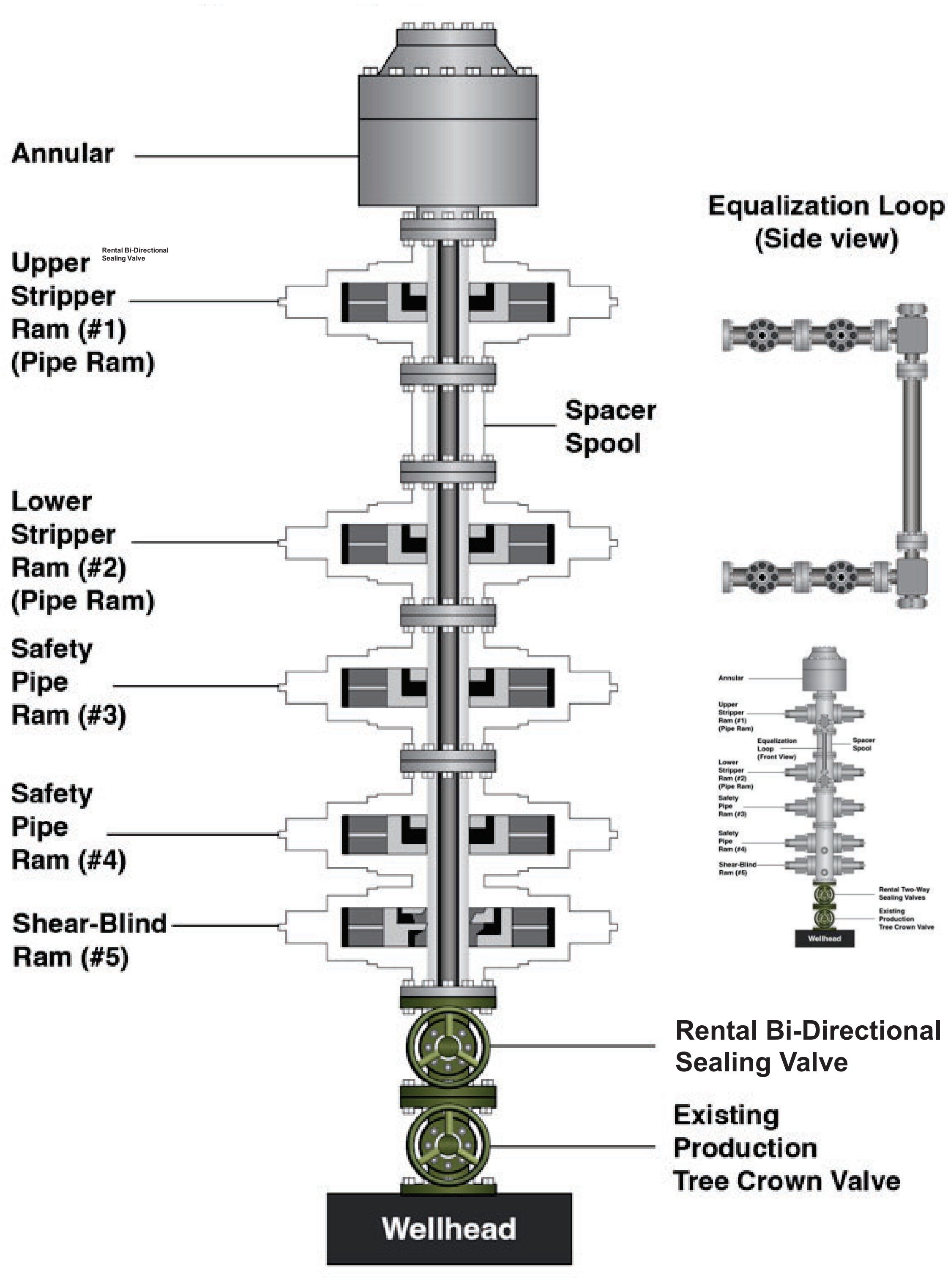

Figure 6: Rig-assist Rigup on a Production Tree.

In current practice, the rental valve shown below the shear-blind ram (“#5”) in Figure 6 is typically hydraulically operated or can sometimes be manual. Note that there are several other tree components between the tree crown valve and the wellhead.

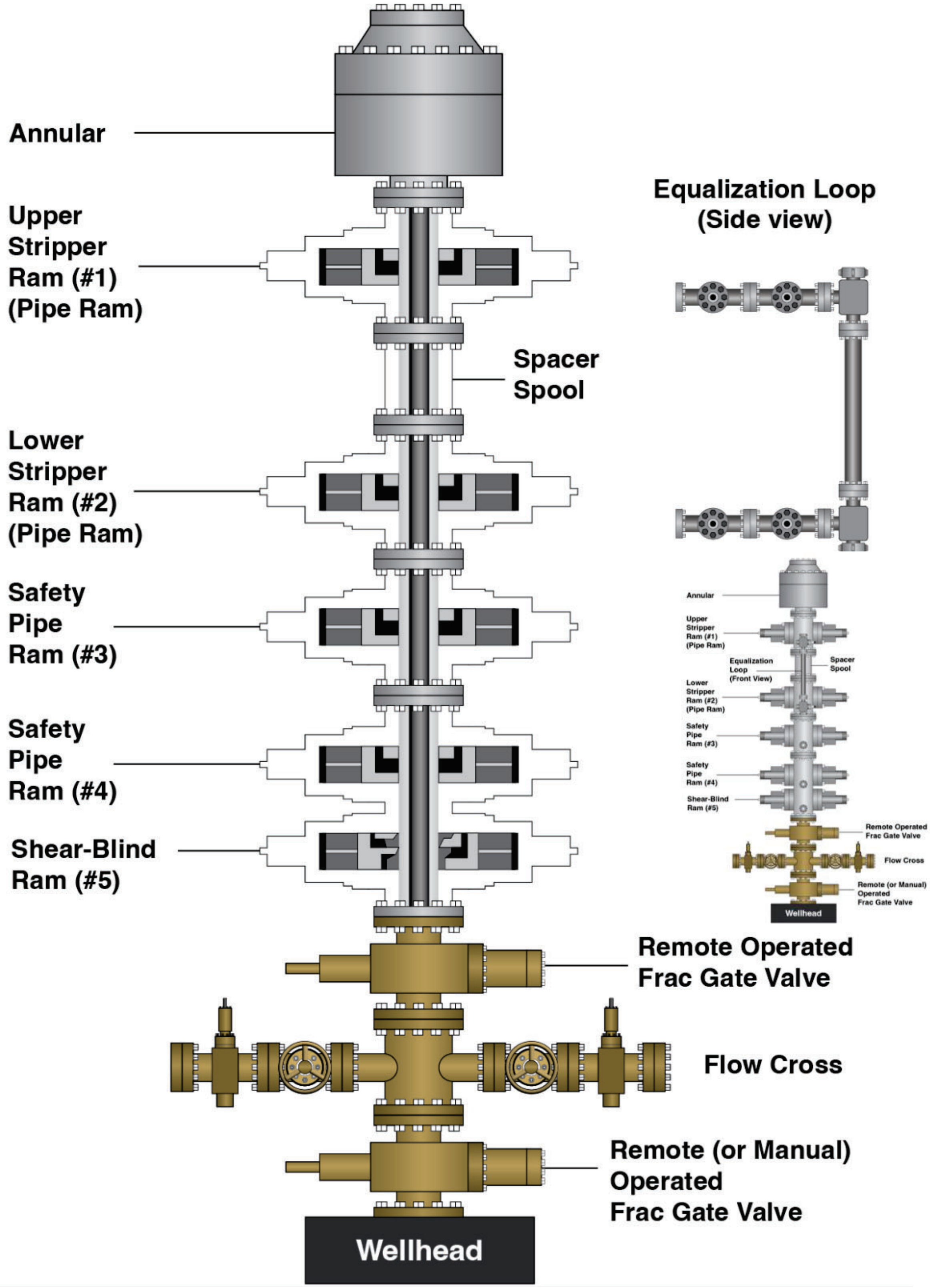

Figure 7: Rig assist Rigup on Frac Valves.

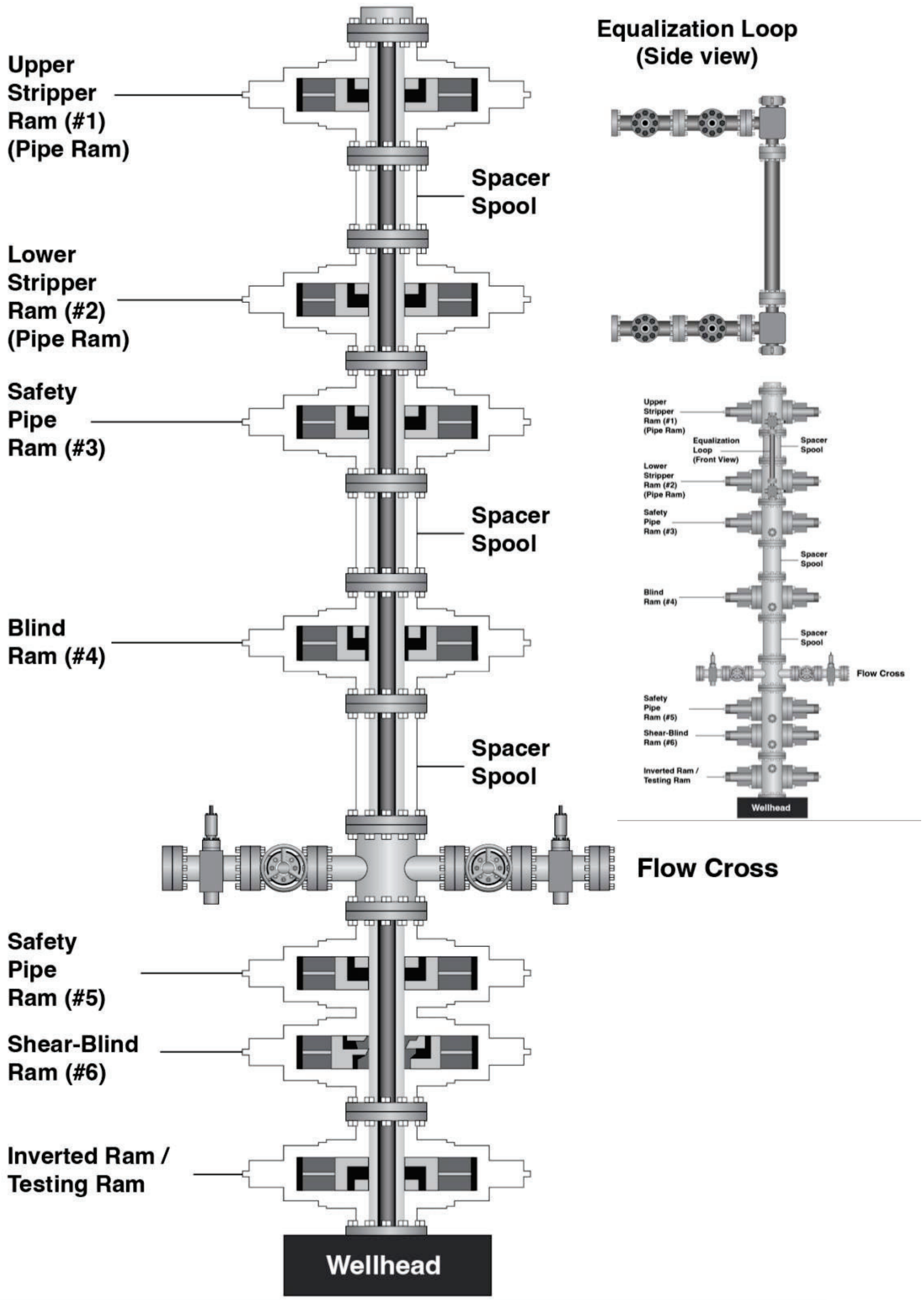

Figure 8: Stand-alone Rigup with an Inverted Test Ram (Annular Not Shown).

The configurations represented by Figure 4 and Figure 5 rely on equipment provided by the snubbing company. However, there are other configuration scenarios, such as the examples shown in Figure 6 and Figure 7 that rely upon equipment present at the site that the snubbing system is rigged up on. As of this writing, there does not appear to be clarity on the requirement for these safety systems in terms of evaluation and verification for snubbing operations, and whether these requirements may be held to the same standard as those for the snubbing equipment in API RP 16SB when it becomes published. This is another area for potential further discussion by the workgroup. Note that the numbering convention, as shown in the figures pertinent to Snubbing is typically used by the industry, whereby the workers oftentimes communicate to each other regarding the particular ram by referring to its sequential number from the top. Often, these numbers are painted on the outside of the ram body once assembled.

5. Discussion

5.1 What Constitutes a Pressure Control 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 are likely to be severe.

The basic idea behind the multiple physical barriers philosophy 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 forces, due in part to the fluid pressures (either from the hydrocarbon reservoir or from applied service pumping operations), and in part to the size, design, and complex nature of the equipment components. It may sometimes be a challenge to identify the boundaries of the physical barrier. 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.

5.1.2 Active and Passive Barriers

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 function, considerations of correct manufacturing, installation, and resistance to external 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.

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 described by pressures, to specify the 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). Figure 9 is a summary of passive and active barriers.

