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Addendum 1

The reference to the Monogram Program shall be removed from Section 1 and elsewhere throughout the document, including the the entire contents of Annex A. The Annex A title will remain as a placeholder, until the next edition, so that Annex B through Annex C citations remain correct.

Section 4.5: *The section heading shall be renamed "Auxiliary Equipment Control Systems".*

Section 5.7.2 *was duplicated within the document. Duplicated section shall be removed.*

Section 5.7.3: *The section shall be updated to:*

5.7.3 Ethylene Glycol Reservoir

The ethylene glycol reservoir, if installed, shall be sized using the maximum anticipated ethylene glycol/water ratio for the minimum anticipated ambient temperature to which the control fluid is to be exposed. The reservoir shall have sufficient capacity to contain enough ethylene glycol to mix at least 1.5 times the power fluid volume of the main accumulator system.

Section 5.10.1: *The second sentence shall change as indicated by the highlighting:*

5.10.1 Close and seal is the process to close a ram BOP with the operator pressure required to seal the wellbore (MOPFLPS) and lock the rams.

NOTE MOPFLPS is not a single number, as environmental conditions can include elevated wellbore pressures at different temperatures.

Section 5.15.3.2: *The section shall be updated to:*

5.15.3.2 The main accumulator system shall be designed such that the loss of an individual accumulator or bank does not result in more than 25 % loss of the total accumulator system capacity.

Section 5.15.7.4: *The section shall be updated to:*

5.15.7.4 Relief valves shall additionally be tested to determine the maximum flow rate through the relief valve without exceeding 115 % of the relief valve's set pressure.

Section 5.16.3.1: *The section shall be changed as shown below:*

5.16.3.1 Visual position indication shall be installed on remote control stations for all function positions that are operable from the remote control station. Control station lamps (or other means of visual indication) that are used to indicate function status shall track the position of the hydraulic control valves. Red, amber, and green shall be used as standard colors for control station indicator lights (or displays). Green shall indicate that the function is in its normal drilling position.

Red shall indicate that the function is in an abnormal position. Amber shall indicate that the function is in a "block" or "vent" position. On functions that have three or more positions, red or green shall be on whenever the “block” or “vent” (amber) indication is on and thereby indicate the function’s last selected position.

NOTE Other indicator colors may be used for information display on functions such as selection of yellow or blue for subsea control pods.

Section 5.16.3.3: *The section shall be updated to:*

5.16.3.3 Control station functionality and external control functionality, excluding the regulator controls, shall require a two-handed operation (e.g., the use of an “ENABLE” or “PUSH and HOLD” in addition to the function).

Section 5.16.3.4: *The section shall be updated as shown by the highlighting:*

5.16.3.4 Physical arrangement of the control station shall be as a graphic representation of the flow path of the BOP stack or diverter, or both. The placement of the function for button and screen arrangements and visual indications shall be laid out such that the function on the right-hand side closes the BOP or choke or kill valve, and the function on the left-hand side shall open the BOP or choke or kill valve.

Section 5.16.5.3: *The first sentence shall be updated to:*

5.16.5.3 The following summary alarms shall have local visual indication with an audible alarm when the listed event(s) condition is met:

Section 5.16.5.3 (d): *The section shall be updated as highlighted in yellow:*

d) control manifold pressure LOW (surface, discrete hydraulic, MUX):
1) BOP manifold (control of ram BOPs, choke/kill outlet valves);
2) wellhead connector manifold;
3) LMRP connector manifold;
4) dedicated shear manifold.

Section 5.16.5.3 (e): *The section shall be updated to:*

e) control manifold pilot pressure LOW (surface, discrete hydraulic, MUX):
1) BOP manifold (control of ram BOPs, choke/kill outlet valves);
2) wellhead connector manifold;
3) LMRP connector manifold;
4) dedicated shear manifold.

Section 5.16.5.3 (j): *The section shall be updated as highlighted in yellow:*

j) pump system FAULT for electric-driven pump systems (surface, discrete hydraulic, MUX):
1) pump system electric power LOSS;
2) pump FAULT.

Section 5.16.6 (k): *The section shall be updated as highlighted in yellow:*

k) regulator pilot pressures (surface, discrete hydraulic, MUX);

Section 5.16.7.1: *The section shall be updated to:*

5.16.7.1 A safety cover or other means (e.g., pop-up controls, mechanical restraint) that does not obstruct visibility of function status, shall be installed to avoid unintended operation of critical functions (where installed) including:

a) connector(s) (LMRP, wellhead, choke & kill) retract / unlock;

b) shear ram(s) close;

c) emergency disconnect sequence activate;

d) deadman/autoshear arm;

e) deadman/autoshear disarm;

f) pod stabs retract / unlock;

g) diverter packer close.

Section 5.16.7.2*: The section shall be updated to:*

5.16.7.2 To prevent operator complacency, noncritical functions shall not have the safety cover or other means described above.

Section 5.17.1.3: *The section shall be updated to:*

5.17.1.3 No more than 130V RMS shall be connected to any component mounted on the face of an electrical enclosure that the user directly interfaces with to make routine adjustment.

NOTE This requirement does not apply to components that do not require routine adjustment, such as glanded cable entries or power switches/disconnects.

Section 5.17.3.3.2: *The section shall be updated to:*

5.17.3.3.2 When a subsystem is integrated, the test procedures shall specify all parameters that can be measured in a partial test to verify conformance to the specifications. The test shall be considered in process, and documentation that specifies the final integrated test requirements shall be supplied to the purchaser.

Section 6.5.1.2.b*: The section shall be updated as shown in yellow:*

b) Provide the power fluid volume and pressure required to close the following functions in sequence:

1) close the annular (largest by operator volume);

2) close and seal with a pipe ram.

This is a quick discharge event, and the accumulator sizing calculations shall be performed using Method C, calculated with the beginning pressure at the pump start pressure.

Section 7.2.1.4: *The section shall be updated as shown in yellow:*

7.2.1.4 There shall be two or more means of surface to subsea power fluid supply (e.g., hydraulic conduits, hydraulic umbilical hoses) as follows:

a) at least two power fluid supplies shall individually satisfy the response time requirements specified in 7.1;

b) at least two (or more) power fluid supplies shall be selectable from each control station.

NOTE LMRP-mounted accumulators (if installed) in conjunction with the required surface to subsea power fluid supplies are an acceptable means to satisfy response time requirements.

Section 7.3.1.8: *The section shall be updated to:*

7.3.1.8 All dedicated subsea accumulator systems shall have an ROV-readable pressure gauge. MUX control systems shall also have a pressure readback of the dedicated subsea accumulator systems.

Section 7.3.3.2: *The section shall be updated to:*

For main control systems that do not use a dedicated shear accumulator bank for high-pressure shear ram closure, the ACR (with the same precharge pressure) shall be the greater of the following:

a) The power fluid volume and pressure required to perform the accumulator drawdown test as defined in API 53. The accumulator pressure after the API 53 drawdown test shall equal or exceed the required MOP. The accumulator capacity required for this test correlates with the results obtained using calculation Method B.

b) The power fluid volume and pressure required to operate the following functions, in sequence:

1) close the annular (largest by operator volume);
2) close and seal with a pipe ram;
3) shear and seal.

The accumulator sizing calculations shall be performed using Method C, calculated with the beginning pressure at the pump start pressure.

c) Provide the power fluid volume required to perform an EDS (if installed). If the control system has more than one EDS mode, the EDS that requires the greatest accumulator capacity shall be used.

This is a quick discharge event, and the accumulator sizing calculations shall be performed using Method C, calculated with the beginning pressure at the pump start pressure.

Section 7.3.3.3: *The section shall be updated to:*

For main control systems that use a dedicated shear accumulator bank for high-pressure shear ram closure, the ACR (with the same precharge pressure) shall be the greater of the following:

a) The power fluid volume and pressure required to perform the accumulator drawdown test as defined in API 53. The accumulator pressure after the API 53 drawdown test shall equal or exceed the required MOP. The accumulator capacity required for this test correlates with the results obtained using calculation Method B.

b) The power fluid volume and pressure required to operate the following functions, in sequence:

1) close the annular (largest by operator volume);
2) close and seal with a pipe ram.

The accumulator sizing calculations shall be performed using Method C, calculated with the beginning pressure at the pump start pressure.

c) Provide the power fluid volume required to perform an EDS (if installed). If the control system has more than one EDS mode, the EDS that requires the greatest accumulator capacity shall be used.

This is a quick discharge event and the accumulator sizing calculations shall be performed using Method C, calculated with the beginning pressure at the pump start pressure.

Section 7.4.9: *The section shall be changed as highlighted in yellow:*

Software controlled discrete hydraulic control systems shall be equipped with automatic data logging as specified in 7.5.2.

Section 7.5.1.3: *The section shall be updated to:*

7.5.1.3 For a subsea one-atmosphere housing where a failure due to temperature would cause the inability to operate BOP stack functions or regulate function pressures, a sensor shall be required that triggers an alarm when the temperature exceeds the operational range of the housing components. This requirement does not apply to secondary and emergency control systems.

Section 7.5.1.4: *The section shall be updated to:*

7.5.1.4 For a subsea one-atmosphere housing where a failure due to humidity would cause the inability to operate BOP stack functions or regulate function pressures, a sensor shall be required that triggers an alarm when the humidity exceeds the operational range of the housing components. This requirement does not apply to secondary and emergency control systems.

Section 7.5.1.5: *The section shall be updated to:*

7.5.1.5 For a subsea one-atmosphere housing where a failure due to fluid ingress would cause the inability to operate BOP stack functions or regulate function pressures, a sensor shall be required that triggers an alarm when there is an ingress of fluid (control fluid, saltwater, dielectric fluid) that is detrimental to system performance per the manufacturer specifications. This requirement does not apply to secondary and emergency control systems.

Section 7.5.2: *The section shall be moved (renumbered) to become* ***Section 7.6*** *and renamed to "Auxiliary Subsea Devices" and subsequent subsections renumbered. The precise following text shall be used:*

7.6 Auxiliary Subsea Devices

7.6.1 Auxiliary devices shall not disable the BOP control system in the event of a failure in the auxiliary devices.

NOTE 1 Auxiliary subsea devices support drilling operations but are not required for well control.

NOTE 2 The transmission of auxiliary device data and power may be through independent conductors in the subsea umbilical (MUX) cable, integrated into the BOP control system or through an independent umbilical cable.

NOTE 3 Auxiliary subsea devices are not required by this standard to comply with the requirements of 7.5.

NOTE 4 Typical auxiliary devices may include but are not limited to the following:

a) measurement of riser angle;

b) measurement of riser stresses;

c) measurement of BOP stack angle;

d) measurement of sea bottom currents and water temperature;

e) measurement of wellbore fluid temperature at the wellhead;

f) measurement of wellbore pressure at the wellhead;

g) transmission of underwater television images;

h) control of TV camera functions (pan, tilt, etc);

i) control and power of underwater TV lights;

j) valve and BOP position indicators.