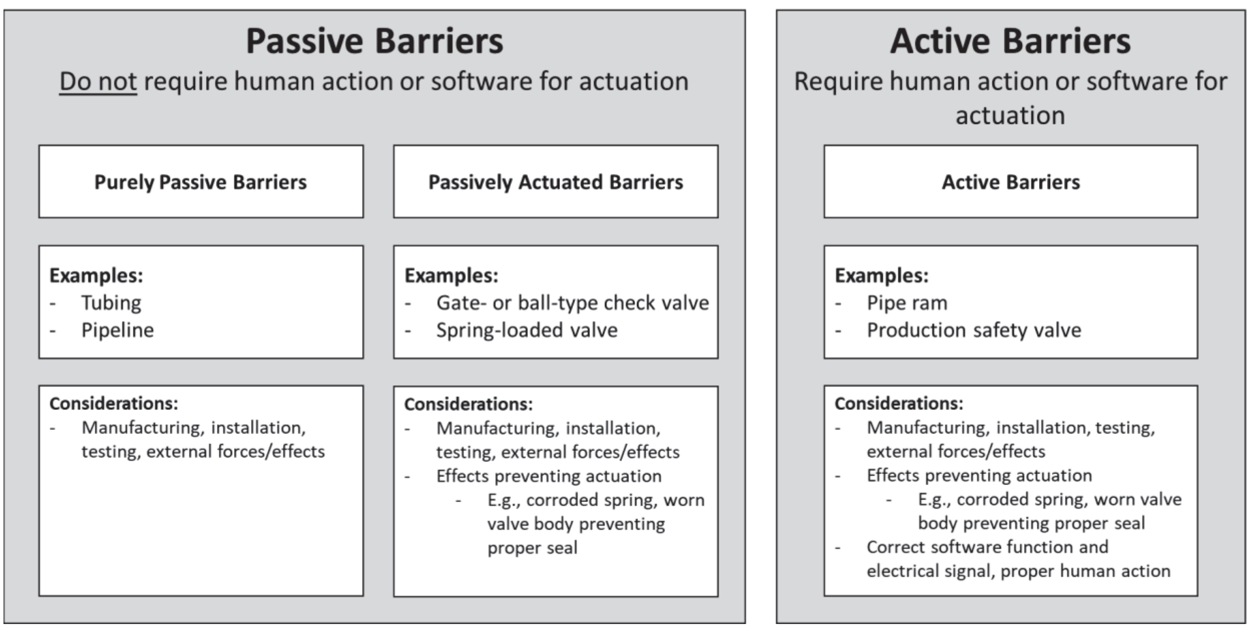

Figure 9: Summary of Active and Passive Barriers.

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. The Argonne Success Path Approach for evaluating multiple physical barriers refers to these actions as four activities—design, construction, operation, and maintenance.

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. 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 multiple physical barriers philosophy focuses on the integrity of the elements always forming the hydrocarbon-sealing envelope. This concept is widely accepted and is most defined by the NORSOK D-010 standard (Standards Norway, 2021). In coiled tubing operations, for example, the equipment components that form a barrier must be able to isolate the full cross-sectional area of the well control stack annulus. This area is typically defined as the area inside the coiled tube, as well as between the outside diameter of the CT string and bore of the well control stack. In addition, the coiled tube itself must maintain its mechanical and pressure-containing integrity to contain the hydrocarbons and hazardous fluids. The analogous philosophy from coiled tubing as described here was carried into this study's discussions on snubbing and HWO.

5.2 Pressure Categories

Pressure categories are a helpful way to evaluate and compartmentalize operational risks. In a way, this is intuitive since higher pressure categories imply a greater consequence of hydrocarbon release 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: Snubbing Pressure Categories

Pressure Category and Barrier Requirement Information			
PC	**MASP Range psig**	**Minimum Stack RWP psig ****	**Min # of PCE Barriers**
0	0	<5,000	NA, not used
1	0-3,500	5,000	2
2	3,501-7,500	10,000	2
3	7,501-12,500	15,000	2

** The minimum RWP of the stack shall be equal to or greater than the MAOP. The are common API ratings.

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 if it is held that way via human intervention, such as deliberate addition of kill fluid, etc.

5.3 Well Control Barrier Elements versus Pressure Control Devices

5.3.1 Continuously Wearing Elements

Consistent with findings during coiled tubing analysis in support of the development of API RP 16ST 2nd Ed., continuously wearing/consumed elements in snubbing, such as stripping rams or annulars would likely be reclassified as continuously degrading pressure control devices rather than well control barriers.

5.3.2 Pressure Control Using Fluids

Weighted fluids are used in snubbing operations to control the well pressure. However, a possible distinction of barriers as mechanical devices that can be left unattended for a prolonged or an indefinite amount of time may call for a special classification of weighted fluids for pressure control. This concept is briefly expanded upon in Section 6.4.1.

5.4 Rental Valves and Frac Valves

As discussed in Section 4.4.2, some snubbing units are stacked up on rental or frac valves, whereby these elements are considered redundant or alternate barriers to primary snubbing barriers, such as a blind ram. However, there does not appear to be consensus on how the reliability of this equipment is verified by the snubbing service provider. Going forward, the API RP 16SB group may benefit from considering a standardized requirement for the verification through certification or other appropriate paperwork and/or testing of these barrier elements.

6. Observations and Findings

6.1 Overall Observations

As stated previously, there was a significant gap in consensus in several areas concerning snubbing and HWO operations. A full Success Path and FMECA process would ordinarily conclude with clear recommendations or demonstrated advantages of a defined barrier configuration and even a possible barrier actuation sequence. While the majority of the FMECA areas assumed redundancy, it was not always clear what the actual redundancy is and how it can be verified, as is the case with rental or frac valves. 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 this study, these risk assessment methods merely tested working assumptions, often made during the study and dialogues. Nevertheless, this study identified several important areas for the API RP 16SB group to consider for the first edition of the document, as presented below.

6.2 Success Path Results

The Success Path analysis was meant to model the consensus-based systems, but instead it served as an exercise to build consensus on certain barriers and operational elements. One of the major areas of debate was about redundancy in power systems. While the rams are driven by accumulators to ensure hydraulic power is delivered rapidly such that the ram can close in a sufficiently short amount of time, there remains a question on what can guarantee sufficient conservatism in the hydraulic system. Possible solutions may include additional accumulators or larger accumulators that allow for greater pre-charge, capable of additional cycles beyond a single close-open-close sequence. The subject matter experts noted this issue to be addressed in the text of API RP 16SB.

6.3 FMECA Results

The FMECA helped to address specific risks related to certain barrier equipment, but because of the time overrun that the team experienced, certain elements were deprioritized from analysis. As described in Section 4.3.1 of this report, general components of rams were grouped together in an attempt to elevate the analysis to a higher level.

However, the FMECA did help to show areas in need of further discussion by the workgroup. Examples include:

- Shear blind ram (SBR) failure, which is reliant upon the sheared segments of pipe above and below the shear-blind ram to be displaced out of the way of creating a proper seal. This failure scenario led to a consequence ranking of 5 as there is not currently a redundant barrier that can replace an SBR. Combined with an occurrence ranking of 2 (“somewhat rare”), this presented a higher risk outcome for some components comprising this barrier.

- Many of the other barrier elements, such as blind ram or pipe ram, and the BHA check valve failures have consequence rankings of 4, meaning many rely on the shear-blind ram for redundancy.
- In configurations where snubbing working stack elements are "replaced" by rental or frac valves and their consequence and occurrence ranking was noted as "NA"

There may be additional barrier or pressure control elements, which had not been identified in this study, that may benefit from further FMECA analyses. The work group may need to further document assumptions and justifications for certain conservative measures recommended in API RP 16SB when it is published.

6.4 Other Observations

Several observations came up in the discussions. The list below represents some of the highlights. A brief but more complete list of these items is presented in Appendix D.

6.4.1 Consensus on Nomenclature and Definitions

Through this exercise, the team of experts made significant breakthroughs on converging on consistent nomenclature. For example, there was a clear need to define pipe rams, blind rams, shear rams, and shear-blind rams as these terms had been used inter-changeably in different ways in the companies' jargon. For example, a short-hand notation for a shear-blind ram was simply "shear," and for a pipe ram that carries a safety function—"safety." There are likely other such terms that the API RP 16SB group will come across and reconcile as they draft the RP.

Notably, the terminology for process safety issues across different well intervention, as well as drilling, operations vary from application to application. For example, the term "well control" can have different meanings in terms of the event that takes place and the warranted response for snubbing versus HWO and may further differ from the actions for coiled tubing, wireline, or drilling activities. This is partly due to the conditions in which these operations take place, as explained below.

Ordinarily snubbing operations take place within wells with surface pressure present. Properly designed and applied snubbing equipment and procedures ensure constant control of pipe forces (pipe light, balance point, and pipe heavy forces) while also controlling surface wellhead pressures. Therefore, the concept of controlling pressure constantly applies, and some may refer to this as "well control" or other terms, like "pressure control," "well management," etc.

On the other hand, HWO operations take place on wells with no pressure at surface. Therefore, in HWO operations, the term "well control" may apply to a situation of responding to an unexpected or sudden influx of pressure from the well, necessitating balancing the well pressure with hydrostatic fluids (circulated or pumped through the workstring or annulus, depending on the situation) and possibly closing the rams (or what some refer to as "designated blowout preventer or BOP," which is another example of terminology issues). In summary, unlike snubbing, HWO operations do not include constant control of well pressures, meaning the term "well control" can be applied differently.

It is additionally worth mentioning that, per discussions with the workgroup, API does not currently require consistency in the definition 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 the gap in common definitions across different oil and gas extraction operations.

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

Support Systems:
- Motive power for hydraulics, electric power, and/or compressed air

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).

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.

6.4.2 Normative References

Several concepts and principles from other standards, specifications, and recommended practice documents were discussed among the API committee experts. 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 16SB 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 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 dated 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 edition November 2018.
- API Spec 16B, *Coiled Tubing, Wireline and Snubbing Well Control Stack Equipment* (In Production)

Additionally, the authors found these references helpful:

- 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.

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

6.4.3 Challenge with Non-Shearables

If a non-shearable object is present in the shear-blind (or any other barrier) upon a power failure affecting the workstring traveling in or out of the well, there is an open question as to how the non-shearable can be moved to enable pressure control. This may present a case for robust redundancy in power systems and/or a configuration that can sustain the ability to shear the workstring and seal across the wellbore. An additional case to consider is the presence of exterior control lines, electric line, slickline, or wireline, in the annulus that can preclude pipe rams from sealing around the workstring.

7. Conclusions

Snubbing and HWO operations are very mature and the expertise that exists within individual organizations or even experts within an organization is invaluable. There appears to be general agreement regarding the fact that snubbing and HWO are highly specialized operations, and the WIWC TG recognizes the need for redundant safety systems to combat the potential associated process safety hazards.

At the same time, when it comes to standardization and governance of the safety best practices in snubbing and HWO operations, there are many areas that still need significant consensus to be reached by the workgroup. For example, while everyone appears to agree that every operation needs a minimum of two barriers, regardless of pressure category, it was not initially clear which barriers can act as redundancies to which other barriers. This made the exercise of building the Success Paths and FMECA components of the study more challenging compared to the study that supported API RP 16ST 2nd Ed development, where the first edition of the RP had already spelled out the proposed minimum stack requirements. Additionally, 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 the future API RP 16SB and in future snubbing and HWO operations. In a way, however, 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 will need to be considered in the development of API RP 16SB.

While these risk analysis tools may not have been utilized to their fullest potential in the course of this study, they helped to document and justify some of the assumptions and rationale that will likely underpin the requirements in API RP 16SB. Success Paths and FMECA that were applied to a limited scope of items in this analysis can be further expanded on by the workgroup as a way to continue documenting their assumptions and simply but effectively showing potential ill effects of lacking conservatism in system design. Success Paths easily point out single points of failure while FMECA simply ranks the risk, which in most cases is higher if 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 snubbing and HWO 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.

A major outcome of this study was the ability to document and justify, through Success Paths and FMECA, any proposed safety and barrier redundancy requirements that may become a part of API RP 16SB once it is published. It may benefit the workgroup to continue to use these tools as a way to track these requirements and the rationale behind them as they continue their work on the Recommended Practice.

An early adoption of definitions and best practice requirements is a prominent case where consensus is needed, and it is recommended that the workgroup continues their hard work with respect to these definitions without losing momentum. Specifically, as the definition of the term "Barrier" continues to vary from operation to operation, it is recommended that BSEE and industry continue to work together to determine a common definition of a barrier.

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 6.3, the FMECA was able to show, in some instances, the elevated risks of systems with insufficient redundancy in power supply systems. In general, redundancy and diversity of power supply appears as a sensible way to evolve snubbing and HWO operations safety, and it is recommended that the workgroup pay attention to findings related to sufficient diversity as they continue to develop API RP 16SB.

As discussed in sections 5.4 and 6.3, there are snubbing configurations where snubbing working stack elements that were "replaced" by rental or frac valves. It is recommended that the workgroup consider providing clear recommendations for the use of these elements as part of API RP 16SB.

Because many aspects in snubbing and HWO operations appear to have significantly evolved over time from company to company, training to accompany the publication or pre-publication of API RP 16SB to educate the many stakeholders may be warranted. This training should include a multitude of items, ranging from something as elementary as nomenclature and terminology to more nuanced, such as barrier definition and associated risks.

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 16SB becomes published. This exercise may help BSEE in technical decision-making in potential future efforts of incorporating the RP by reference.

In possible future Success Path and FMECA analyses, it will be helpful if the minimum rigup configurations are already agreed upon or proposed configurations are hypothesized prior to analysis, such that the analysis can be used as a tool to confirm or give basis to recommended modifications for certain safety features. Having this starting point can significantly improve the efficiency of the Success Path and FMECA analyses. The workgroup may consider the configurations presented in section 4.4 as a starting point.

Additional recommendations 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 equipment that may benefit a more complete risk analysis.
- More detailed level of FMECA that focuses on components of each barrier or pressure control component that can underpin or help justify the decision-making in the requirements in 16SB when it is published.
- Potential consideration for proposing a standardized verification instrument for rental or frac valves, or other equipment that is relied upon for safety but may be outside of the scope of snubbing equipment.
- Whether or not additional barriers (and how many) should be recommended for H2S service to address potential issues with the gas's toxic and corrosive properties.
- Some shear-blind rams have been reported to not function properly when under pressure from below. If true, there needs to be a remedy or definition of limits especially if this is a limitation when the pipe is light from wellbore pressure forces and shearing is underway.
- If a non-shearable is present in the shear-blind during hydraulic power failure, there is an open question as to whether the pipe (tubing) can be moved axially to enable shearing. This depends on the control systems including whether the jack hydraulic power is coming for a common source with the barrier and accumulator systems.

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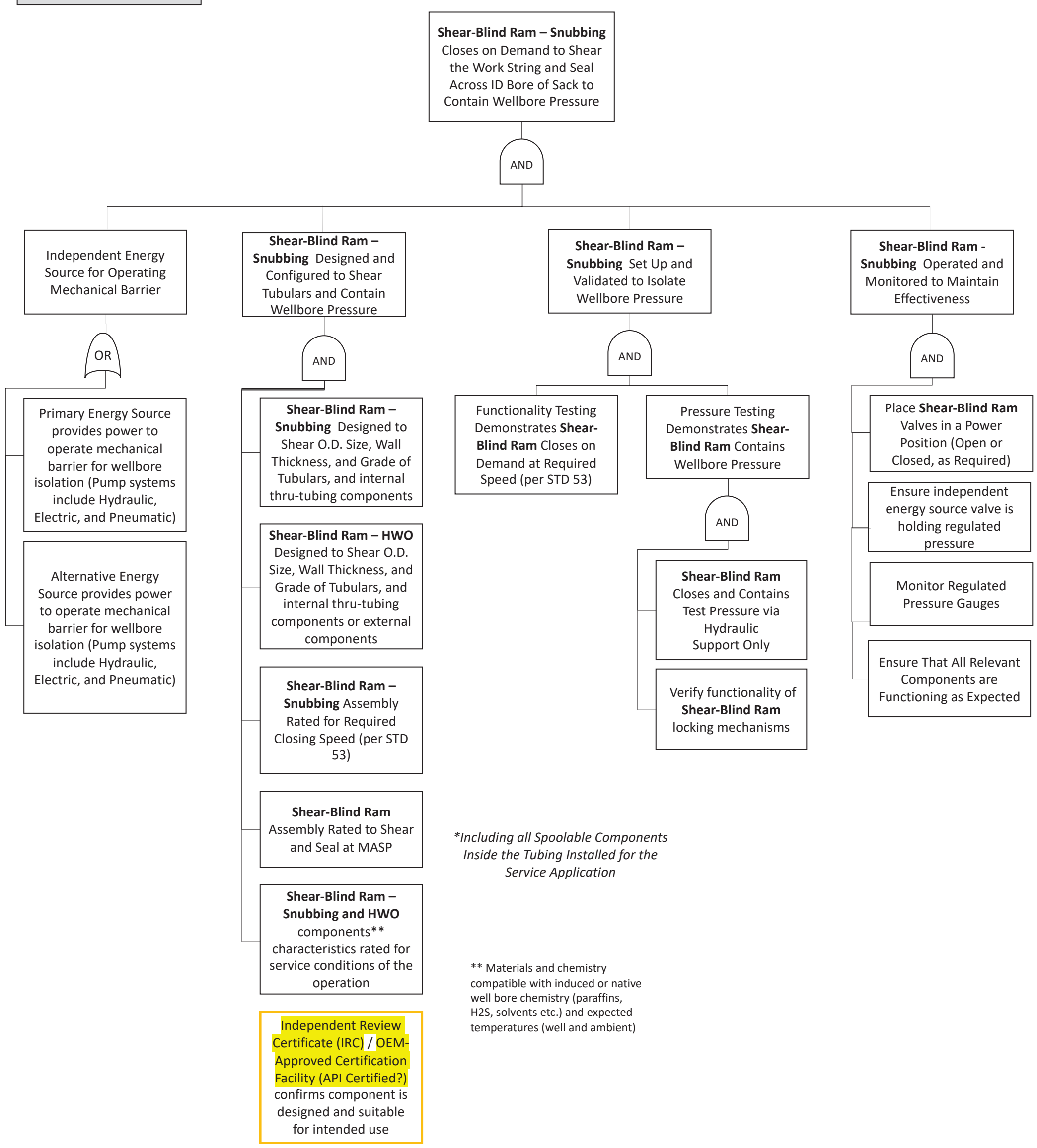
Appendix A. Snubbing Operations Success Paths

The completed set of Success Paths for snubbing operations is presented below.

Physical Barrier Element: Working Shear-Blind Ram – Snubbing

Applicability	**Snubbing Operations**
Critical Safety Function	
Success Path	

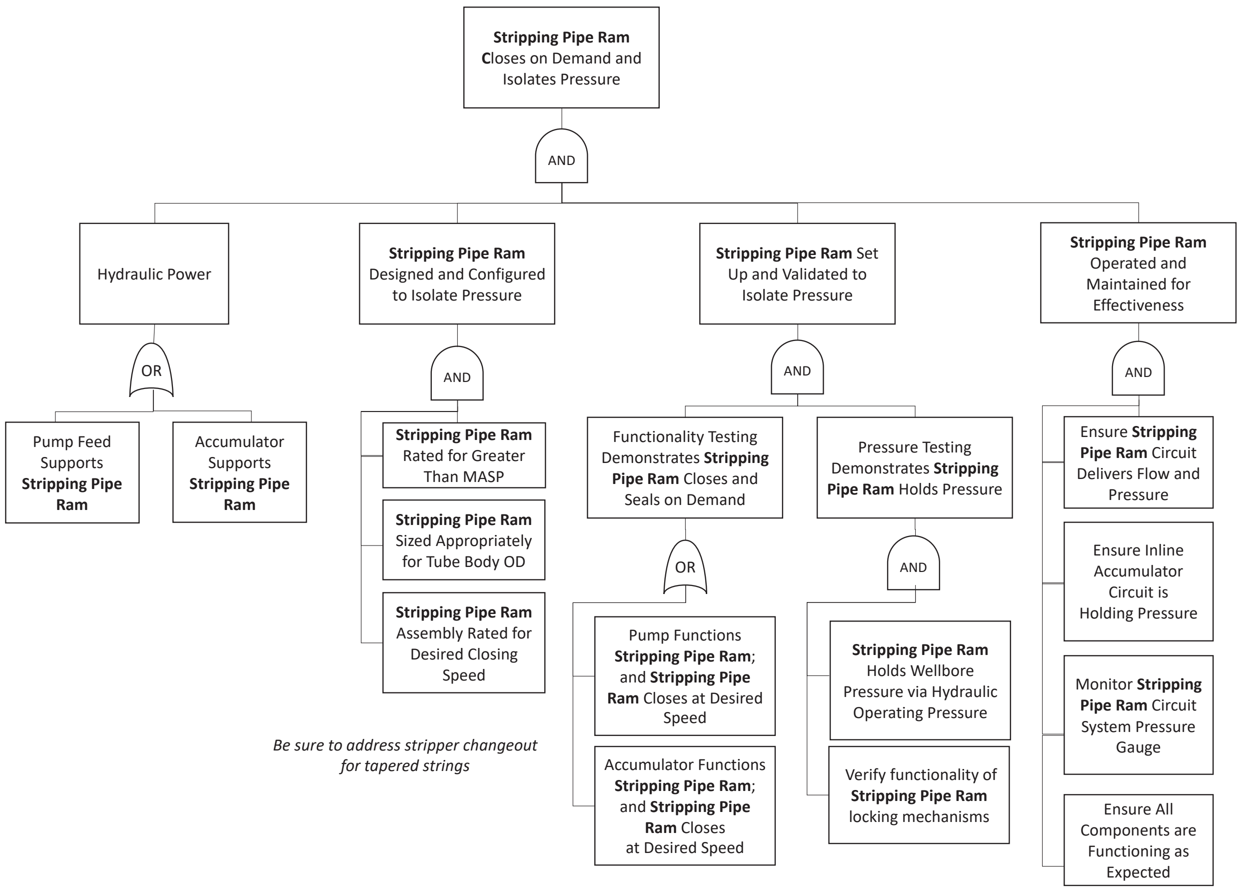


Alternate Success Path	**Blind Ram and Shear Ram; Flow Control Components; Dedicated SBR**
Critical Support Systems	**Hydraulic power to rams**
Threat Scenarios	**Shear blade sizing and sufficient hydraulic pressure must be confirmed.**

Note that highlighted areas, including those marked in different colors, in the Success Path were left in to indicate areas that the workgroup is encouraged to revisit as they make progress on drafting API RP 16SB

Physical Barrier Element: Stripping - Pipe Ram

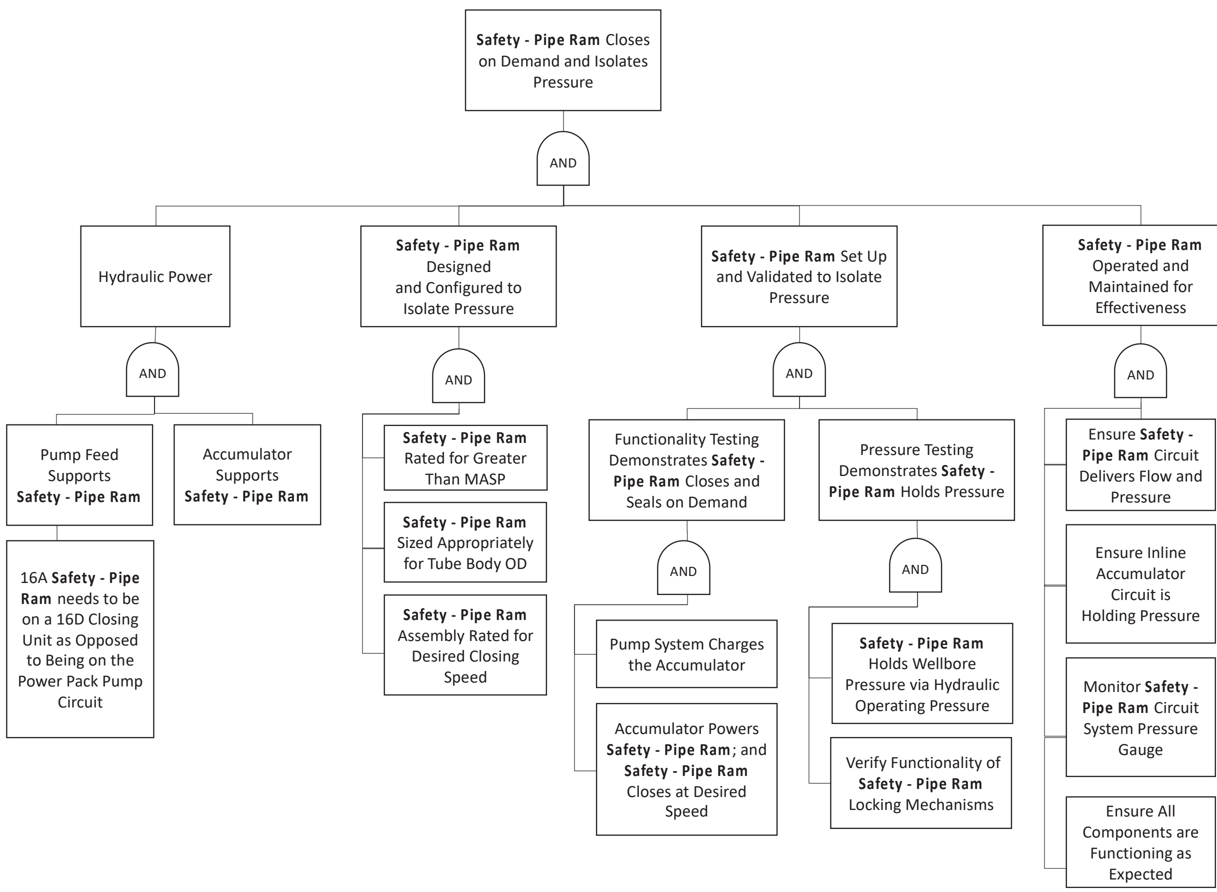
Applicability	Snubbing Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear-Blind Ram, Additional Pipe Ram(s)
Critical Support Systems	Hydraulic Power
Threat Scenarios	Element wear or damage can be a factor.

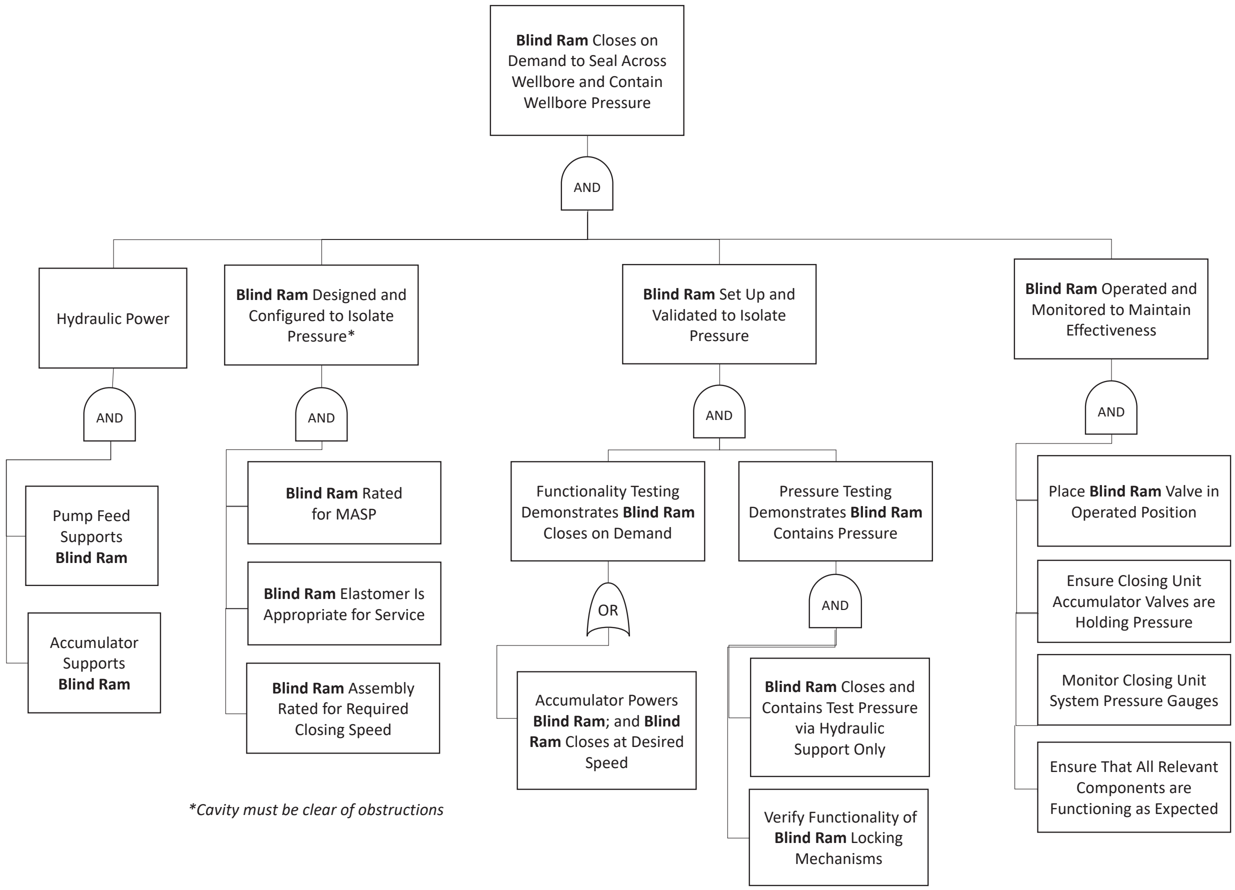
Physical Barrier Element: Safety - Pipe Ram