Section 7.6.2: *The section shall be renumbered (and located appropriately) to be 7.5.2*

Section 7.6.3: *The section shall be renumbered (and located appropriately) to be 7.5.3*

Section 7.6.4: *The section shall be renumbered (and located appropriately) to be 7.5.4*

Section 7.6.5: *The section shall be renumbered (and located appropriately) to be 7.5.5*

Section 7.6.6: *The section shall be renumbered (and located appropriately) to be 7.5.6*

Section 7.6.7: *The section shall be renumbered (and located appropriately) to be 7.5.7*

Section 7.6.8: *The section shall be renumbered (and located appropriately) to be 7.5.8*

Section 7.6.9: *The section shall be renumbered (and located appropriately) to be 7.5.9*

Section 7.6.10: *The section shall be renumbered (and located appropriately) to be 7.5.10*

Section 10.3.2.14: *The section shall be updated to:*

10.3.2.14 There shall be a manual override mode in which the diverter can be closed without operating the diverter sequence or performing interlocked functions. The manual override shall be operable from the driller's remote control station.

Section 10.3.4.2: *The section shall be updated to:*

10.3.4.2 Separate panel controls for a common hydraulic manifold shall have a mode to select between BOP mode and diverter mode on the panel.

Section 10.4.5: *The following new section shall be added:*

10.4.5 Diverter control function valve handles and button/screen arrangements shall be placed in the orientation per 5.15.6.

Section 10.6.4: *The section shall be changed as highlighted in yellow:*

10.6.4 For diverters controlled by the BOP control system, the accumulator system shall also meet or exceed the requirements listed in **6.5.1**.

Section 14.3.10: *The section shall be changed as highlighted in yellow:*

14.3.10 Electrostatic discharge control shall be in accordance with ANSI/ESD S20.20 or an equivalent recognized national or international standard.

Section 14.3.11.1: *The section shall be changed as highlighted in yellow:*

14.3.11.1 Ground conductors shall be sized in accordance with NFPA 70 or an equivalent recognized national or international standard.

Section 14.4.2: *The first line shall be changed as highlighted in yellow:*

Control Pod equipment shall conform to the following:

Section 14.8.5: *The section shall be updated as shown below:*

14.8.5 A certificate of the relief valve setting and operation shall be provided indicating the set point and the pressure at which the relief valve re-seats.

Annex D: *The annex title shall be updated to "Summary of Accumulator Sizing Examples"*

Section D.1: *The heading shall be deleted.*

The remaining Addendum updates are related to the Accumulator Sizing Examples (Examples being updated: 2, 3, 5, 6, 7, 8, and 12). Please see the following sheets.

Table D.1: *The content shall be updated to reflect the updated volumes for the related examples, and shall be replaced with the following:*

Example	System Case	Equipment Case	Design Method	Circuit Pressure [a]	Notes	Minimum Required Accumulator Volume (gal)
1	Land Rig	Main Accumulators	B (drawdown) C (well control)	3000 2700	±50 °F temperature range considered	79.5
2	Offshore Surface Sack with dedicated shear accumulator	Main Accumulators	B (drawdown) C (well control)	3000 2700	±30 °F temperature range considered	247.7
3		Pilot Accumulators	B (close all BOPS)	3000	±30 °F temperature range considered	0.097
4		Dedicated Shear Accumulators (not supplied by main accumulators)	C	4500	±30 °F temperature range considered	90.7
5		Diverter Accumulators	C	3000	±30 °F temperature range considered	140.1
6	Offshore Surface Stack without dedicated shear accumulator	Main Accumulators	B (drawdown) C (well control)	3000 2700	±30 °F temperature range considered	546.6
7	Subsea Stack	Main Accumulators	B (drawdown) C (well control)	5000 4500	—	975.5
8		Pilot Accumulators	B (open and close all BOPS C (EDS)	3000	—	1.449
9		DMAS/Shear Accumulators	C	5000	—	1576.9
10		Acoustic Accumulators	B	5000	—	530.0
11		Diverter Accumulators	C	5000	—	90.5
12	Special Purpose	Depth Compensated Accumulators	C	5000	—	687.9
13		Choke and Kill Valve Closure Assist Accumulators	C	3000	—	58.4

[a] Based on pump start and stop pressures or regulated pressures.

Table D.4: *The content shall be replaced with the following:*

Examples 2, 3, 4, & 5: BOP Stack Configuration and Parameters for *Offshore Surface Stack*

The following examples size accumulator systems for a surface BOP. The main, pilot, dedicated shear and diverter accumulators will be sized. This example will take a 30° F temperature range into consideration.

Stack	Rated Working Pressure (psia)	Pressure Required / MOPFLPS (psig)	Closing Volume (gal)	Opening Volume (gal)	Closing/Shearing Ratio	
Annular BOP, 13"	10,000	1,500	26.50	24.30	-	
Blind Shear Ram, 13"	10,000	1,600	21.50	16.00	18.20	Shearing
		520			6.20	Sealing
Upper Pipe Ram, 13"	10,000	600	12.30	10.80	7.65	
Middle Pipe Ram, 13"	10,000	600	12.30	10.80	7.65	
Lower Pipe Ram, 13"	10,000	600	12.30	10.80	7.65	
Choke & Kill Valve	10,000	780	0.65	0.65	-	

Pilot - Volume to pilot all BOPs closed			
Functions	QTY	Size	Total Volume (gal)
1X Annular	1	1.5" SPM	0.0060
4X Rams	4	1.0" SPM	0.0120
		Total	0.0180
		200%	0.0360

Diverter System		
Function	Pressure (psig)	Volume (gal)
Sequence	1,500	11
Diverter	1,500	25
	Total	36

System Parameters		
System Pressure	3,000	psig
System Pressure (HP shear circuit)	5,000	psig

Environmental Conditions		
Surface Temperature at Precharge	90	°F
Temperature Range (+/- °F)	30	°F
Minimum Surface Temperature	60	°F
Maximum Surface Temperature	120	°F
Atmospheric Pressure	14.7	psia

Relevant References

Pump System

- Primary pump start at 90% of system RWP
- Primary pump stop between 98%-100% of system RWP

Ex. 2 Main Accumulator System

- Example rig uses dedicated shear accumulators for high pressure shear ram closure

Drawdown Test
- Close all rams, open valve, close annular
- Use pump stop pressure
- Method B

Well Control Sequence
- Close annular
- Use pump start pressure
- Method C
* Volume for shear rams provided by dedicated shear accumulators

Ex. 3 Pilot Accumulators

- 200% of volume to close all BOPs
- Method B
- Minimum Pressure Required to pilot control valve: 1,500 psig
- Minimum Pressure Required by hydraulically piloted regulators: 1,500 psig

Ex. 4 Dedicated Shear Accumulators

- Example rig's dedicated shear accumulators are not supplied by the main accumulator system and, therefore, pump start pressure is used
- Method C

Ex. 5 Diverter Accumulators

- Example rig's diverter accumulators are supplied by the main accumulator system and are checked in, therefore, pump stop pressure is used
- Method C

Table D.5: *The content has been updated to remove the pipe ram from the well control sequence, and shall be replaced with the following:*

Example 2: Surface Stack - Main Accumulator Sizing

Main Accumulator

This worksheet details the sizing calculations for the Main Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s) - Accumulator Drawdown (Method B)	Rated Working Pressure (psia)	Opening Volume (gal)	Closing Volume (gal)	Closing Ratio*	Pressure to Close Against RWP (psig)
Annular BOP, 13"	10,000	24.30	26.50	-	1,500
Blind Shear Ram, 13"	10,000	16.00	21.50	6.20	1,611
Upper Pipe Ram, 13"	10,000	10.80	12.30	7.65	1,305
Middle Pipe Ram, 13"	10,000	10.80	12.30	7.65	1,305
Lower Pipe Ram, 13"	10,000	10.80	12.30	7.65	1,305
Choke & Kill Valve	10,000	0.65	0.65	-	780

Pressure Required (psig) to Close Blind Shear Ram against Rated Working Pressure = Rated Working Pressure / Closing Ratio = 10000 / 6.2 = 1610.6

Total Functional Volume Requirement (FVR_B)	85.55	gal
Pressure Required	1,611	psig

*Use the sealing ratio for the drawdown test calculations when a shear ram has a different closing ratio for shearing and sealing.

Operator Function(s) - Well Control Sequence (Method C)*	Rated Working Pressure (psia)	Pressure Required / MOPFLPS (psig)	Closing Volume (gal)	Closing Ratio	Adjusted Pressure Required (psig)
Annular BOP, 13"	10,000	1,500	26.50	-	1,500

*Rig has dedicated shear accumulators that will supply shear and seal functions.

Total Functional Volume Requirement (FVR_C)	26.50	gal
Pressure Required	1,500	psig

Environmental Conditions		
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Temperature Range (+/-)	30	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	3,000	psig
Pump Stop Pressure (Method B - 100%)	3,000	psig
Pump Start Pressure (Method C - 90%)	2,700	psig

Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density and entropy based upon gas temperature and absolute pressure.

Charged Accumulator Pressure (psia) = Surface Supply Pressure + Atmospheric Pressure = 3000 + 14.7 = 3014.7

Condition 1 - Charged Accumulator Densities	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_1	Entropy S_1
Charged Condition - High Temp (Method B)	3,000	3,015	120	12.623	
Charged Condition - Normal (Method B)	3,000	3,015	90	13.429	
Charged Condition - Low Temp (Method B)	3,000	3,015	60	14.365	
Charged Condition - High Temp (Method C)	2,700	2,715	120	11.518	1.2614603
Charged Condition - Normal (Method C)	2,700	2,715	90	12.259	1.2453902
Charged Condition - Low Temp (Method C)	2,700	2,715	60	13.122	1.2279664

2. Calculate minimum operating pressures

Calculate the minimum operating pressure (psia)for each case.

Minimum Operating Pressure (psia) = Pressure Required + Atmospheric Pressure = 1610.6 + 14.7 = 1625.3

Calculate MOPs	Pressure Required (psig)	Minimum Operating Pressure (psia)
Minimum Operating Pressure - (Method B)	1,611	1,625
Minimum Operating Pressure - (Method C)	1,500	1,515

3. Calculate minimum operating densities

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 temperature (for Method B) or Condition 1 entropy (for Method C).