Applicability	Snubbing Operations
Critical Safety Function	
Success Path	



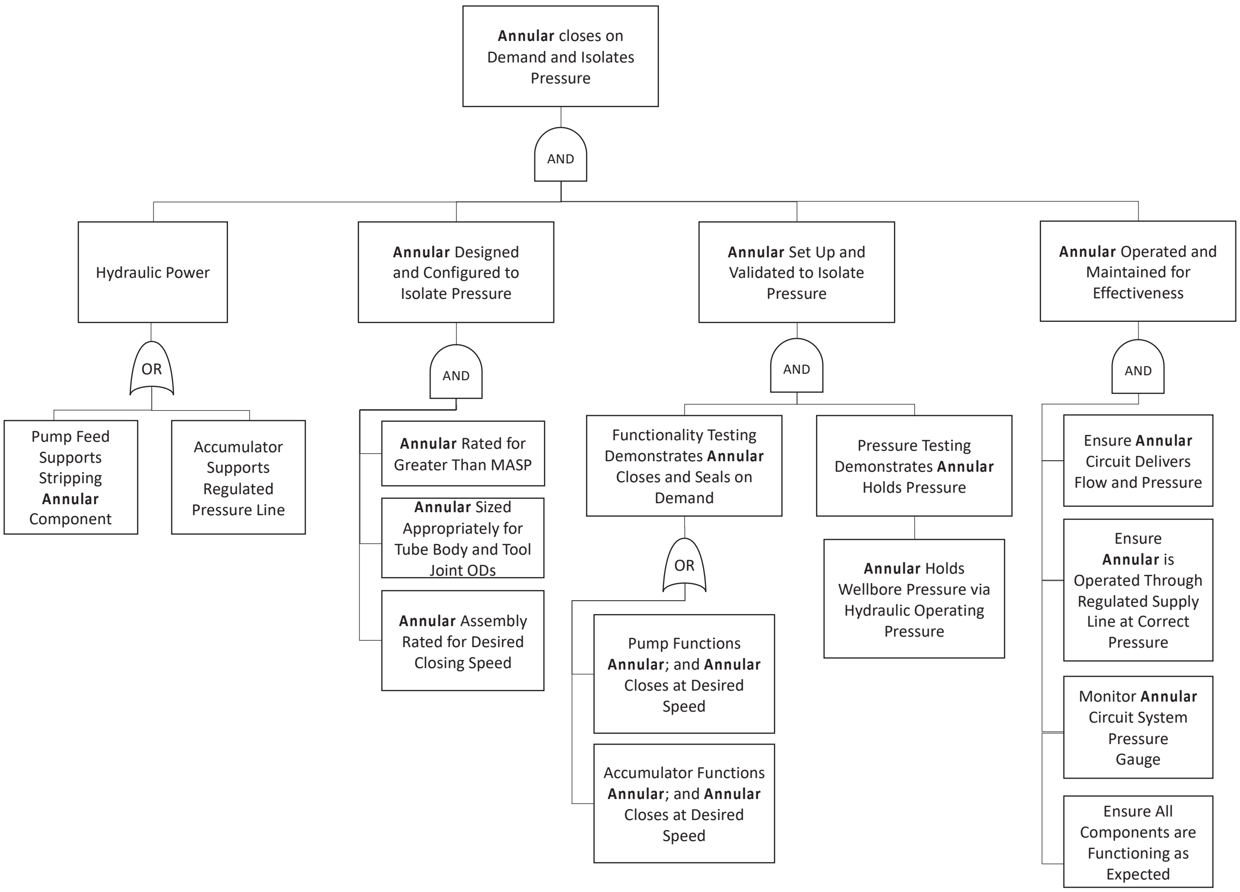
Alternate Success Path	Shear-Blind Ram, Additional Pipe Ram(s)
Critical Support Systems	Hydraulic Power
Threat Scenarios	Element wear or damage can be a factor.

Physical Barrier Element: Blind Ram	
Applicability	**Snubbing Operations**
Critical Safety Function	
Success Path	



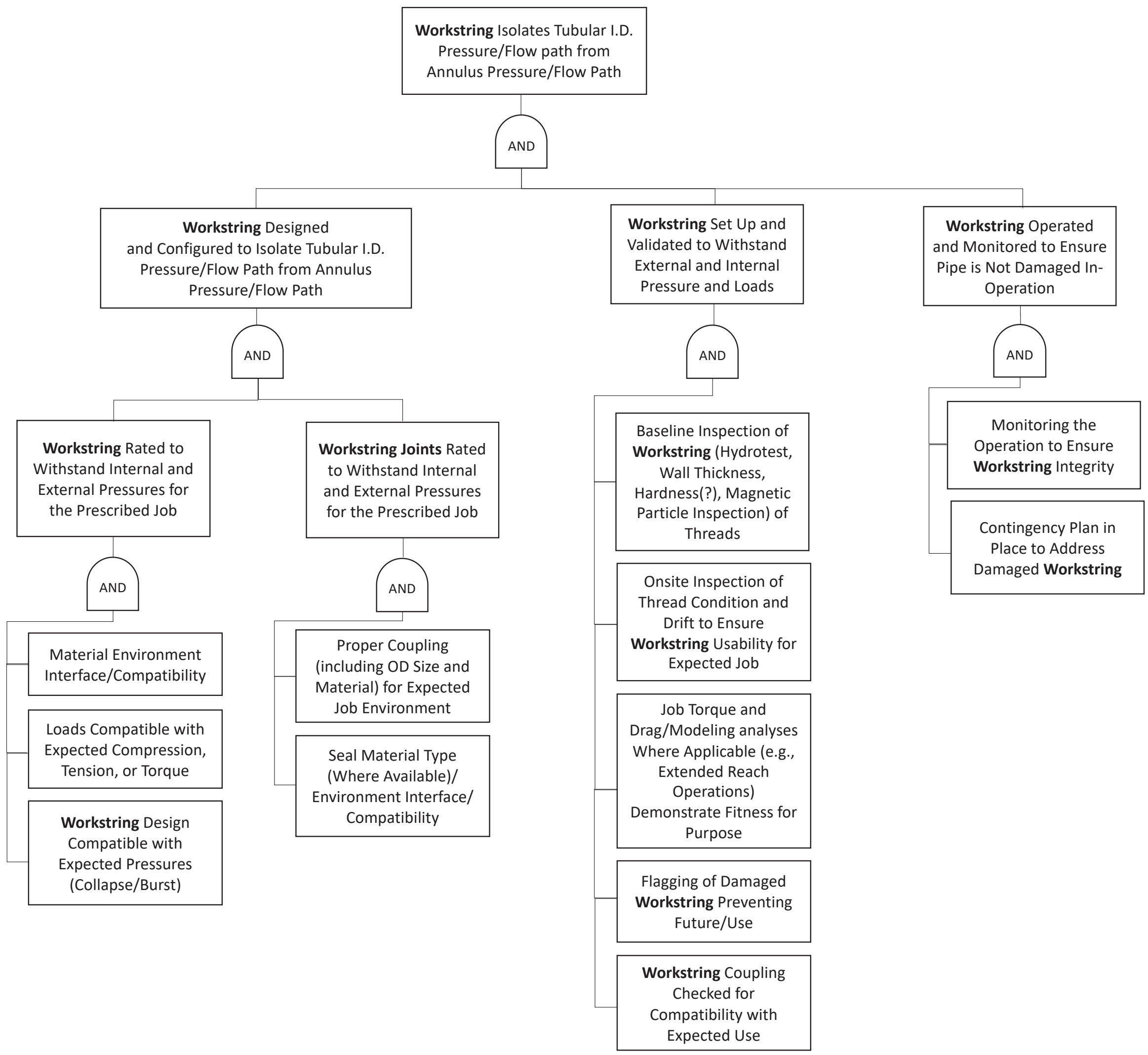
Alternate Success Path	**Shear-Blind Ram**
Critical Support Systems	**Hydraulic power to rams and ability to ensure tubulars are removed from Blind Ram cavity position**
Threat Scenarios	**Sequence of Shear Ram closure followed by inability to Clear the ID bore across the blind ram after shear ram closing.**

Physical Barrier Element: Annular	
Applicability	Snubbing Operations
Critical Safety Function	
Success Path	



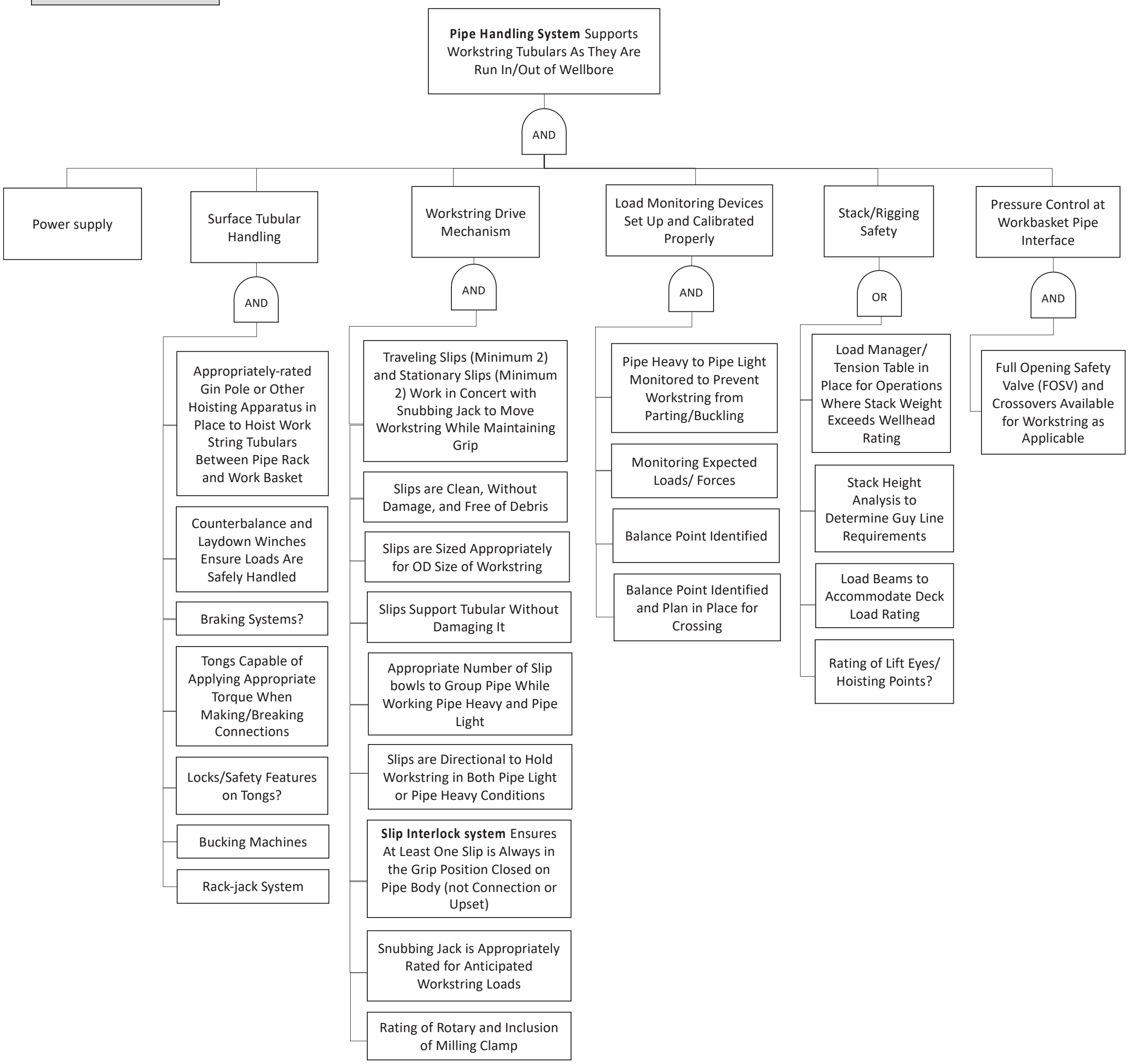
Alternate Success Path	Shear-Blind Ram, Additional Pipe Ram(s)
Critical Support Systems	Hydraulic Power
Threat Scenarios	Element wear or damage can be a factor.

Physical Barrier Element: Workstring/Tubular	
Applicability	Snubbing Operations
Critical Safety Function	
Success Path	



Alternate Success Path	Shear Ram and Blind Ram or Shear-Blind Ram
Critical Support Systems	Pipe Handling: Slip Interlock set to prevent buckling or parting pipe handling, winches; workstring stab-in guide system, counter-balance valves (i.e., braking systems) for controlling jack; tongs Workstring backflow protection system, where applicable; pipe dope supports joints
Threat Scenarios	Surface defects, service fatigue, mechanical damage, correct joints

Critical Support Element: Pipe Handling	
Applicability	Snubbing Operations
Critical Safety Function	
Success Path	



Alternate Success Path	--
Critical Support Systems	Slip Interlock Support/Stabilization Required (Crane, Support Stand, Lateral Guy Wires, Derrick) Power Pack Hydraulic System Required to Enable the Slip Interlock
Threat Scenarios	The Slip Interlock can cause damage to the Tubular(e.g., grip/wear marks, scratches, gouges, misalignments) during operations, degrading Tubular's life/survivability.