Condition 2 - MOP Densities	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_2
Minimum Operating Density - High Temp (Method B)	1,611	1,625	120	7.166
Minimum Operating Density - Normal (Method B)	1,611	1,625	90	7.623
Minimum Operating Density - Low Temp (Method B)	1,611	1,625	60	8.155
Minimum Operating Density - High Temp (Method C)	1,500	1,515	29	8.229
Minimum Operating Density - Normal (Method C)	1,500	1,515	4	8.815
Minimum Operating Density - Low Temp (Method C)	1,500	1,515	-22	9.509

4. Calculate optimum precharge density

Optimum precharge density

- *Method B: $\rho_0 = 1.0/(1.4/\rho_{2BL} - 1.4/\rho_{1BL} + 1.0/\rho_{1BH})$*
- *Method C: $\rho_0 = 1.0/(1.0/\rho_{2CL} - 1.0/\rho_{1CL} + 1.0/\rho_{1CH})$*
- *See Annex C for Derivation*

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure - (Method B)	6.517	90	1,367	1,382
Optimum Precharge Pressure - (Method C)	8.637	90	1,838	1,853

Calculate the overall optimum precharge that satisfies requirements for both Method B and Method C. See Annex C for explanation.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Overall Optimum Precharge Pressure	6.517	90	1,367	1,382

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- *maintaining precharge pressure below the maximum rated working pressure*
- *maintaining precharge pressure above 25% of system working pressure*
- *permitting a range of precharge pressures during operations*
- *following manufacturer's recommendations.*

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_0
Selected Precharge Pressure at Precharge Temperature		1,367	1,382	90	6.516
Selected Precharge Pressure at Minimum Temperature		1,276	1,291	60	6.516
Selected Precharge Pressure at Maximum Temperature		1,457	1,472	120	6.516

Precharge Verification

Accumulator Precharge Pressure at Minimum Temperature	Precharge pressure (1291 psia) is greater than 25% of charged accumulator pressure (754 psia).
Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (1457 psig) is less than accumulator rated working pressure (3000 psig).

6. Determine volumetric efficiencies

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft³)
Condition 0: Precharged Accumulators	90	1,367	1,382	6.516
Condition 1: Charged accumulators @ 3000 psi	90	3,000	3,015	13.429
Condition 1: Charged accumulators @ 2700 psi	90	2,700	2,715	12.259
Condition 2: Minimum Operating Pressure - (Method B)	90	1,611	1,625	7.623
Condition 2: Minimum Operating Pressure - (Method C)	4	1,500	1,515	8.815

Method B Volumetric Efficiencies

Pressure Limited $VE_{PL} = (\rho_0/\rho_{2BL} - \rho_0/\rho_{1BL})/1.0$	0.345
Volume Limited $VE_{VH} = (1.0-\rho_0/\rho_{1BH})/1.4$	0.346
Volumetric Efficiency $VE_B = \min(VE_{PL}, VE_{VH})$	0.345
Accumulator Volume Required (gal) $ACR_B = FVR_B/VE_B$	247.7

Method C Volumetric Efficiencies

Pressure Limited $VE_{PL} = (\rho_0/\rho_{2CL} - \rho_0/\rho_{1CL})/1.1$	0.172
Volume Limited $VE_{VH} = (1.0-\rho_0/\rho_{1CH})/1.1$	0.395
Volumetric Efficiency $VE_C = \min(VE_{PL}, VE_{VH})$	0.172
Accumulator Volume Required (gal) $ACR_C = FVR_C/VE_C$	154.5

Minimum Accumulator Volume Required (gal) = $\max(ACR_B, ACR_C)$	247.7

***Figure D.2:** The content shall be replaced with the following:*

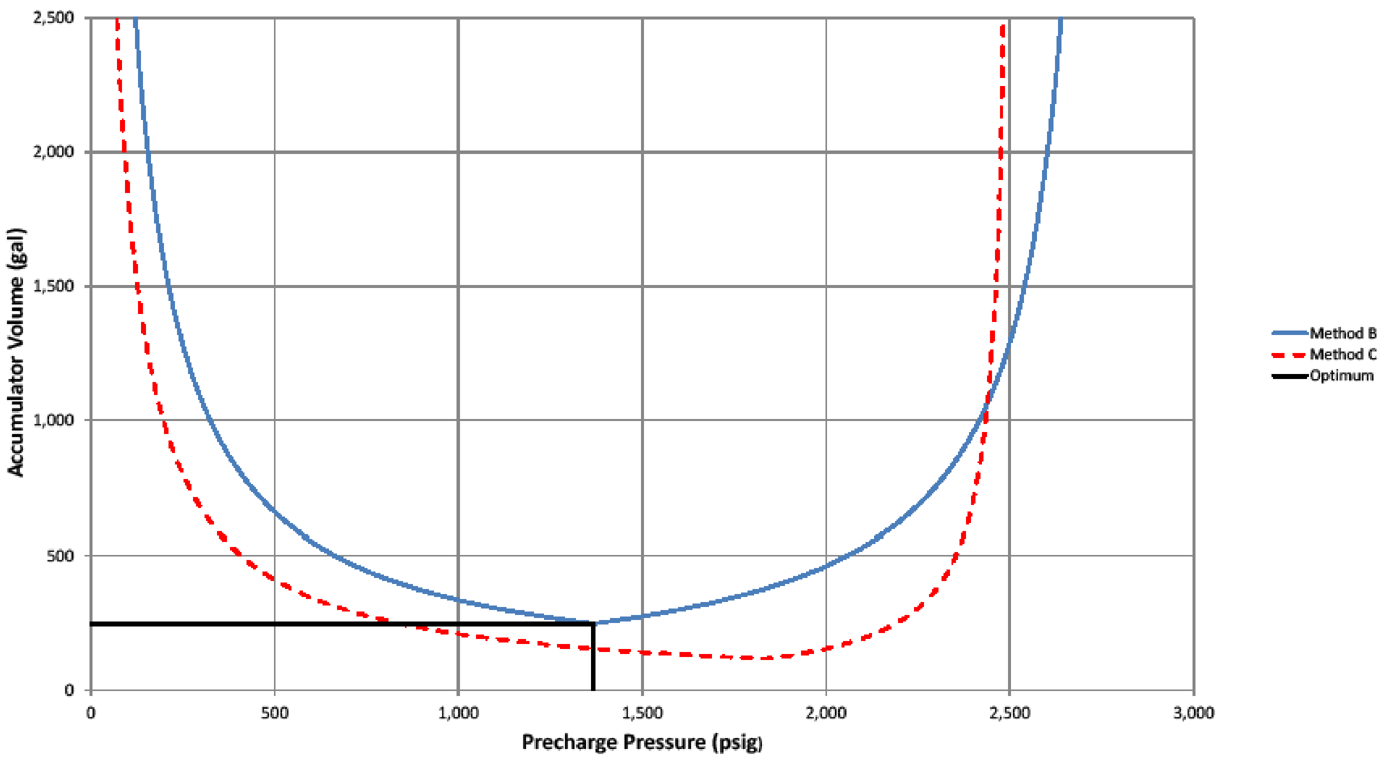

Table D.6: *The content has been updated to change text from "200 % of volume to open and close all BOPs (FVR)" to "200 % of volume to close all BOPs (FVR)", and shall be replaced with the following:*

Example 3: Surface Stack - Pilot System Accumulator Sizing

Pilot Accumulator

This worksheet details the sizing calculations for the Pilot Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s)	Valve Size (in.)	Pilot Open Volume (gal)	Pilot Close Volume (gal)	Pilot Pressure Required by Control Valve (psig)
Annular BOP, 13"	1.5	0.006	0.006	1,500
Blind Shear Ram, 13"	1.0	0.003	0.003	1,500
Upper Pipe Ram, 13"	1.0	0.003	0.003	1,500
Middle Pipe Ram, 13"	1.0	0.003	0.003	1,500
Lower Pipe Ram, 13"	1.0	0.003	0.003	1,500

Volume to close all BOPs	0.0180	gal
200% of volume to close all BOPs (FVR)	0.0360	
Pressure Required	1,500	psig

Minimum pilot pressure Required by Hydraulically Piloted Regulator (psig)
1,500

Environmental Conditions		
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Temperature Range (+/-)	30	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	3,000	psig
Regulated Supply Pressure	3,000	psig

Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density based upon gas temperature and absolute pressure.

Charged Accumulator Pressure (psia) = Regulated Supply Pressure + Atmospheric Pressure = 3000 + 14.7 = 3014.7

Condition 1 - Charged Accumulator Density	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_1
Charged Condition - High Temp	3,000	3,015	120	12.623
Charged Condition - Normal	3,000	3,015	90	13.429
Charged Condition - Low Temp	3,000	3,015	60	14.365

2. Calculate minimum operating pressure

Calculate the minimum operating pressure (psia)

Minimum Operating Pressure (psia) = Pressure Required + Atmospheric Pressure = 1500 + 14.7 = 1514.7

Calculate MOP	Pressure Required (psig)	Minimum Operating Pressure (psia)
Minimum Operating Pressure	1,500	1,515

3. Calculate minimum operating density

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 temperature.

Condition 2 - MOP Density	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_2
Minimum Operating Density - High Temp	1,500	1,515	120	6.698
Minimum Operating Density - Normal	1,500	1,515	90	7.123
Minimum Operating Density - Low Temp	1,500	1,515	60	7.618

4. Calculate optimum precharge density

Optimum precharge density

- $\rho_0 = 1.0/(1.4/\rho_{2L} - 1.4/\rho_{1L} + 1.0/\rho_{1H})$
- See Annex C for derivation

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure	6.041	90	1,264	1,278

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- *maintaining precharge pressure below the maximum rated working pressure*
- *maintaining precharge pressure above 25% of system working pressure*
- *permitting a range of precharge pressures during operations*
- *following manufacturer's recommendations.*

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_0
Selected Precharge Pressure at Precharge Temperature		1,264	1,278	90	6.041
Selected Precharge Pressure at Minimum Temperature		1,181	1,195	60	6.041
Selected Precharge Pressure at Maximum Temperature		1,346	1,361	120	6.041

Precharge Verification

Accumulator Precharge Pressure at Minimum Temperature	Precharge pressure (1195 psia) is greater than 25% of charged accumulator pressure (754 psia).
Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (1346 psig) is less than accumulator rated working pressure (3000 psig).