Appendix B. FMECA 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
3	System disabled, no direct impact on barrier, normal operations suspended
3.5	System disabled/degraded with barrier degraded but operational
4	Barrier disabled, but alternative barrier remains
5	Barrier(s) disabled, no barriers remaining

System = component or device being assessed

Occurrence Ranking		
Rank	**Frequency WE ARE USING THIS ONE**	**Probability (Estimated Occurrence Post-Test)**
1	Very rare/unheard of	1 in 100
2	Somewhat rare	1 in 50
3	Somewhat common	1 in 25
4	Very common/frequent	1 in 10

Consequence Ranking Multiplier			
PC	**Health and Employee Safety**	**Environment**	**Assets/Facility**
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

Pressure Category and Barrier Requirement Information			
PC	MASP Range psig	Minimum Stack RWP psig **	Min # of PCE Barriers
0	0*	<5,000	NA, not used
1	0-3,500	5,000	2
2	3,501-7,500	10,000	2
3	7,501-12,000	15,000	2

* PC-0 applies to those wells demonstrated as incapable of unassisted flow to surface (based on local regulatory agency guidelines)

** The minimum RWP of the stack shall be equal to or greater than the MAOP

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: Barrier					
		Occurrence Ranking			
		1	2	3	4
Consequence Ranking	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	3.5	3.5	7	10.5	14
	4	4	8	12	16
	5	5	10	15	20

Low	Medium	High

Risk Ranking: Health and Employee Safety

Consequence Ranking		Occurrence Ranking			
		1	2	3	4
	0.1	0.1	0.2	0.3	0.4
	0.2	0.2	0.4	0.6	0.8
	0.3	0.3	0.6	0.9	1.2
	0.35	0.35	0.7	1.05	1.4
	0.4	0.4	0.8	1.2	1.6
	0.5	0.5	1	1.5	2
	0.8	0.8	1.6	2.4	3.2
	1	1	2	3	4
	1.5	1.5	3	4.5	6
	1.6	1.6	3.2	4.8	6.4
	1.75	1.75	3.5	5.25	7
	2	2	4	6	8
	2.4	2.4	4.8	7.2	9.6
	2.5	2.5	5	7.5	10
	2.8	2.8	5.6	8.4	11.2
	3.2	3.2	6.4	9.6	12.8
	4	4	8	12	16

Risk Ranking: Environment

Consequence Ranking	Occurrence Ranking 1	2	3	4
0.6	0.6	1.2	1.8	2.4
0.99	0.99	1.98	2.97	3.96
1.2	1.2	2.4	3.6	4.8
1.8	1.8	3.6	5.4	7.2
1.98	1.98	3.96	5.94	7.92
2.1	2.1	4.2	6.3	8.4
2.4	2.4	4.8	7.2	9.6
2.97	2.97	5.94	8.91	11.88
3	3	6	9	12
3.465	3.465	6.93	10.40	13.86
3.96	3.96	7.92	11.88	15.84
4.95	4.95	9.9	14.85	19.8

Risk Ranking: Assets/Facility

Consequence Ranking	Occurrence Ranking 1	2	3	4
1.2	1.2	2.4	3.6	4.8
2	2	4	6	8
2.4	2.4	4.8	7.2	9.6
3.6	3.6	7.2	10.8	14.4
4	4	8	12	16
4.2	4.2	8.4	12.6	16.8
4.8	4.8	9.6	14.4	19.2
6	6	12	18	24
7	7	14	21	28
8	8	16	24	32
10	10	20	30	40

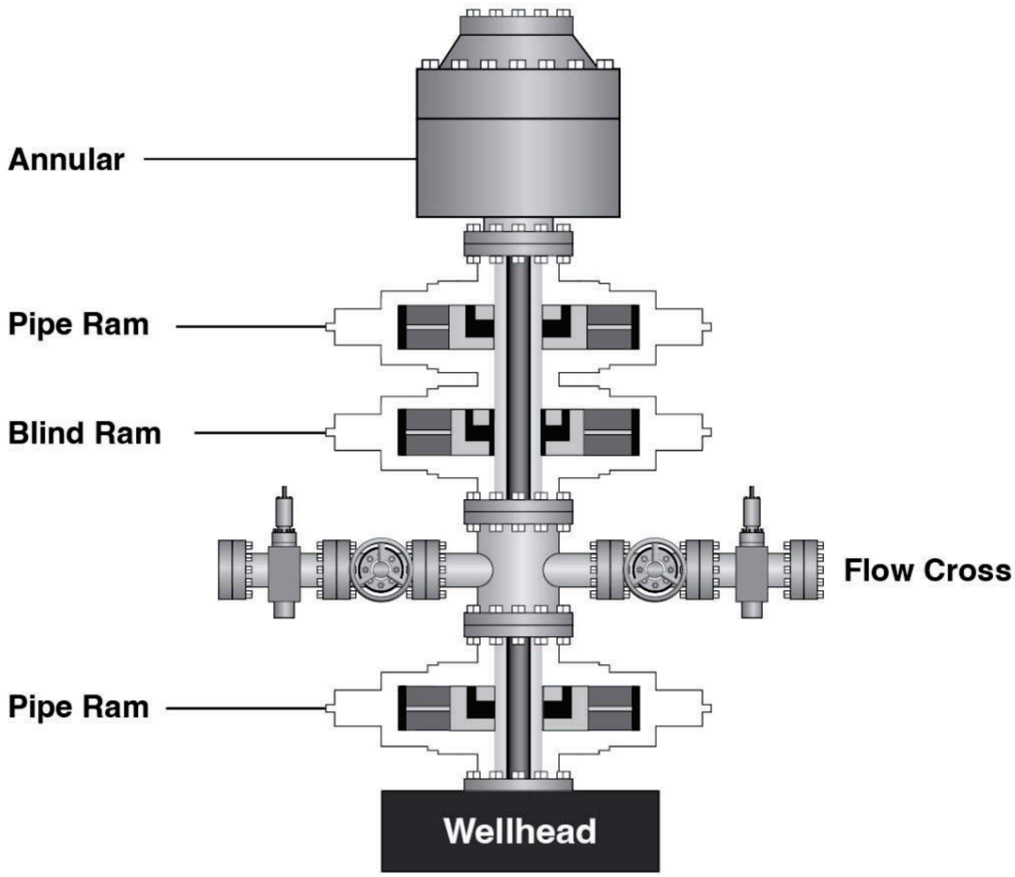
An example FMECA sheet for the analysis of Shear Blind Ram components is below.

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	Operation (Rig Assist or Stand-Alone)	Configuration ID (or name)	Pressure Category No.	Consequence Ranking (Barrier)	Consequence Ranking (Health & Empl. Safety)	Consequence Ranking (Environment)	Consequence Ranking (Assets/ Facility)	Occurrence Ranking	Risk Ranking (Barrier)	Risk Ranking (Health & Employee Safety	Risk Ranking (Environment)	Risk Ranking (Assets/Facility)	Consequence Notes	Occurrence Notes	Detection Mechanisms	Prevention Controls	Other Notes
Shear -Blind Ram	Ram Hydra ulic Seals	Hydraulic operating system	Leak hydraulic operating fluid	Internal (most frequently) or possibly external leak	Shear-blind ram ineffective	Wear and tear/damage of seal. Damage/corrosi on.	Rig assist	RA Simple	PC: 1	5	0.5	3	6	2	10	1	6	12	No redundancy to SBR	May need further discussion	Observed leakage	Performance qualification testing(??) and maintenance; possibly install a redundant SBR (with totally redundant accumulator bank for each SBR)	
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Mini	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Prod Tree	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Frac Tree	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
							Stand-alone	Stand-alone	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
Shear -Blind Ram	Ram Wellb ore Seal	Ram block elastomer s	Leak path across ram/work string interface	Cannot isolate wellbore pressure	Shear-blind ram ineffective	Wear and tear/damage of seal. Inadequate or loss of hydraulic operating pressure. Debris across Pipe ram/ workstring interface.	Rig assist	RA Simple	PC: 1	5	0.5	3	6	2	10	1	6	12	No redundancy to SBR	May need further discussion	Observed leakage	Performance qualification testing(??) and maintenance; possibly install a redundant SBR (with totally redundant accumulator bank for each SBR)	
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Mini	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Prod Tree	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Frac Tree	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
							Stand-alone	Stand-alone	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					

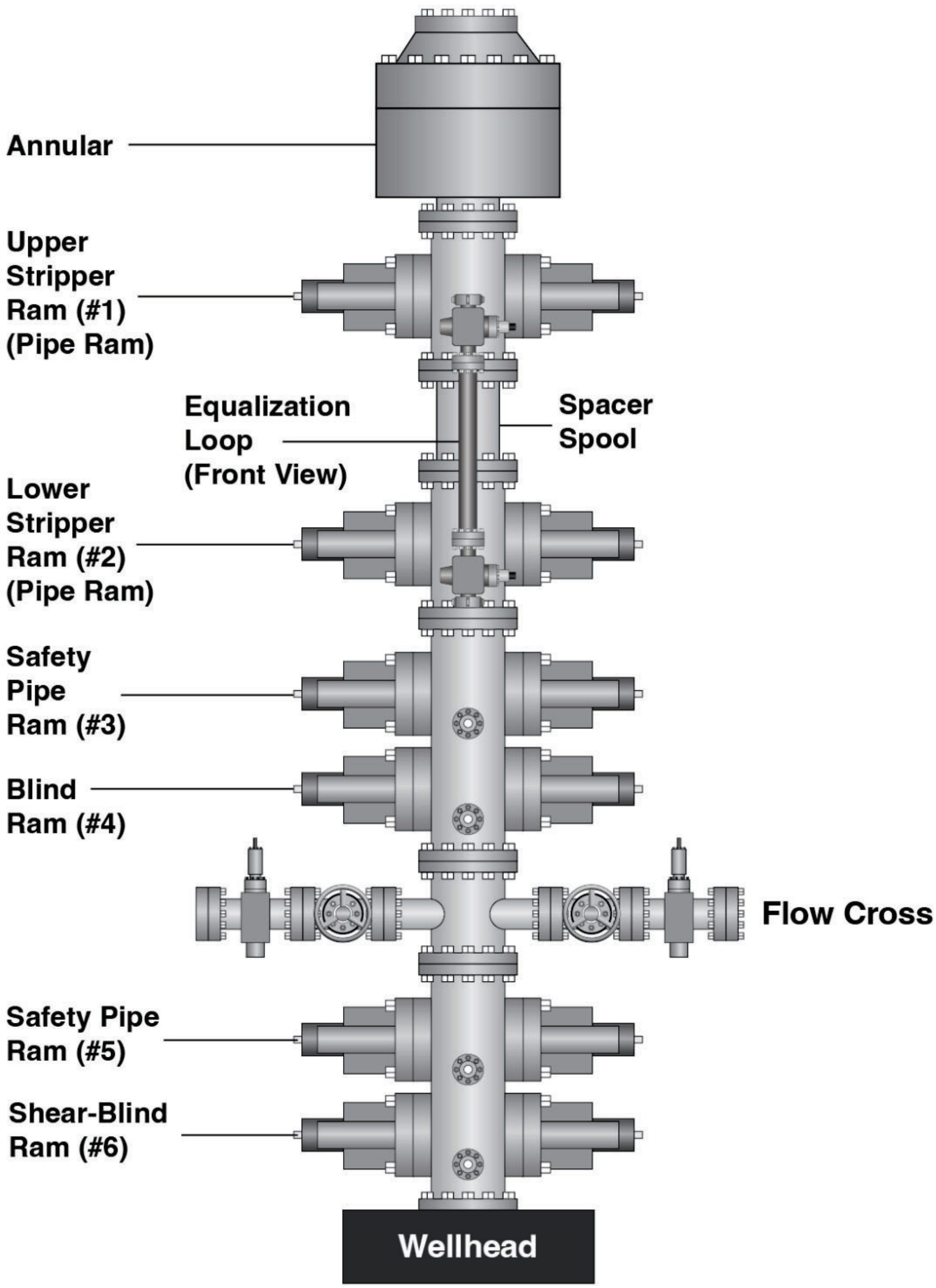
Barrier/Pressure Control element	Component	Component Function	Failure Mode	Local Consequence of Failure	Consequence of Failure on Barrier(s)	Cause(s)/ Mechanism(s) of Failure	Operation (Rig Assist or Stand-Alone)	Configuration ID (or name)	Pressure Category No.	Consequence Ranking (Barrier)	Consequence Ranking (Health & Empl. Safety)	Consequence Ranking (Environment)	Consequence Ranking (Assets/ Facility)	Occurrence Ranking	Risk Ranking (Barrier)	Risk Ranking (Health & Employee Safety	Risk Ranking (Environment)	Risk Ranking (Assets/Facility)	Consequence Notes	Occurrence Notes	Detection Mechanisms	Prevention Controls	Other Notes
Shear -Blind Ram	Body/ Housing	Ram body	Leak path across ram body, flange connections, or welded outlets	Cannot isolate wellbore pressure	Shear-blind ram ineffective	Corrosion, wear and tear, mechanical damage.	Rig assist	RA Simple	PC: 1	5	0.5	3	6	2	10	1	6	12	No redundancy to SBR	May need further discussion	Observed leakage	Performance qualification testing(??) and maintenance; possibly install a redundant SBR (with totally redundant accumulator bank for each SBR)	
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Mini	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Prod Tree	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
								RA Frac Tree	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
							Stand-alone	Stand-alone	PC: 1	5	0.5	3	6	2	10	1	6	12					
									PC: 2	5	2.5	3	6	2	10	5	6	12					
									PC: 3	5	4	4.95	10	2	10	8	9.9	20					
Shear -Blind Ram	Shearing Element	Shears pipe to make way for wellbore sealing element	7ncomplete shear	Cannot shear to isolate wellbore pressure	Shear-blind ram ineffective in pressure sealing	Corrosion, wear and tear, mechanical damage.	Rig assist	RA Simple	PC: 1	5	0.5	3	6	1	5	0.5	3	6	No redundancy to SBR	7Incomp-lete of 1 given there has been a qualifi-caiton test	7Incomp-lete closure	Performance qualification testing(??) and maintenance; possibly install a redundant SBR (with totally redundant accumulator bank for each SBR)	
									PC: 2	5	2.5	3	6	1	5	2.5	3	6					
									PC: 3	5	4	4.95	10	1	5	4	4.95	10					
								RA Mini	PC: 1	5	0.5	3	6	1	5	0.5	3	6					
									PC: 2	5	2.5	3	6	1	5	2.5	3	6					
									PC: 3	5	4	4.95	10	1	5	4	4.95	10					
								RA Prod Tree	PC: 1	5	0.5	3	6	1	5	0.5	3	6					
									PC: 2	5	2.5	3	6	1	5	2.5	3	6					
									PC: 3	5	4	4.95	10	1	5	4	4.95	10					
								RA Frac Tree	PC: 1	5	0.5	3	6	1	5	0.5	3	6					
									PC: 2	5	2.5	3	6	1	5	2.5	3	6					
									PC: 3	5	4	4.95	10	1	5	4	4.95	10					
							Stand-alone	Stand-alone	PC: 1	5	0.5	3	6	1	5	0.5	3	6					
									PC: 2	5	2.5	3	6	1	5	2.5	3	6					
									PC: 3	5	4	4.95	10	1	5	4	4.95	10					