6. Determine volumetric efficiencies

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft^3)
Condition 0: Precharged Accumulators	90	1,264	1,278	6.041
Condition 1: Charged accumulators	90	3,000	3,015	13.429
Condition 2: Minimum Operating Pressure	90	1,500	1,515	7.123

Pressure Limited $VE_{PL} = (\rho_0/\rho_{2L} - \rho_0/\rho_{1L})/1.0$	0.372
Volume Limited $VE_{VH} = (1.0-\rho_0/\rho_{1H})/1.4$	0.372
Volumetric Efficiency $VE = \min(VE_{PL}, VE_{VH})$	0.372
Minimum Accumulator Volume Required (gal) ACR = FVR/VE	0.097

Figure D.3: *The content shall be replaced with the following:*

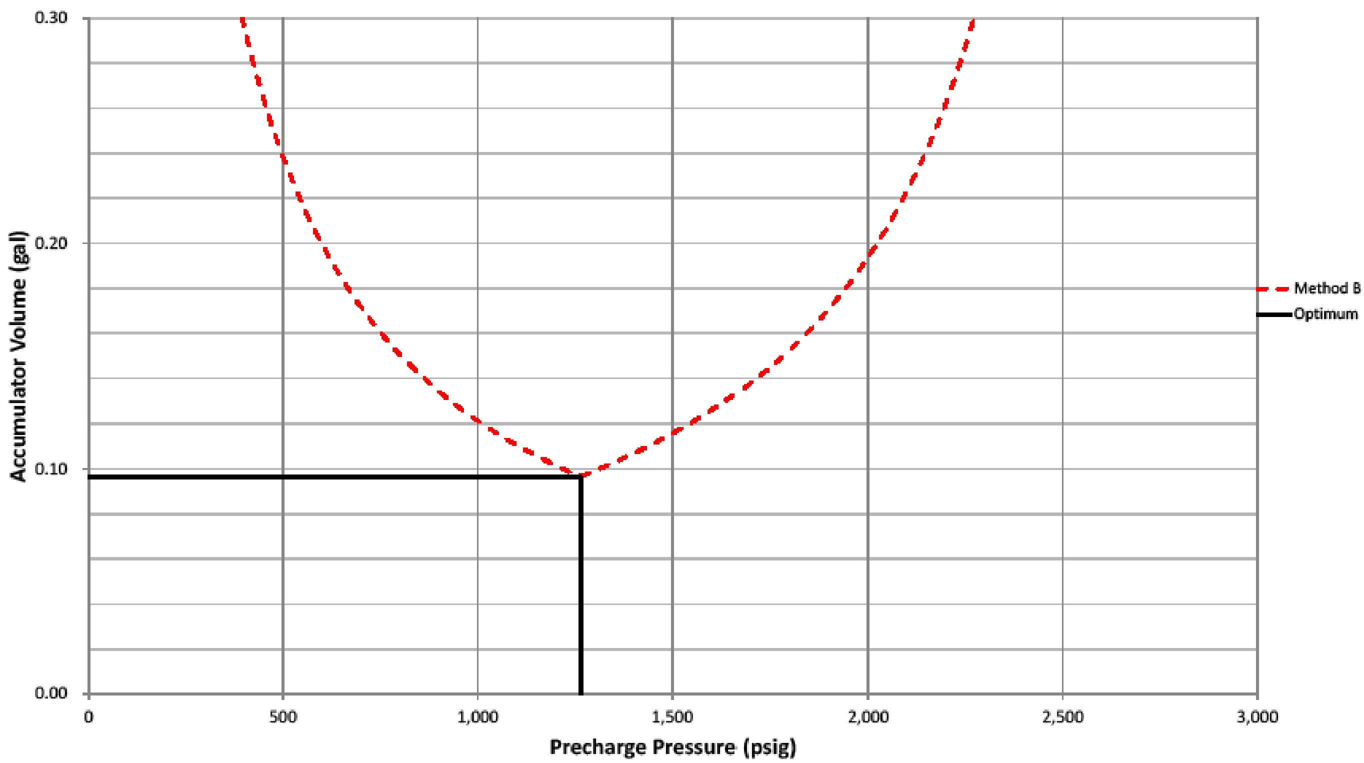

Table D.8: *The content has been updated to correct over-writing text, and shall be replaced with the following:*

Example 5: Surface Stack - Diverter Accumulator Sizing

Diverter Accumulator

This worksheet details the sizing calculations for the Diverter Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s)	Rated Working Pressure (psig)	Pressure Required (psig)	Function Volume (gal)
Divert Mode Functional Sequence	1,500	1,500	11.00
Diverter	500	1,500	25.00

Sequence

Total Functional Volume Requirement (FVR)	36.00
Pressure Required	1,500

Environmental Conditions		
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Temperature Range (+/-)	30	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	3,000	psig
Pump Stop Pressure (100%)	3,000	psig

Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density and entropy based upon gas temperature and absolute pressure.

Charged Accumulator Pressure (psia)= Surface Supply Pressure + Atmospheric Pressure = 3000 + 14.7 = 3014.7

Condition 1 - Charged Accumulator Density	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_1	Entropy S_1
Charged Condition - High Temp	3,000	3,015	120	12.623	1.2523076
Charged Condition - Normal	3,000	3,015	90	13.429	1.2360478
Charged Condition - Low Temp	3,000	3,015	60	14.365	1.2184071

2. Calculate minimum operating pressure(s)

Calculate the minimum operating pressures for each step within the sequence and adjust for hydrostatic effects.

Minimum Operating Pressure (psia) = Pressure Required + Atmospheric Pressure = 1500 + 14.7 = 1514.7

Calculate MOP(s)	Pressure Required (psig)	Minimum Operating Pressure (psia)
Minimum Operating Pressure	1,500	1,515

3. Calculate minimum operating density(s)

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 entropy.

Condition 2 - MOP Density(s)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Entropy S_2	Density (lbm/ft³) ρ_2	Temperature (°F)
Minimum Operating Density - High Temp	1,500	1,515	1.2523076	8.557	14
Minimum Operating Density - Normal	1,500	1,515	1.2360478	9.179	-10
Minimum Operating Density - Low Temp	1,500	1,515	1.2184071	9.919	-34

4. Calculate optimum precharge density

Optimum precharge density

- $\rho 0 = 1.0/(1.0/\rho_{2L} - 1.0/\rho_{1L} + 1.0/\rho_{1H})$

- See Annex C for derivation

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft³)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure - Sequence 1	9.056	90	1,934	1,948

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- *maintaining precharge pressure below the maximum rated working pressure*
- *maintaining precharge pressure above 25% of system working pressure*
- *permitting a range of precharge pressures during operations*
- *following manufacturer's recommendations.*

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_0
Selected Precharge Pressure at Precharge Temperature		1,934	1,948	90	9.056
Selected Precharge Pressure at Minimum Temperature		1,798	1,813	60	9.056
Selected Precharge Pressure at Maximum Temperature		2,068	2,083	120	9.056

Precharge Verification

Greater than 25% of Accumulator Charged Pressure	Precharge pressure (1948 psia) is greater than 25% of charged accumulator pressure (754 psia).
Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (2068 psig) is less than accumulator rated working pressure (3000 psig).

6. Determine volumetric efficiencies

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft³)
Condition 0: Precharged Accumulators	90	1,934	1,948	9.056
Condition 1: Charged accumulators	90	3,000	3,015	13.429
Condition 2: Minimum Operating Pressure	-10	1,500	1,515	9.179

Pressure Limited $VE_{PL} = (\rho_0/\rho_{2L} - \rho_0/\rho_{1L})/1.1$	0.257
Volume Limited $VE_{VH} = (1.0-\rho_0/\rho_{1H})/1.1$	0.257
Volumetric Efficiency $VE = \min(VE_P, VE_V)$	0.257

Minimum Accumulator Volume Required (gal) ACR = FVR/VE	140.1

Figure D.5: *The content shall be replaced with the following:*

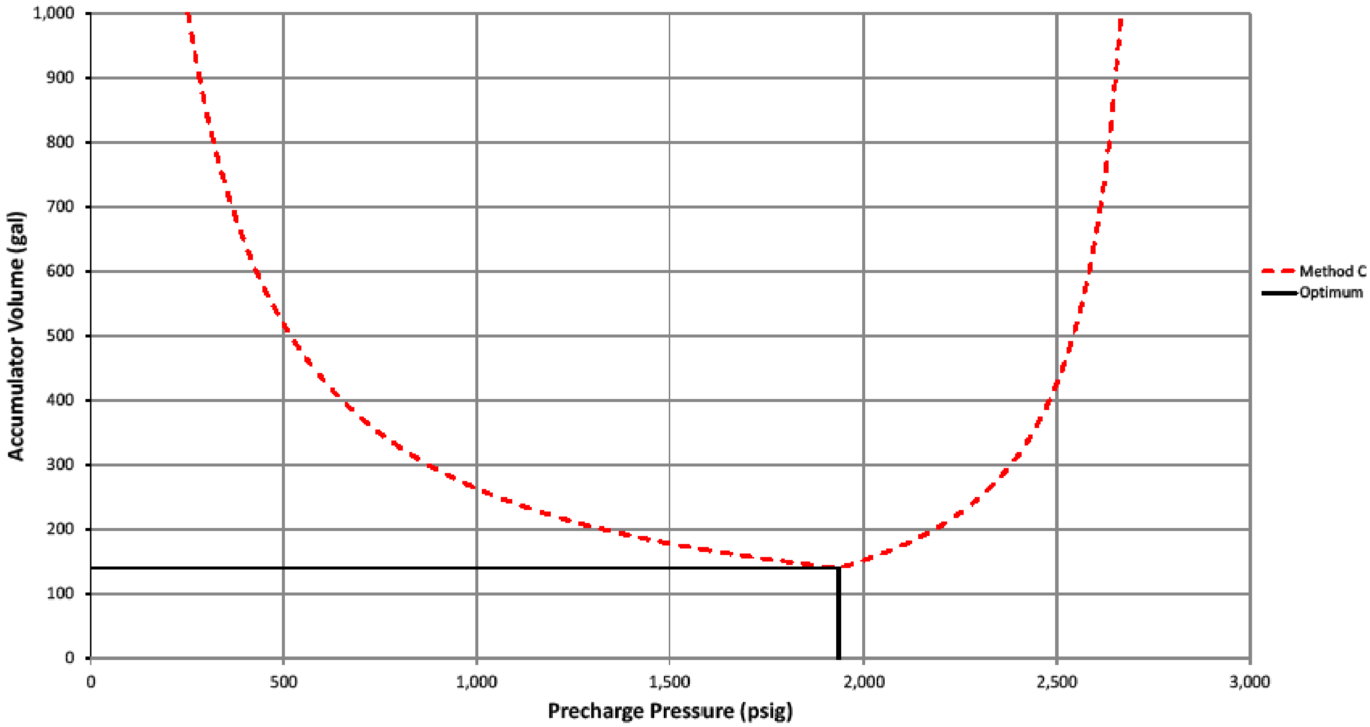

Table D.9: *The content has been updated to remove the pipe ram from the well control sequence, and shall be replaced with the following:*

Example 6: BOP Stack Configuration and Parameters for *Offshore Surface Stack*

The following example sizes accumulators for a surface BOP. The main accumulators will be sized. This example will take a 30°F temperature range into consideration. Rig does not have dedicated shear accumulators.

Stack	Rated Working Pressure (psia)	Pressure Required / MOPFLPS (psig)	Closing Volume (gal)	Opening Volume (gal)	Closing/Shearing Ratio	
Annular BOP, 13"	10,000	1,500	26.50	24.30	-	
Blind Shear Ram, 13"	10,000	1,600	21.50	16.00	18.20	Shearing
		520			6.20	Sealing
Upper Pipe Ram, 13"	10,000	750	12.30	10.80	7.65	
Middle Pipe Ram, 13"	10,000	750	12.30	10.80	7.65	
Lower Pipe Ram, 13"	10,000	750	12.30	10.80	7.65	
Choke & Kill Valve	10,000	780	0.65	0.65	-	

System Parameters		
System Pressure	3,000	psig

Environmental Conditions		
Surface Temperature at Precharge	90	°F
Temperature Range (+/- °F)	30	°F
Minimum Surface Temperature	60	°F
Maximum Surface Temperature	120	°F
Atmospheric Pressure	14.7	psia

Relevant References

Pump System

- Primary pump start at 90% of system RWP
- Primary pump stop between 98%-100% of system RWP

Ex. 6 Main Accumulator System

- Example rig does *not* use dedicated shear accumulators for high pressure shear ram closure

Drawdown Test
- Close all rams, open valve, close annular
- Use pump stop pressure
- Method B

Well Control Sequence
- Close annular and blind shear ram
- Use pump start pressure
- Method C

Example 6: Surface Stack - Main Accumulator Sizing

Main Accumulator

This worksheet details the sizing calculations for the Main Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s) - Accumulator Drawdown (Method B)	Rated Working Pressure (psia)	Opening Volume (gal)	Closing Volume (gal)	Closing Ratio*	Pressure to Close Against RWP (psig)
Annular BOP, 13"	10,000	24.30	26.50		1,500
Blind Shear Ram, 13"	10,000	16.00	21.50	6.20	1,611
Upper Pipe Ram, 13"	10,000	10.80	12.30	7.65	1,305
Middle Pipe Ram, 13"	10,000	10.80	12.30	7.65	1,305
Lower Pipe Ram, 13"	10,000	10.80	12.30	7.65	1,305
Choke & Kill Valve	10,000	0.65	0.65		780

Pressure Required (psig) to Close against Rated Working Pressure = Rated Working Pressure / Closing Ratio = 10000 / 6.2 = 1610.6

Total Functional Volume Requirement (FVR_B)	85.55	gal
Pressure Required	1,611	psig

*Use the sealing ratio for the drawdown test calculations when a shear ram has a different closing ratio for shearing and sealing.