Appendix C. HWO and Snubbing Stack Minimum Requirement Diagrams

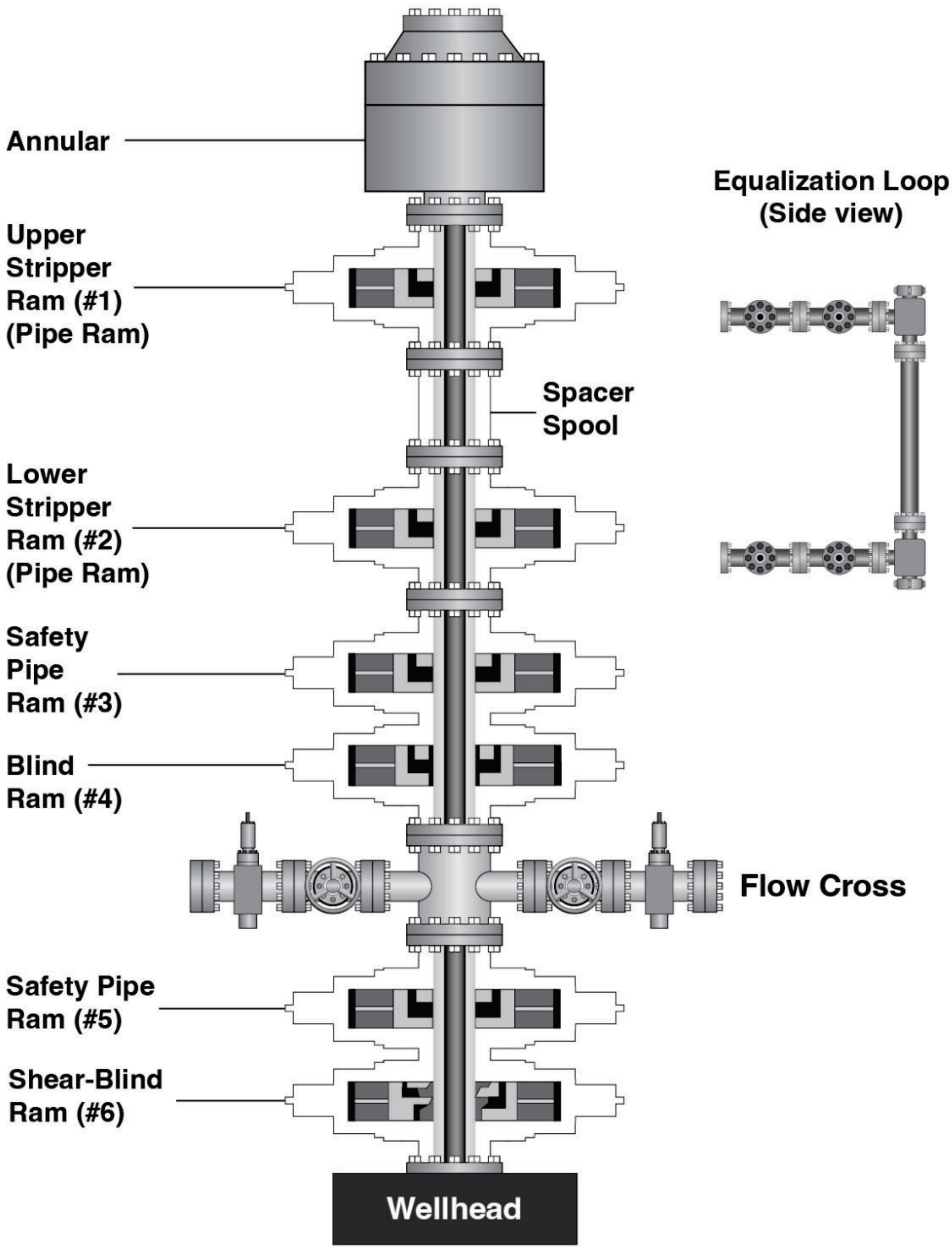
Hydraulic Workover (HWO)



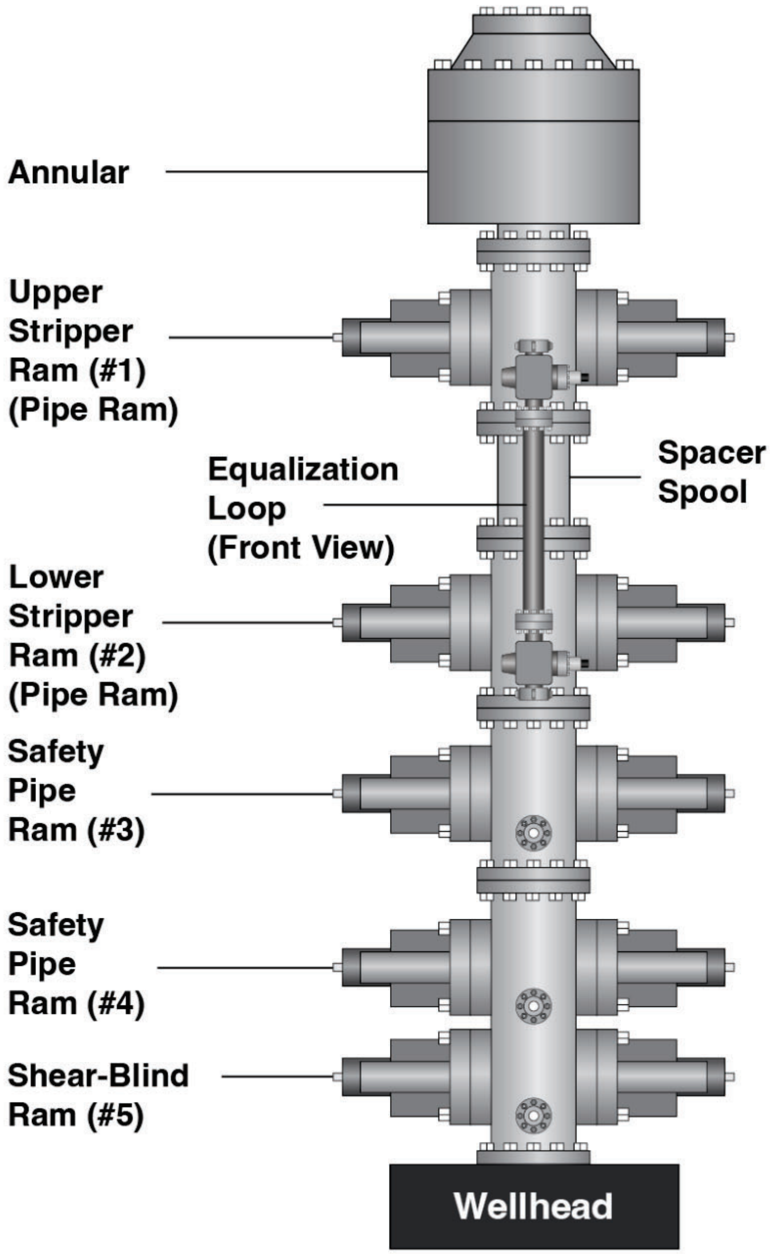
Rig-Assist, Six Ram Design for Simple BHA



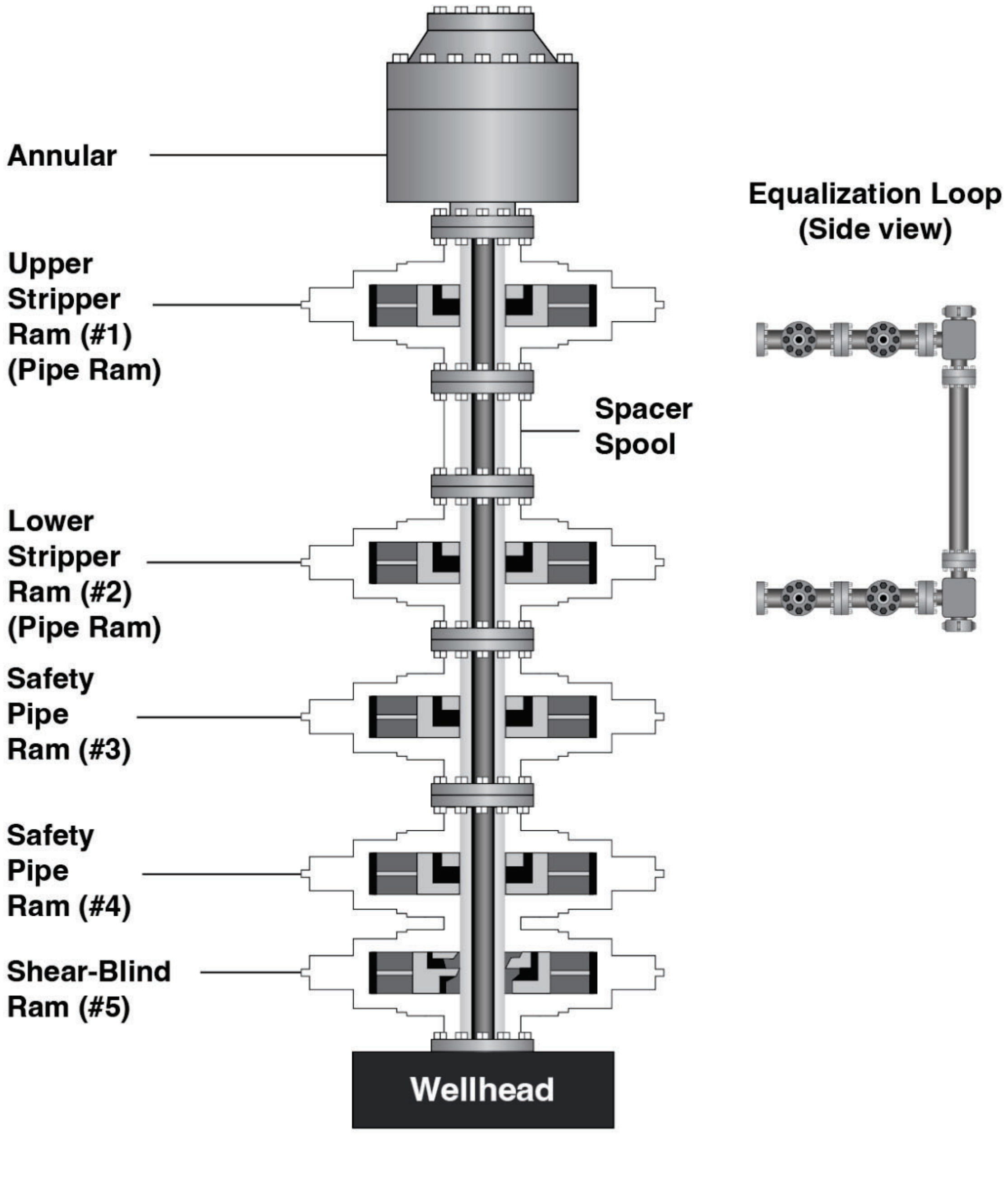
Rig-Assist, Six Ram Design for Simple BHA