Operator Function(s) - Well Control Sequence (Method C)	Rated Working Pressure (psia)	Pressure Required / MOPFLPS (psig)		Closing Volume (gal)	Closing or Shearing Ratio	Adjusted Pressure Required (psig)
Annular BOP, 13"	10,000	1,500		26.50		1,500
Blind Shear Ram, 13"	10,000	1,600	Shear	21.50	18.20	2,149
		520	MOPFLPS		6.20	2,131

Pressure Required (psig) to Shear with Blind Shear Ram = Shear Pressure + Rated Working Pressure/Shearing Ratio = 1600 + 10000 / 18.2 = 2148.7

Minimum Pressure Required (psig) to Seal with Blind Shear Ram = MOPFLPS + Rated Working Pressure / Closing Ratio = 520 + 10000 / 6.2 = 2130.6

Total Functional Volume Requirement (FVR_C)	48.00	gal
Pressure Required	2,149	psig

Environmental Conditions		
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Temperature Range (+/-)	30	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	3,000	psig
Pump Stop Pressure (Method B - 100%)	3,000	psig
Pump Start Pressure (Method C - 90%)	2,700	psig

Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density and entropy based upon gas temperature and absolute pressure.

Charged Accumulator Pressure (psia) = Surface Supply Pressure + Atmospheric Pressure = 3000 + 14.7 = 3014.7

Condition 1 - Charged Accumulator Densities	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_1	Entropy S_1
Charged Condition - High Temp (Method B)	3,000	3,015	120	12.623	
Charged Condition - Normal (Method B)	3,000	3,015	90	13.429	
Charged Condition - Low Temp (Method B)	3,000	3,015	60	14.365	
Charged Condition - High Temp (Method C)	2,700	2,715	120	11.518	1.2614603
Charged Condition - Normal (Method C)	2,700	2,715	90	12.259	1.2453902
Charged Condition - Low Temp (Method C)	2,700	2,715	60	13.122	1.2279664

2. Calculate minimum operating pressures

Calculate the minimum operating pressure (psia)for each case.

Minimum Operating Pressure (psia) = Pressure Required + Atmospheric Pressure = 1610.6 + 14.7 = 1626

Calculate MOPs	Pressure Required (psig)	Minimum Operating Pressure (psia)
Minimum Operating Pressure - (Method B)	1,611	1,625
Minimum Operating Pressure - (Method C)	2,149	2,163

3. Calculate minimum operating densities

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 temperature (for Method B) or Condition 1 entropy (for Method C).

Condition 2 - MOP Densities	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_2
Minimum Operating Density - High Temp (Method B)	1,611	1,625	120	7.166
Minimum Operating Density - Normal (Method B)	1,611	1,625	90	7.623
Minimum Operating Density - Low Temp (Method B)	1,611	1,625	60	8.155
Minimum Operating Density - High Temp (Method C)	2,149	2,163	83	10.144
Minimum Operating Density - Normal (Method C)	2,149	2,163	55	10.826
Minimum Operating Density - Low Temp (Method C)	2,149	2,163	27	11.627

4. Calculate optimum precharge density

Optimum precharge density

- *Method B: $\rho_0 = 1.0/(1.4/\rho_{2BL} - 1.4/\rho_{1BL} + 1.0/\rho_{1BH})$*
- *Method C: $\rho_0 = 1.0/(1.0/\rho_{2CL} - 1.0/\rho_{1CL} + 1.0/\rho_{1CH})$*
- *See Annex C for Derivation*

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure - Method B	6.517	90	1,367	1,382
Optimum Precharge Pressure - Method C	10.350	90	2,235	2,249

Calculate the overall optimum precharge that satisfies requirements for both Method B and Method C. See Annex C for explanation.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Overall Optimum Precharge Pressure	9.857	90	2,119	2,134

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- *maintaining precharge pressure below the maximum rated working pressure*
- *maintaining precharge pressure above 25% of system working pressure*
- *permitting a range of precharge pressures during operations*
- *following manufacturer's recommendations.*

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_0
Selected Precharge Pressure at Precharge Temperature		2,119	2,134	90	9.857
Selected Precharge Pressure at Minimum Temperature		1,968	1,983	60	9.857
Selected Precharge Pressure at Maximum Temperature		2,269	2,284	120	9.857

Precharge Verification

Accumulator Precharge Pressure at Minimum Temperature	Precharge pressure (1983 psia) is greater than 25% of charged accumulator pressure (754 psia).
Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (2270 psig) is less than accumulator rated working pressure (3000 psig).

6. Determine volumetric efficiencies

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft^3)
Condition 0: Precharged Accumulators	90	2,119	2,134	9.857
Condition 1: Charged accumulators @ 3000 psi	90	3,000	3,015	13.429
Condition 1: Charged accumulators @ 2700 psi	90	2,700	2,715	12.259
Condition 2: Minimum Operating Pressure - (Method B)	90	1,611	1,625	7.623
Condition 2: Minimum Operating Pressure - (Method C)	55	2,149	2,163	10.826

Method B Volumetric Efficiencies

Pressure Limited $VE_{PL} = (\rho_0/\rho_{2BL} - \rho_0/\rho_{1BL})/1.0$	0.523
Volume Limited $VE_{VH} = (1.0-\rho_0/\rho_{1BH})/1.4$	0.157
Volumetric Efficiency $VE_B = \min(VE_{PL}, VE_{VH})$	0.157
Accumulator Volume Required (gal) $ACR_B = FVR_B/VE_B$	546.6

Method C Volumetric Efficiencies

Pressure Limited $VE_{PL} = (\rho_0/\rho_{2CL} - \rho_0/\rho_{1CL})/1.1$	0.088
Volume Limited $VE_{VH} = (1.0-\rho_0/\rho_{1CH})/1.1$	0.131
Volumetric Efficiency $VE_C = \min(VE_{PL}, VE_{VH})$	0.088
Accumulator Volume Required (gal) $ACR_C = FVR_C/VE_C$	546.6

Minimum Accumulator Volume Required (gal) = $\max(ACR_B, ACR_C)$	546.6

Figure D.6: *The content shall be replaced with the following:*

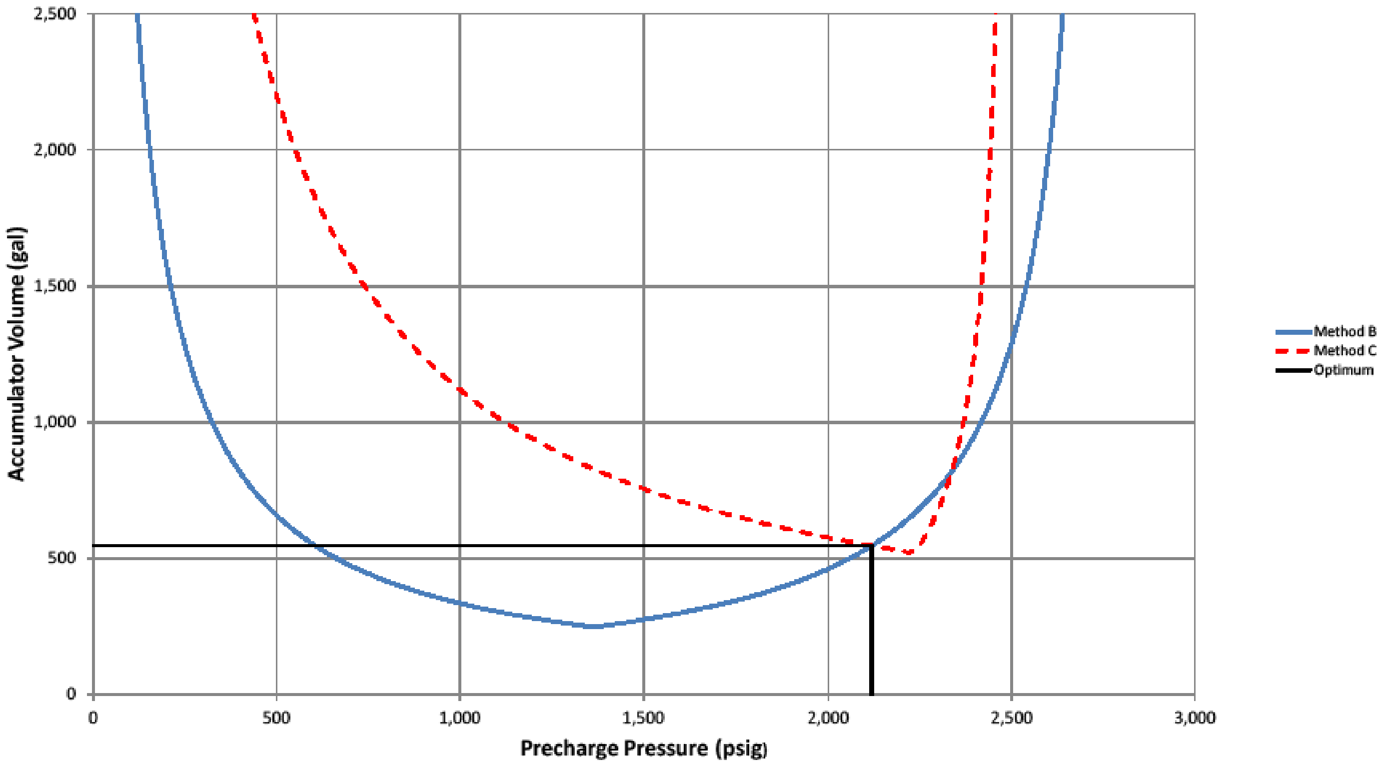

Table D.10: *The content shall be replaced with the following:*

Example 7, 8, 9, 10 & 11: BOP Stack Configuration for *Subsea BOP Stack*

The following examples size accumulators for a subsea MUX BOP. The main surface, pod pilot, deadman/autoshear, acoustic and diverter accumulators will be sized.

Stack	Rated Working Pressure (psia)	Pressure Required / MOPFLPS (psig)	Closing Volume (gal)	Opening Volume (gal)	Closing/Shearing Ratio	
Upper Annular BOP, 18-3/4"	10,000	1,500	85.30	64.80	-	
Lower Annular BOP, 18-3/4"	10,000	1,500	85.30	64.80	-	
Upper Blind Shear Ram, 18-3/4"	15,000	1,710	40.30	35.00	15.24	Shearing
		520			6.40	Sealing
Casing Shear Ram, 18-3/4"	15,000	2,035	40.30	35.00	15.24	
Lower Blind Shear Ram, 18-3/4"	15,000	1,710	40.30	35.00	15.24	Shearing
		520			6.40	Sealing
Upper Pipe Ram, 18-3/4"	15,000	750	20.75	17.30	7.20	
Middle Pipe Ram, 18-3/4"	15,000	750	20.75	17.30	7.20	
Lower Pipe Ram, 18-3/4"	15,000	750	20.75	17.30	7.20	

Pod Pilot System - Volume to pilot EDS with Largest Volume Demand		
QTY	Size	Total Volume (gal)
1	1.5" SPM	0.0059
1	1.0" SPM	0.0026
1	0.5" SPM	0.0016
	Total	0.0102
	200%	0.0204

Pod Pilot System - Volume to pilot all BOPs closed and open		
QTY	Size	Total Volume (gal)
1	1.5" SPM	0.0119
1	1.0" SPM	0.0052
1	0.5" SPM	0.0000
	Total	0.0171
	200%	0.0342

Acoustic Functions	Volume (gal)
Upper Blind Shear Ram*	40.30
Casing Shear Ram*	40.30
Upper Pipe Ram	20.75
Middle Pipe Ram	20.75
All Stabs Retract	5.00
Riser Connector Primary + SecondaryUnlatch	25.00
Total	152.10
Total*	71.50

**Volume to operate UBSR and CSR not included in sizing of acoustic accumulators. Volume for shear rams will be shared with the deadman/autoshear accumulators.*

System Parameters				
System Pressure	5,000	psig		
Regulated Supply Pressure	3,000	psig		
Riser Air Gap	75	ft		
Control Fluid Air Gap	75	ft		
Control Fluid Weight	8.34	ppg	→ 5,463	psia
Sea Water Weight	8.54	ppg	→ 5,560	psia
Water Depth	12,500	ft		

Environmental Conditions		
Surface Temperature at Precharge	90	°F
Maximum Surface Temperature	120	°F
Subsea Operating Temperature	35	°F
Atmospheric Pressure	14.7	psia

Diverter System		
Function	Pressure (psig)	Volume (gal)
Sequence	1,500	11.00
Diverter	2,000	25.00
	Total	36.00

Relevant References

Pump System

- Primary pump start at 90% of system RWP
- Primary pump stop between 98%-100% of system RWP

Ex. 7 Main Accumulator System

- Example rig uses dedicated shear accumulators for high pressure shear ram closure

Drawdown Test
- Close and open largest annular and 4 smallest ram BOPs
- Use pump stop pressure
- Method B

Well Control Sequence.
- Close annular and pipe ram
- Use pump start pressure
- Method C
*Volume for shear rams provided by dedicated shear accumulators

Ex. 8 Pod Pilot Accumulators

- 200% of volume to close and open all BOPs (Method B)
- 200% of volume to operate most demanding EDS sequence. (Method C)
- Minimum Pressure Required to pilot control valve: 1,500 psig
- Minimum Pressure Required by hydraulically piloted regulators: 1,500 psig

Ex. 9 DMAS Accumulators

- Example rig's emergency accumulators are supplied by the main accumulator system and are checked in, therefore, pump stop pressure is used
- Method C

Ex. 10 Acoustic Accumulators

- Shear and seal function (casing shear ram and blind shear ram) volume shared with DMAS accumulators
- Example rig's acoustic accumulators are supplied by the main accumulator system and are checked in, therefore, pump stop pressure is used
- Acoustic EDS not utilized by example rig.
- Method B

Ex. 11 Diverter Accumulators

- Example rig's diverter accumulators are supplied by the main accumulator system and are checked in, therefore, pump stop pressure is used
- Method C

Table D.11: *The content shall be replaced with the following:*

Example 7: Subsea Stack - Main Accumulator Sizing

Main Accumulator

This worksheet details the sizing calculations for the Main Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s) - Accumulator Drawdown (Method B)	Rated Working Pressure (psig)*	Opening Volume (gal)	Closing Volume (gal)	Closing Ratio**	Pressure to Close Against RWP (psig)
Upper Annular BOP, 18-3/4"	10,000	64.80	85.30		1,500
Upper Blind Shear Ram, 18-3/4"	15,000	35.00	40.30	6.40	2,344
Upper Pipe Ram, 18-3/4"	15,000	17.30	20.75	7.20	2,083
Middle Pipe Ram, 18-3/4"	15,000	17.30	20.75	7.20	2,083
Lower Pipe Ram, 18-3/4"	15,000	17.30	20.75	7.20	2,083

Pressure Required (psig) to Close Blind Shear Ram against Rated Working Pressure = Rated Working Pressure / Closing Ratio = 15000 / 6.4 = 2343.8

Total Functional Volume Requirement (FVR_B)	339.55	gal
Pressure Required	2,344	psig

* Rated working pressure for the main accumulators on a subsea stack is taken as a gauge pressure. See annex section B4.

**Use the sealing ratio for the drawdown test calculations when a shear ram has a different closing ratio for shearing and sealing.

Operator Function(s) - Well Control Sequence (Method C)***	Rated Working Pressure (psig)*	Pressure Required / MOPFLPS (psig)	Closing Volume (gal)	Closing Ratio	Adjusted Pressure Required (psig)
Upper Annular BOP, 18-3/4"	10,000	1,500	85.30		1,500
Middle Pipe Ram, 18-3/4"	15,000	750	20.75	7.20	2,833

Minimum Pressure Required (psig) to Seal with Pipe Ram = MOPFLPS + (Rated Working Pressure - Seawater Static Pressure) / Closing Ratio = 750 + (15000 - 5560) / 7.2 = 2833.4

***Volume for shear rams provided by dedicated emergency accumulators.

Total Functional Volume Requirement (FVR_C)	106.05	gal
Pressure Required	2,833	psig

Environmental Conditions		
Water Depth	12,500	ft
Control Fluid Air Gap	75	ft
Riser Air Gap	75	ft
Control Fluid Weight	8.34	ppg
Seawater Weight	8.54	ppg
Control Fluid Static Pressure	5,463	psia
Seawater Static Pressure	5,560	psia
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Subsea Operating Temperature	35	°F
Maximum Surface Temperature	120	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	5,000	psig
Pump Stop Pressure (Method B - 100%)	5,000	psig
Pump Start Pressure (Method C - 90%)	4,500	psig

Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density and entropy based upon gas temperature and absolute pressure.

Charged Accumulator Pressure (psia) = Surface Supply Pressure + Atmospheric Pressure = 5000 + 14.7 = 5014.7

Condition 1 - Charged Accumulator Density	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_1	Entropy S_1
Charged Condition - (Method B)	5,000	5,015	90	20.001	
Charged Condition - (Method C)	4,500	4,515	90	18.547	1.1999016

2. Calculate minimum operating pressures

Calculate the minimum operating pressures for each case and adjust for hydrostatic effects.

Minimum Operating Pressure (psia) = Surface Pressure Required + Seawater Hydrostatic Absolute Pressure = 2834 + 5560 = 8393.4

Minimum Operating Pressure (psig) = Minimum Operating Pressure (psia) - Control Fluid Head = 8394 - 5463 = 2930.4

Calculate MOPs	Pressure Required (psig)***	Minimum Operating Pressure (psig)****	Minimum Operating Pressure (psia)****
Minimum Operating Pressure - (Method B)	2,344	2,441	7,904
Minimum Operating Pressure - (Method C)	2,833	2,930	8,393

*** When stack is on surface

****When stack is subsea

3. Calculate minimum operating densities

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 temperature (for Method B) or Condition 1 entropy (for Method C).

Condition 2 - MOP Densities	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_2
Minimum Operating Density - (Method B)	2,441	2,455	90	11.209
Minimum Operating Density - (Method C)	2,930	2,945	28	15.249

4. Calculate optimum precharge density

Optimum precharge density

- Method B: $\rho_0 = 1.0/(1.4/\rho_2 - 0.4/\rho_1)$

- Method C: $\rho_0 = \rho_2$

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft³)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure - (Method B)	9.533	90	2,043	2,058
Optimum Precharge Pressure - (Method C)	15.249	90	3,494	3,509

Calculate the overall optimum precharge that satisfies requirements for both Method B and Method C. See Annex C for explanation.

Condition 0	Optimum Precharge Density (lbm/ft³)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Overall Optimum Precharge Pressure	10.255	90	2,212	2,227

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- maintaining precharge pressure below the maximum rated working pressure

- maintaining precharge pressure above 25% of system working pressure

- permitting a range of precharge pressures during operations

- following manufacturer's recommendations.

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_0
Selected Precharge Pressure at Precharge Temperature		2,212	2,227	90	10.255
Selected Precharge Pressure at Maximum Temperature		2,370	2,385	120	10.255

Precharge Verification

Greater than 25% of Accumulator Charged Pressure	Precharge pressure (2227 psia) is greater than 25% of charged accumulator pressure (1254 psia).
Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (2370 psig) is less than accumulator rated working pressure (5000 psig).