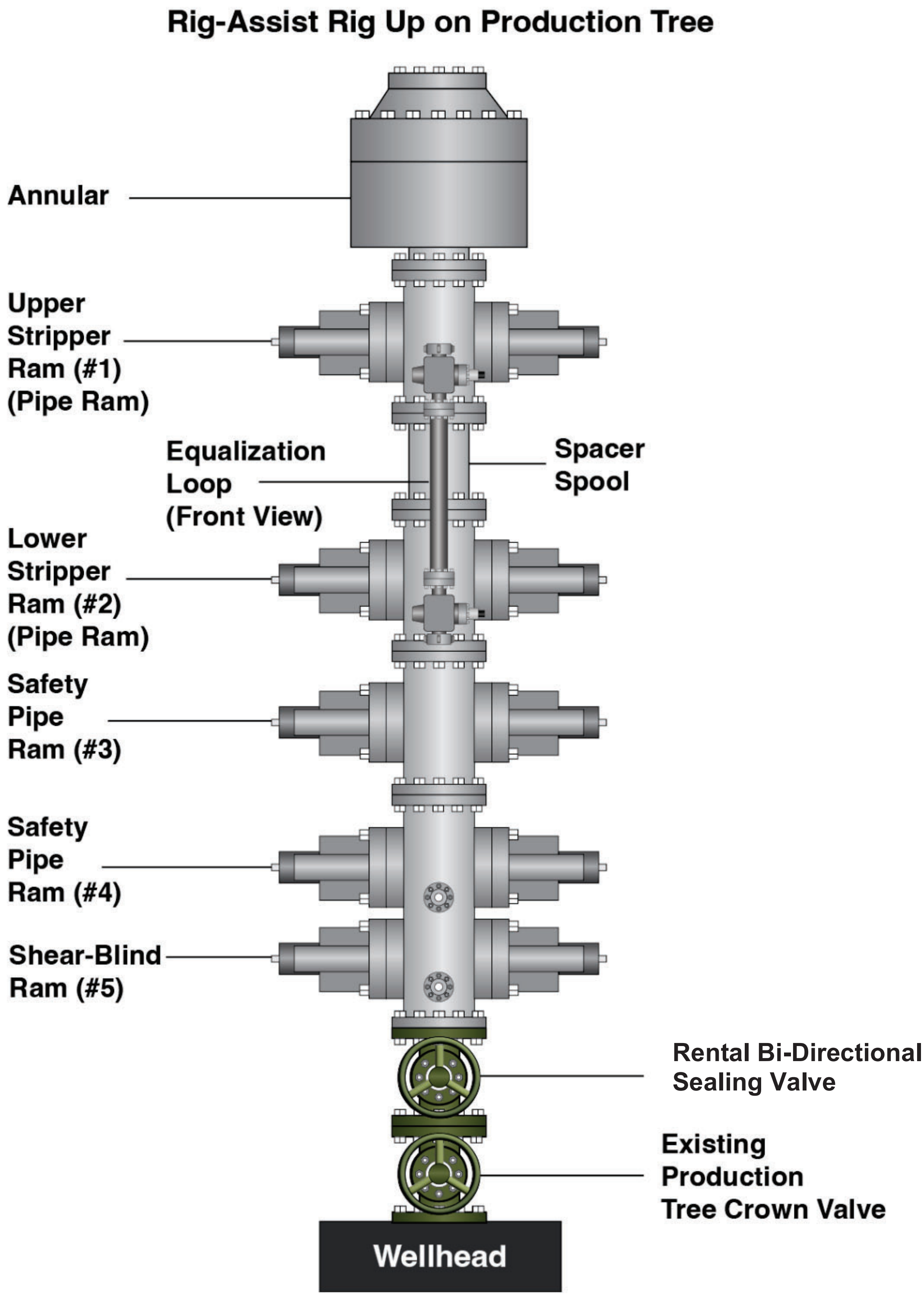


Rig-Assist, Five Ram Design for Simple BHA for "Mini" Unit

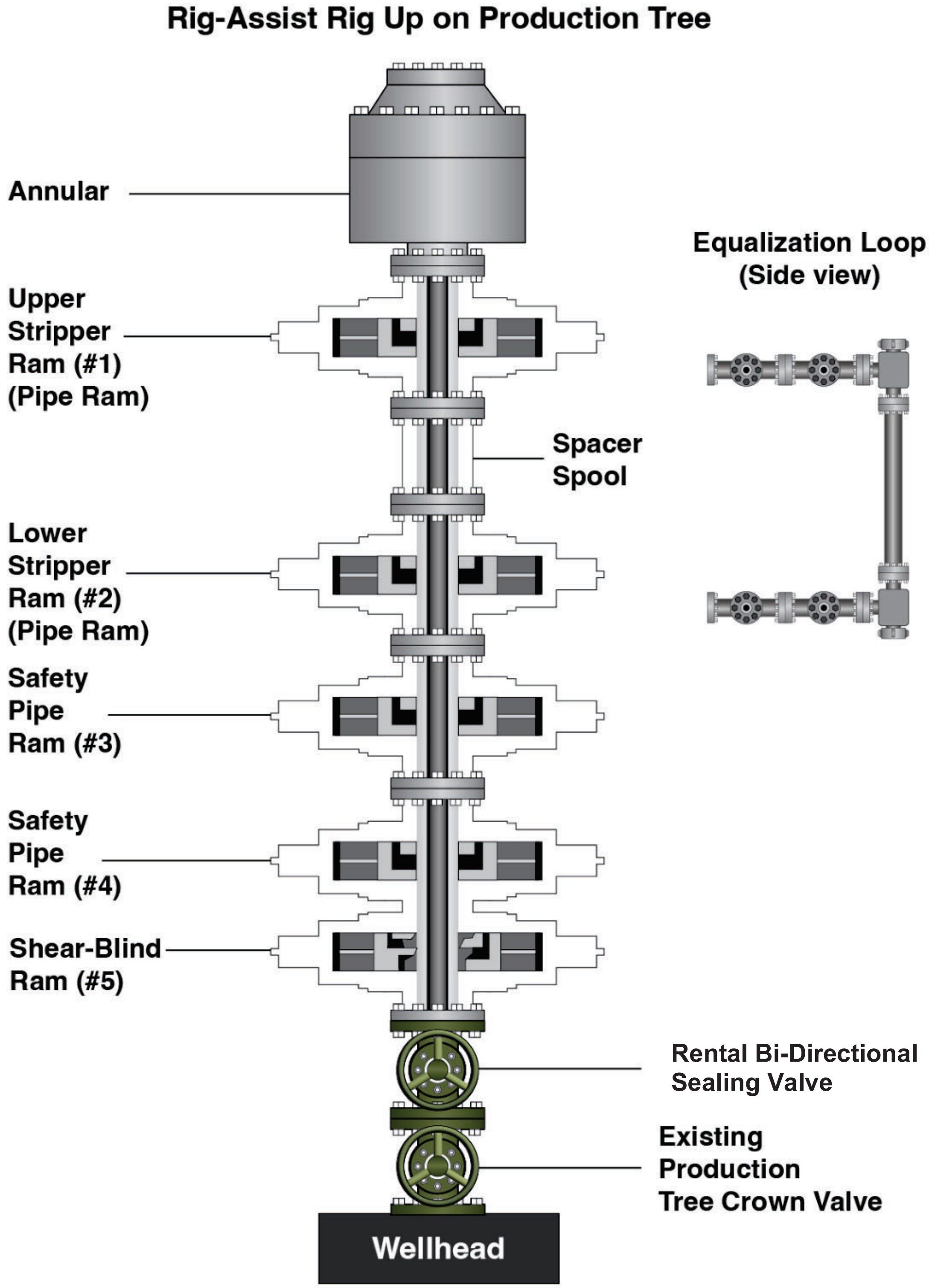


Rig-Assist, Five Ram Design for Simple BHA for "Mini" Unit



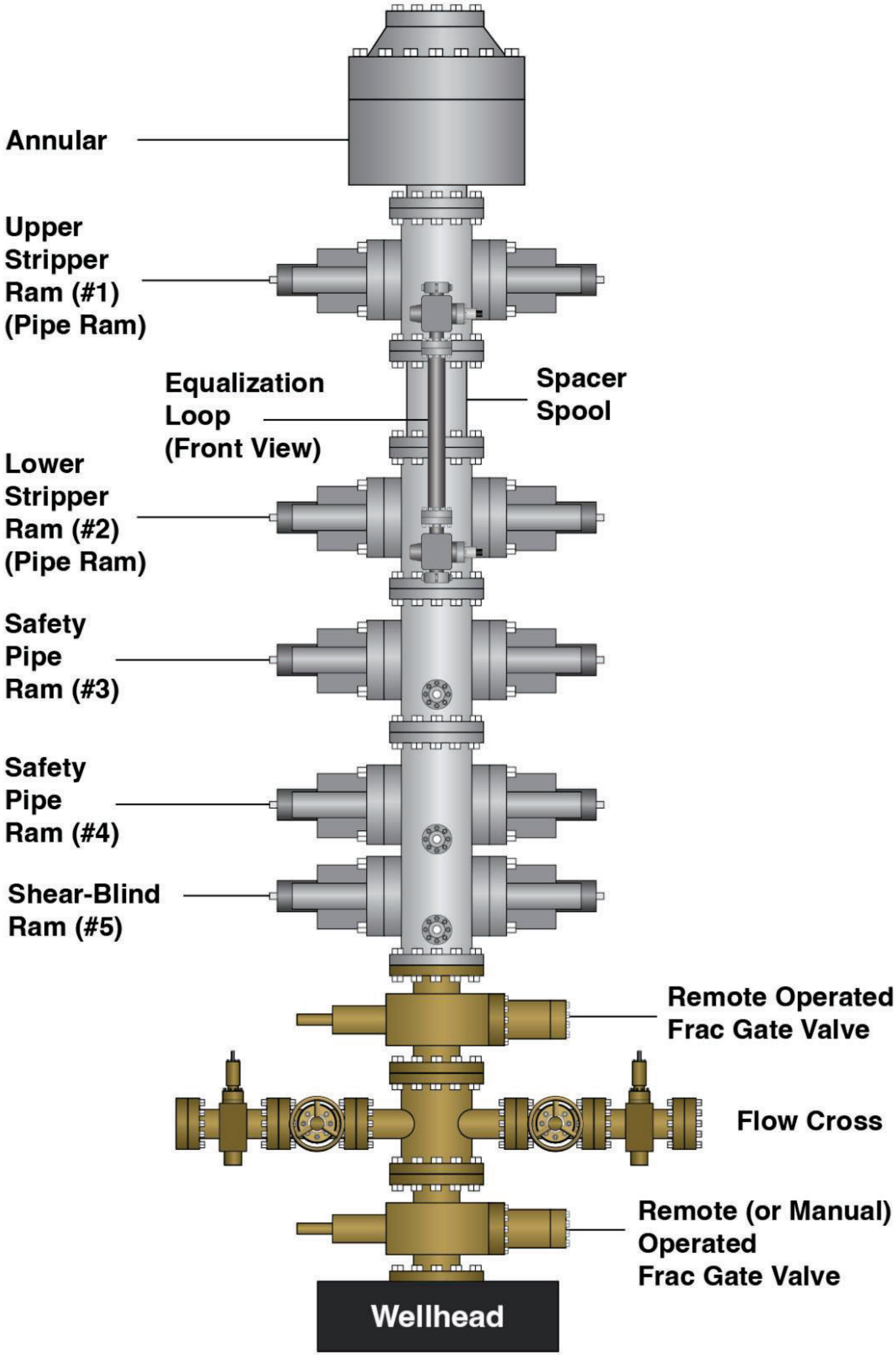


In current practice, the rental valve shown below the shear-blind ram ("#5") in this figure is typically hydraulically operated or can sometimes be manual. Note that there are several other tree components between the tree crown valve and the wellhead.

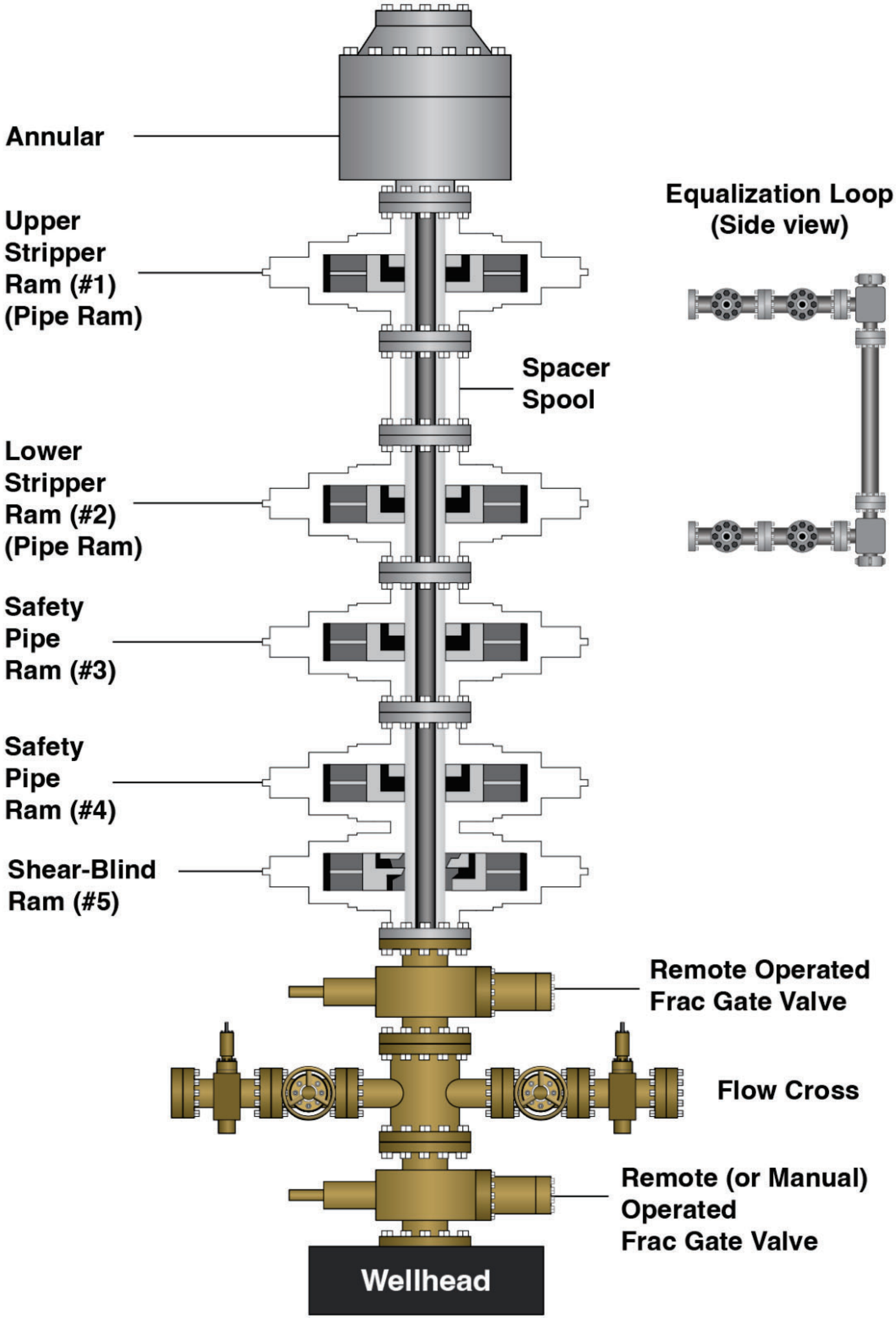


In current practice, the rental valve shown below the shear-blind ram ("#5") in this figure is typically hydraulically operated or can sometimes be manual. Note that there are several other tree components between the tree crown valve and the wellhead.