6. Determine volumetric efficiencies

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft³)
Condition 0: Precharged Accumulators	90	2,212	2,227	10.255
Condition 1: Charged accumulators @ 5000 psi	90	5,000	5,015	20.001
Condition 1: Charged accumulators @ 4500 psi	90	4,500	4,515	18.547
Condition 2: Minimum Operating Pressure (Method B)	90	2,441	2,455	11.209
Condition 2: Minimum Operating Pressure (Method C)	28	2,930	2,945	15.249

Method B Volumetric Efficiencies

Pressure Limited $VE_P = (\rho_0/\rho_{2B} - \rho_0/\rho_{1B})/1.0$	0.402
Volume Limited $VE_V = (1.0-\rho_0/\rho_{1B})/1.4$	0.348
Volumetric Efficiency $VE_B = \min(VE_P, VE_V)$	0.348
Minimum Accumulator Volume Required (gal) $ACR_B = FVR_B/VE_B$	975.5

Method C Volumetric Efficiencies

Pressure Limited $VE_P = (\rho_0/\rho_{2C} - \rho_0/\rho_{1C})/1.1$	0.109
Volume Limited $VE_V = (1.0-\rho_0/\rho_{1C})/1.1$	0.406
Volumetric Efficiency $VE_C = \min(VE_P, VE_V)$	0.109
Min. Accumulator Volume Required (gal) $ACR_C = FVR_C/VE_C$	975.5

Overall Min. Accumulator Volume Required (gal) = $\max(ACR_B, ACR_C)$	975.5

Figure D.7: *The content shall be replaced with the following:*

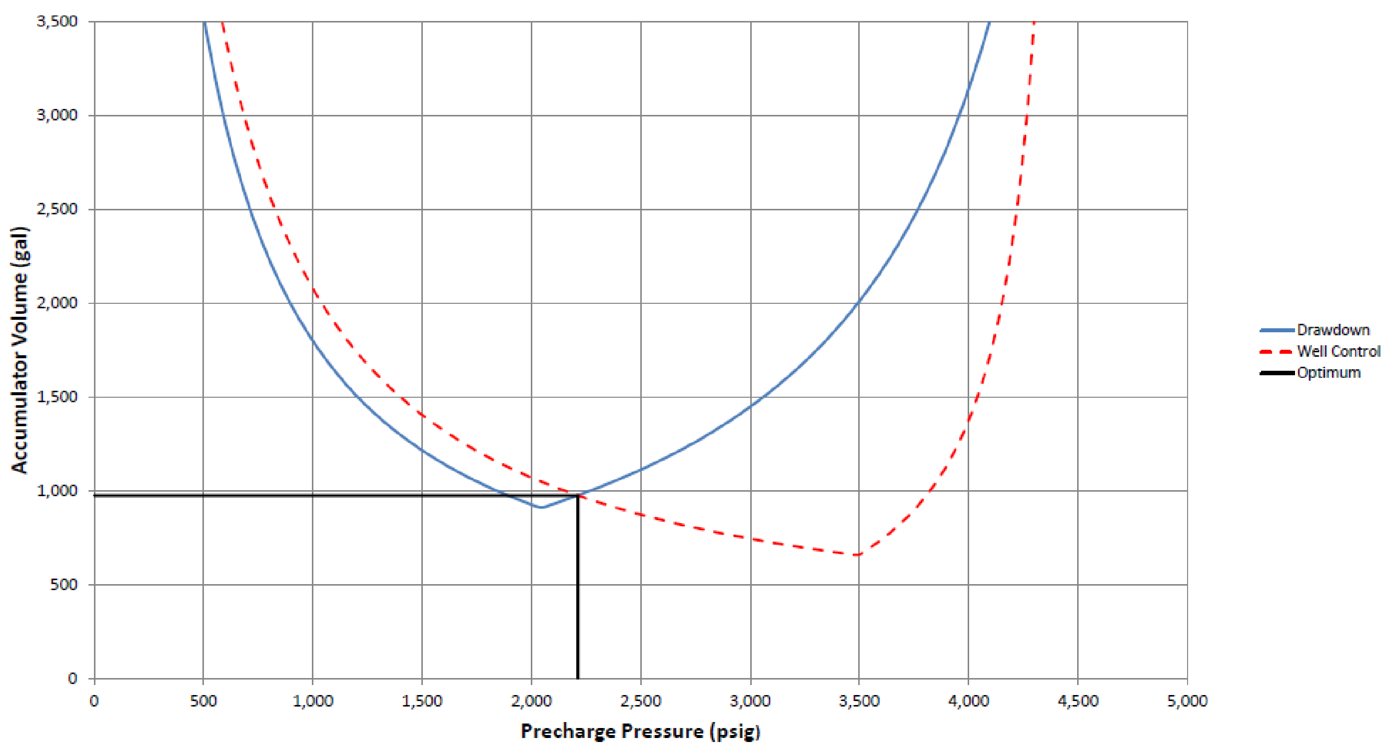

Table D.12: *The content has been updated to incorporate regulator setting for MOPFLPS at RWP and shall be replaced with the following:*

Example 8: Subsea Stack - Pilot System Accumulator Sizing

Pilot Accumulator

This worksheet details the sizing calculations for the Pilot Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s) - Open & Close all BOPs (Method B)	Valve Size (in.)	Pilot Open Volume (gal)	Pilot Close Volume (gal)	Pilot Pressure Required by Control Valve (psig)
Upper Annular BOP, 18-3/4"	1.5	0.006	0.006	1,500
Lower Annular BOP, 18-3/4"	1.5	0.006	0.006	1,500
Upper Blind Shear Ram, 18-3/4"	1.0	0.003	0.003	1,500
Casing Shear Ram, 18-3/4"	1.0	0.003	0.003	1,500
Lower Blind Shear Ram, 18-3/4"	1.0	0.003	0.003	1,500
Upper Pipe Ram, 18-3/4"	1.0	0.003	0.003	1,500
Middle Pipe Ram, 18-3/4"	1.0	0.003	0.003	1,500
Lower Pipe Ram, 18-3/4"	1.0	0.003	0.003	1,500

Volume to open and close all BOPs	0.060	gal
200% of volume to open and close all BOPs (FVR $_B$)	0.120	gal
Pressure Required	1,500	psig

Operator Function(s) - Emergency Disconnect Sequence (Method C)	Valve Size (in.)	Pilot Volume Required (gal)	Pilot Pressure Required by Control Valve (psig)
DMAS system Arm	0.5	0.002	1,500
Casing Shear Ram Close	1.0	0.003	1,500
Choke & Kill Stabs Retract	0.5	0.002	1,500
Wetmate Connector Retract	0.5	0.002	1,500
Acoustic Stabs Retract	0.5	0.002	1,500
Blind Shear Rams Close	1.0	0.003	1,500
Riser Connector Unlock - Primary	1.0	0.003	1,500
Riser Connector Unlock - Secondary	1.0	0.003	1,500

Minimum pilot pressure Required by Hydraulically Piloted Regulator (psig)
1,500

Volume to pilot largest demand EDS	0.020	gal
200% of volume to pilot largest demand EDS (FVR $_C$)	0.040	gal
Pressure Required	1,500	psig

Environmental Conditions		
Water Depth	12,500	ft
Control Fluid Air Gap	75	ft
Riser Air Gap	75	ft
Control Fluid Weight	8.34	ppg
Seawater Weight	8.54	ppg
Control Fluid Static Pressure	5,463	psia
Seawater Static Pressure	5,560	psia
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Subsea Operating Temperature	35	°F
Maximum Surface Temperature	120	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	7,500	psig
Subsea Regulated?	Yes	
Regulated Supply Pressure	3,000	psig

Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density and entropy based upon gas temperature and absolute pressure.

Charged Accumulator Pressure (psia) = Regulated Supply Pressure + Seawater Head = 3000 + 5560 = 8560

Charged Accumulator Pressure (psig) = Charged Accumulator Pressure (psia) - Seawater Head = 8560 - 5560 = 3000

Condition 1 - Charged Accumulator Density	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_1	Entropy S_1
Charged Condition - (Method B)	3,000	8,560	35	30.148	
Charged Condition - (Method C)	3,000	8,560	35	30.148	1.1094044

2. Calculate minimum operating pressures

Calculate the minimum operating pressures for each case and adjust for hydrostatic effects.

Minimum Operating Pressure (psia) = Pressure Required + Seawater Hydrostatic Absolute Pressure = 1500 + 5560 = 7060

Calculate MOPs	Pressure Required (psig)	Minimum Operating Pressure (psia)
Minimum Operating Pressure - (Method B)	1,500	7,060
Minimum Operating Pressure - (Method C)	1,500	7,060

3. Calculate minimum operating densities

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 temperature (for Method B) or Condition 1 entropy (for Method C).

Condition 2 - MOP Densities	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_2	Entropy S_2
Minimum Operating Density - (Method B)	1,500	7,060	35	27.372	
Minimum Operating Density - (Method C)	1,500	7,060	12	28.541	1.1094044

4. Calculate optimum precharge density

Optimum precharge density

- Method B: $\rho_0 = 1.0/(1.4/\rho_2 - 0.4/\rho_1)$

- Method C: $\rho_0 = \rho_2$

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure - (Method B)	26.399	90	7,804	7,819
Optimum Precharge Pressure - (Method C)	28.541	90	9,044	9,059

Calculate the overall optimum precharge that satisfies requirements for both Method B and Method C. See Annex C for explanation.

Condition 0	Optimum Precharge Density (lbm/ft^3)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Overall Optimum Precharge Pressure	26.399	90	7,804	7,819

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- *maintaining precharge pressure below the maximum rated working pressure*
- *maintaining precharge pressure above 25% of system working pressure*
- *permitting a range of precharge pressures during operations*
- *following manufacturer's recommendations.*

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft^3) ρ_0
Selected Precharge Pressure at Precharge Temperature	6900	6,900	6,915	90	24.609
Selected Precharge Pressure at Operating Temperature		284	5,844	35	24.609
Selected Precharge Pressure at Maximum Temperature		7,478	7,493	120	24.609

NOTE: The optimum precharge exceeds the accumulator RWP at maximum temperature. Therefore, a lower precharge has been selected.

Precharge Verification

Accumulator Precharge Pressure at Minimum Temperature	Precharge pressure (5844 psia) is greater than 25% of charged accumulator pressure (2140 psia).
Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (7478 psig) is less than accumulator rated working pressure (7500 psig).

6. Determine volumetric efficiencies

Use the NIST fluid property references to determine accumulator absolute pressure using the Condition 0 density and Condition 1 entropy or temperature

Condition 3	Density (lbm/ft^3) ρ_3	Entropy S_3	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)
Total Discharge - (Method B)	24.609		284	5,844	35
Total Discharge - (Method C)	24.609	1.1094044	-1,219	4,341	-41

Use the NIST fluid property references to determine gas density using Condition 1 entropy or temperature and the Seawater Head for accumulator pressure

Condition 3	Density (lbm/ft^3) ρ_3	Entropy S_3	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)
Seawater Hydrostatic Limit - (Method B)	23.878		0	5,560	35
Seawater Hydrostatic Limit - (Method C)	26.590	1.1094044	0	5,560	-15

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft^3)
Condition 0: Precharged Accumulators	90	6,900	6,915	24.609
Condition 1: Charged accumulators - (Method B)	35	3,000	8,560	30.148
Condition 1: Charged accumulators - (Method C)	35	3,000	8,560	30.148
Condition 2: Minimum Operating Pressure (Method B)	35	1,500	7,060	27.372
Condition 2: Minimum Operating Pressure (Method C)	12	1,500	7,060	28.541
Condition 3: Total Discharge - (Method B)	35	284	5,844	24.609
Condition 3: Seawater Hydrostatic Limit - (Method C)	-15	0	5,560	26.590

Method B Volumetric Efficiencies

Pressure Limited $VE_P = (\rho_0/\rho_{2B} - \rho_0/\rho_{1B})/1.0$	0.083
Volume Limited $VE_V = (1.0 - \rho_0/\rho_{1B})/1.4$	0.131
Cond. 3 - Hydrostatic Limited $VE_V = (\rho_0/\rho_{3B} - \rho_{0B}/\rho_{1B})/1.4$	NR
Volumetric Efficiency $VE_B = \min(VE_P, VE_V)$	0.083
Minimum Accumulator Volume Required (gal) $ACR_B = FVR_B/VE_B$	1.449