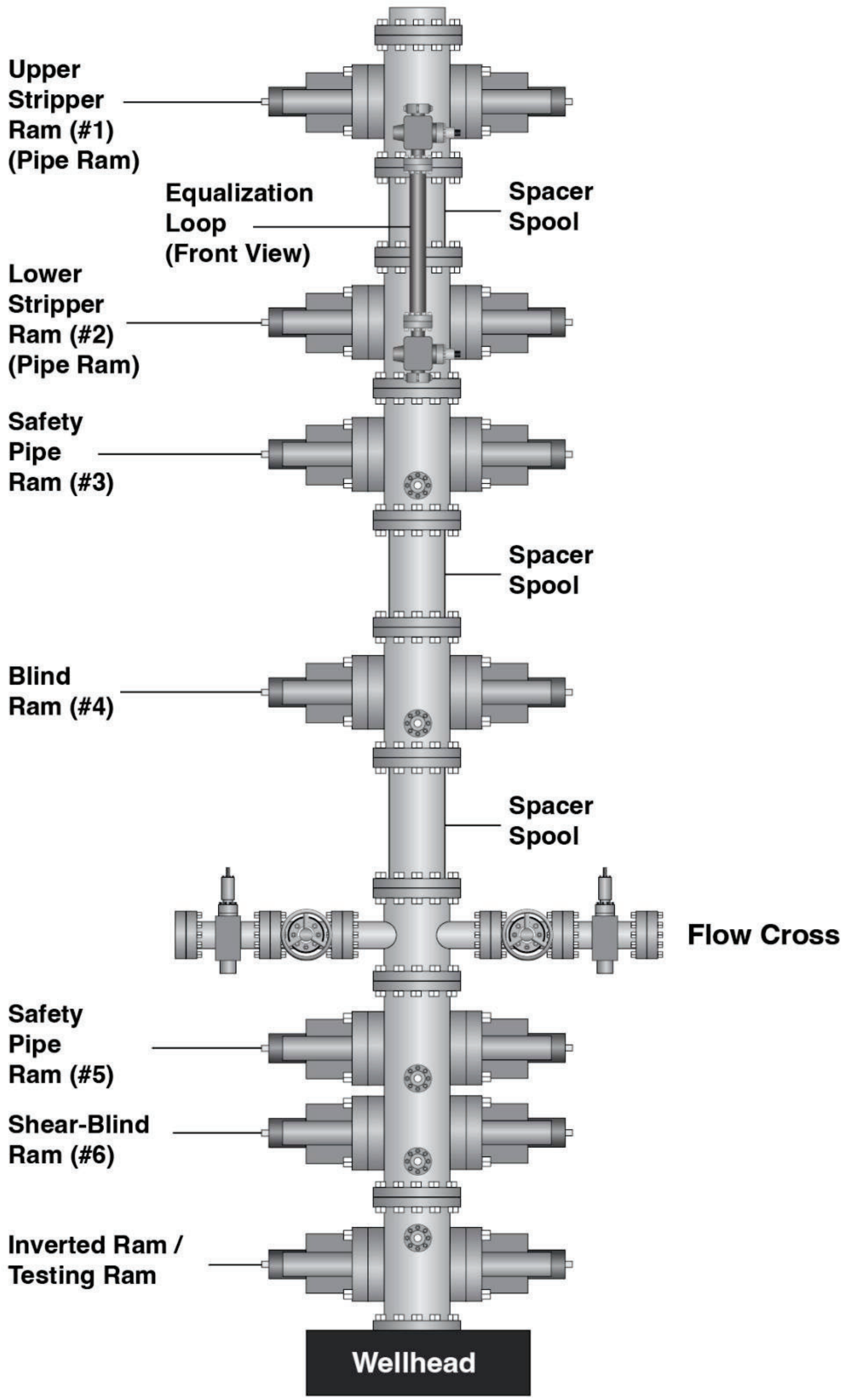
Rig-Assist Rig Up on Frac Valve

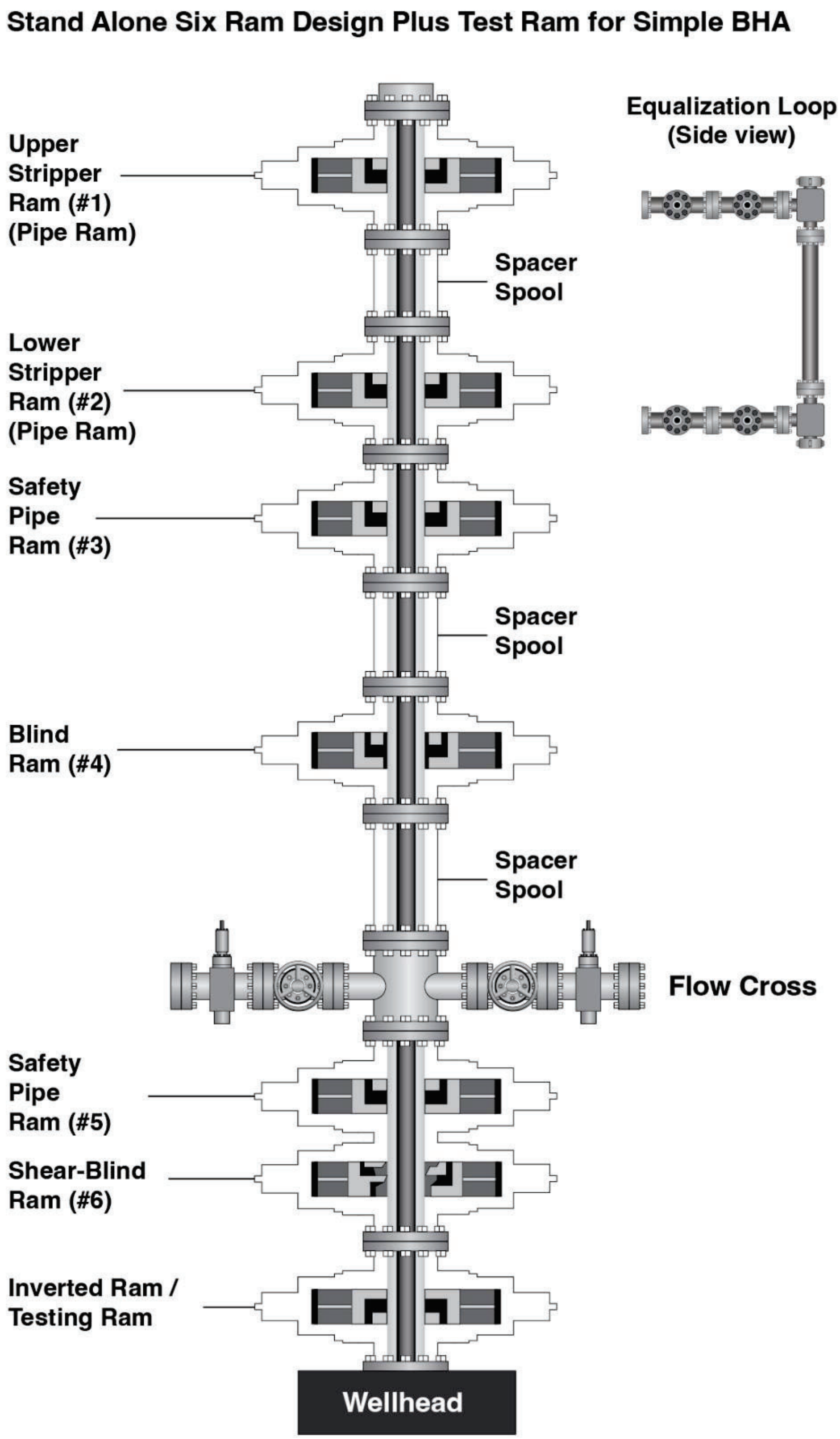


Rig-Assist Rig Up on Frac Valve



Stand Alone Six Ram Design Plus Test Ram for Simple BHA




Stand Alone Six Ram Design Plus Test Ram for Simple BHA
Upper Stripper Ram (#1) (Pipe Ram)
Spacer Spool
Lower Stripper Ram (#2) (Pipe Ram)
Safety Pipe Ram (#3)
Spacer Spool
Blind Ram (#4)
Spacer Spool
Flow Cross
Safety Pipe Ram (#5)
Shear-Blind Ram (#6)
Inverted Ram / Testing Ram
Wellhead
Equalization Loop (Side view)

Appendix D. API Rules of Conduct

The group 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 Group Discussion Topics

The following table lists subjects that arose among the API subject matter experts in discussions while developing snubbing Success Paths and FMECAs. Some may or may not be appropriate for an API snubbing document. Also, this list should not be construed as complete and comprehensive. Items noted with a question mark are those that remain open as of this writing.

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 well workovers. ▪ Enumerate good practices for well control and personnel safety independent of the entity providing that equipment.
References:		
	API; adopting portions or concepts of	▪ 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 dated 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 edition November 2018.

Type	Topic	Text Considerations (not in any order of precedence or importance):
	API; consider (or equivalent)	▪ 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	▪ Identify any 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 the document? ▪ Active or passive states? Define components and commonly accepted synonyms.
	Major Components	▪ Annular rams, stripping rams, pipe rams (safeties?), SBRs, jack, traveling slips, stationary slips, hydraulics, accumulators, hoses, equalizer loop, connectors, and work string tubulars.
	Support systems	▪ Motive power for hydraulics. ▪ Rig assist ▪ Electric power
	Service Categories	▪ Pressure ranges, associated equipment rated working pressures, ▪ Barrier requirement counts, or similar. ▪ Rig assist, stand alone, and hydraulic workover. ▪ Based on MASP?

Type	Topic	Text Considerations (not in any order of precedence or importance):
General:	Leaks	▪ Major versus minor?
	Barrier philosophy	▪ Two tested barriers available during all operations. ▪ Rams locked when unattended? Hydraulic locks allowed?
	Pressure Control philosophy	▪ Two pressure control barriers available at all times and between personnel and well bore when performing maintenance. ▪ Pressure control status requires constant personnel presence. ▪ Hydraulic locks allowed?
	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. ▪ Should not impact pressure control or barrier functionality; just impact number of functions possible during off-normal situations.
	Field Pressure Tests	▪ Criteria and extent of systems tested. ▪ Use of components other than barriers for test purposes (inverted ram or tree valve?).
	Shop Tests	▪ Pressure and function tests to be performed after refurbishing or repairing components or systems. ▪ Documentation package content.
	H_2S Service	▪ Requirements for H_2S service (including number of barriers and pressure control devices).
	Lighting	▪ Night or low light operations ▪ Battery backup
	Well Bore Access	▪ Provisions for well bore access below snubbing equipment.
	Tubular shearing	▪ SBR ▪ Qualification similar to that for drilling BOPs-(from manufacturer for types of tubing anticipated). ▪ Post-shear shape of tubular ▪ Open area of sheared tubular.
	Spare and replacement parts	▪ Minimum requirements.

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.
	Manually operated barriers	▪ Criteria on use, when and where.
	Manufacturer Certifications	▪ Certificates of Conformance and /or Compliance ▪ Expansion certification practice. ▪ Documentation package minimums…tests, 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 ▪ Basis ▪ Field operation, shop, or both?
	Pre job shop inspection process	▪ Identify components and processes. ▪ Checklist
	Independent Third-Party (I3P) Review	▪ When and where recommended/required. ▪ Company/Individual Credentials (PE?) ▪ Records
	Effluent management	▪ Environmental 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.
	Hydraulic workover barrier exception	▪ Number of barriers required

Type	Topic	Text Considerations (not in any order of precedence or importance):
	Startup	▪ Confirmation of hydraulic connections and functions. ▪ Checklist
	Rig Assisted	▪ Special requirements above 4000/4500psi (engineering studies and I3P?) ▪ Spreader beam requirements offshore. ▪ Simple, frac, and tree types.
	Cables in Bore	▪ Shear ram and pipe ram sealing. ▪
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. ▪ Manifolds ▪ 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.
	Hydraulic power	▪ General capability ▪ Number of pumps ▪ Reservoir sizing ▪ Reservoir monitoring ▪ Location ▪ Returns ▪ Pressure control
	Air/Hydraulic	▪ Acceptable application
	Hydraulic Hose	▪ Routing criteria

Type	Topic	Text Considerations (not in any order of precedence or importance):
	Pipe handling	▪ Joint making procedures ▪ Doping ▪ Drifting (Confirming inside diameter)
	Basket Controls	▪ Minimum controls and pressure gauges.
	Emergency Control Panels	▪ Placement. ▪ Number. ▪ Authority to use.
	Equalization Loop	▪ Requirements ▪ Roles in well control or safety isolation
	Anti-rotation rams	▪ Requirements ▪
Components:	SBRs	▪ Tubular centering device? ▪ Pressure test in field. ▪ Alternate ram actuation technologies (electric, explosive, pneumatic, etc) ▪ Ram locks: manual, visible status? ▪ Ram lock testing in shop. ▪ Added requirement for bonnet seal because of potential environmental impacts of leakage? ▪ Function with pressure from below? ▪ Pipe light or stuck pipe conditions after shear-blind actuation Non-shearables issue
	Work string	▪ Seamless design only ▪ Inspection and recertification between jobs-service records and tracking ▪ No welding allowed. ▪ Thread dope ▪ Buckling criteria ▪ Drift checks (confirming inside diameter)
	Traveling Slips	▪ Number of bowls ▪ Interlocks with stationary slips

Type	**Topic**	**Text Considerations (not in any order of precedence or importance):**
	Stationary Slips	▪ Number of bowls ▪ Interlocks with traveling slips.
	Jack	▪ Prime mover common with other hydraulics? ▪ Dedicated hydraulics or part of overall hydraulics system? ▪ Braking system
	Pipe Rams	▪ Variable bore type allowed. ▪ Barrier or pressure control type? ▪ Tubular centering device? ▪ Pressure test in field. ▪ Alternate ram actuation technologies (electric, explosive, pneumatic, etc.) ▪ Ram locks: manual, status visible? ▪ Ram lock testing in shop. ▪ Added requirement for bonnet seal because of potential environmental impacts of leakage.
	Stripping Rams	▪ Hydraulics common with stripping ram or other rams? ▪ Sized for work string. ▪ Variable pipe string diameters ▪ High cycle design (GT 1000 cycles) Unique requirements ▪ Pressure gauges to monitor pressure drop from wear.
	Full Opening Safety Valve	▪ Type ▪ Location (basket) ▪ Implementing tools and equipment
	Downhole flapper valves	▪ Number required. ▪ Leak rate allowed. ▪ Design requirements ▪ Manufacturing requirements
	Diverter	▪ Required?

Type	Topic	Text Considerations (not in any order of precedence or importance):
	Hydraulic Hose Connectors	▪ Internal sealing (check valves to contain hydraulic fluid when disconnected) ▪ No internal blockage when connections made. ▪ Sensitive to side loads?
	Swivel	▪ Never used in conjunction with FOSV ▪ No role in well control?
		▪

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