Method C Volumetric Efficiencies

Pressure Limited $VE_P = (\rho_0/\rho_{2C} - \rho_0/\rho_{1C})/1.1$	0.042
Volume Limited $VE_V = (1.0 - \rho_0/\rho_{1C})/1.1$	NR
Cond. 3 - Hydrostatic Limited $VE_V = (\rho_{0C}/\rho_{3C} - \rho_{0C}/\rho_{1C})/1.1$	0.099
Volumetric Efficiency $VE_C = \min(VE_P, VE_V)$	0.042
Minimum Accumulator Volume Required (gal) $ACR_C = FVR_C/VE_C$	0.957

Overall Min. Accumulator Volume Required (gal) = max (ACR_B, ACR_C)	1.449

Figure D.8: *The content shall be replaced with the following:*

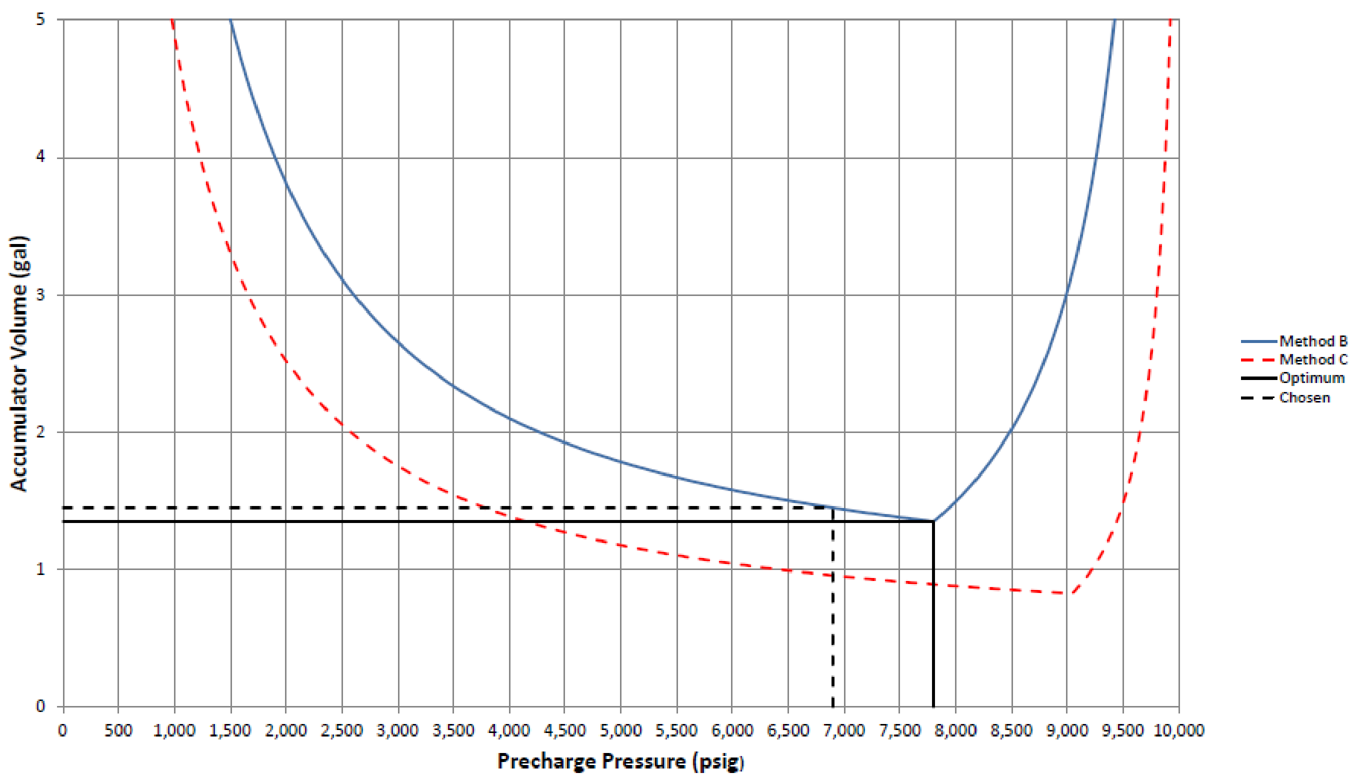

Table D.16: *The content shall be replaced with the following:*

Example 12 & 13: BOP Stack Configuration for *Special Purpose Accumulators*

The following examples size accumulators for special purpose functions. The deadman/autoshear (with Depth Compensated Bottles) and choke & kill valve closure assist accumulators will be sized.

Stack	Rated Working Pressure (psia)	Pressure Required / MOPFLPS (psig)	Closing Volume (gal)	Opening Volume (gal)	Closing/Shearing Ratio	
Upper Annular BOP, 18-3/4"	10,000	1,500	85.30	64.80	-	
Lower Annular BOP, 18-3/4"	10,000	1,500	85.30	64.80	-	
Upper Blind Shear Ram, 18-3/4"	15,000	1,710	40.30	35.00	15.24	Shearing
		520			6.40	Sealing
Casing Shear Ram, 18-3/4"	15,000	2,035	40.30	35.00	15.24	
Lower Blind Shear Ram, 18-3/4"	15,000	1,710	40.30	35.00	15.24	Shearing
		520			6.40	Sealing
Upper Pipe Ram, 18-3/4"	15,000	750	20.75	17.30	7.20	
Middle Pipe Ram, 18-3/4"	15,000	750	20.75	17.30	7.20	
Lower Pipe Ram, 18-3/4"	15,000	750	20.75	17.30	7.20	
Choke & Kill Valve	15,000	780	0.65	0.65	-	

System Parameters				
System Pressure*	5,000	psig		
Regulated Pressure**	3,000	psig		
Riser Air Gap	75	ft		
Control Fluid Air Gap	75	ft		
Control Fluid Weight	8.34	ppg	→ 5,463	psia
Sea Water Weight	8.54	ppg	→ 5,561	psia
Water Depth	12,500	ft		

*For Example 12
**For Example 13

Environmental Conditions		
Surface Temperature at Precharge	90	°F
Maximum Surface Temperature	120	°F
Subsea Operating Temperature	35	°F
Atmospheric Pressure	14.7	psia

Relevant References

Pump System

- Primary pump start at 90% of system RWP
- Primary pump stop between 98%-100% of system RWP

Ex. 12 DMAS Accumulators

- Example rig's emergency accumulators are supplied by the main accumulator system and are checked in, therefore, pump stop pressure is used
- Method C

Ex. 13 Choke & Kill Closure Assist Accumulators

- Hydraulic charge pressure (regulated 3 KSI)
- Method C
- accumulator system to close all inner choke & kill valves (qty 6)

Table D.17: *The content shall be updated to remove the term "Bladder" from "Depth Compensated Bladder Accumulator", and shall be replaced with the following:*

Example 12: Special Purpose - Subsea Depth Compensated Accumulator Sizing

Depth Compensated Accumulator

This worksheet details the sizing calculations for the Depth Compensated Accumulator utilizing API 16D 3rd. Edition calculations.

Operator Function(s)	Sequence	Rated Working Pressure (psia)	Pressure Required (psig)		Function Volume (gal)	Closing or Shearing Ratio	Adjusted Pressure (psig)
Casing Shear Ram, 18-3/4"	1	15,000	2,035	Shear	40.30	15.24	2,654
Timing Circuit	2	3,000 psig	1,500		1.00	-	1,500
Upper Blind Shear Ram, 18-3/4"	2	15,000	1,710	Shear	40.30	15.24	2,329
			520	MOPFLPS		6.20	2,042

Pressure Required (psig) to Shear with Casing Shear Ram = Shear Pressure + (Rated Working Pressure - Seawater Static Pressure) / closing ratio = 2035 + (15000 - 5561) / 15.24 = 2654.4
Pressure Required (psig) to Shear with Blind Shear Ram = Shear Pressure + (Rated Working Pressure - Seawater Static Pressure) / closing ratio = 1710 + (15000 - 5561) / 15.24 = 2329.4
Minimum Pressure Required (psig) to Seal with Blind Shear Ram = MOPFLPS + (Rated Working Pressure - Seawater Static Pressure) / closing ratio = 520 + (15000 - 5561) / 6.2 = 2042.5

Sequence	1	2	
Total Functional Volume Requirement (FVR)	40.30	41.30	gal
Pressure Required	2,654	2,329	psig

Environmental Conditions		
Water Depth	12,500	ft
Control Fluid Air Gap	75	ft
Riser Air Gap	75	ft
Control Fluid Weight	8.34	ppg
Seawater Weight	8.54	ppg
Control Fluid Static Pressure	5,463	psia
Seawater Static Pressure	5,561	psia
Atmospheric Pressure	14.7	psia
Surface Temperature at Precharge	90	°F
Subsea Operating Temperature	35	°F
Maximum Surface Temperature	120	°F

Accumulators		
Precharge Gas	Nitrogen	
Accumulator RWP	10,000	psig
Area Ratio (AR)	1.1738	
Gas Volume (per accumulator)	158.3330	gal
Hydraulic Volume (per accumulator)	20.6600	gal
Quantity of accumulators	5	
Subsea Regulated	no	
Pump Start Pressure (100%)	5,000	psig

Legend	
Input	Rig specific data
Transfer	Transferred within worksheet
Calculated	Calculated from table data
NIST	Data from NIST reference program

1. Calculate accumulator conditions at charged state

Use NIST fluid property references to determine gas density and entropy based upon gas temperature and absolute pressure.

Charged Hydraulic Accumulator Pressure (psia) = Surface Supply Pressure + Control Fluid Hydrostatic Absolute Pressure = 5000 + 5463 = 10463
Charged Hydraulic Accumulator Pressure (psig) = Charged Hydraulic Accumulator Pressure (psia) - Seawater Hydrostatic Absolute Pressure = 10463 - 5561 = 4902
Charged Gas Accumulator Pressure (psia) = (Charged Hydraulic Accumulator Pressure (psia) - Seawater Head) / Area Ratio = (10463 - 5561) / 1.1738 = 4176.2

Condition 1 - Charged Accumulator Density	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_1	Entropy S_1
Charged Condition - Gas	NR	4,176	35	19.717	1.1722480
Charged Condition - Hydraulic	4,902	10,463	NR	NR	NR

2. Calculate minimum operating pressure(s)

Calculate the minimum operating pressures for each step within the sequence and adjust for hydrostatic effects.

Minimum Operating Pressure (psia) = Pressure Required + Seawater Hydrostatic Absolute Pressure = 2655 + 5561 = 8215.4

Calculate MOP(s)	Pressure Required (psig)	Minimum Operating Pressure (psia)
Minimum Operating Pressure - Sequence 1	2,654	8,215
Minimum Operating Pressure - Sequence 2	2,329	7,890

3. Calculate minimum operating density(s)

Use NIST fluid property references to determine gas density at MOP based upon absolute pressure and Condition 1 entropy.

Condition 2 - MOP Density(s)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Entropy S_2	Density (lbm/ft³) ρ_2	Temperature (°F)
Minimum Operating Density - Sequence 1 Gas	NR	2,261	1.1722480	15.007	-42
Minimum Operating Density - Sequence 1 Hydraulic	2,654	8,215	NR	NR	NR
Minimum Operating Density - Sequence 2 Gas	NR	1,984	1.1722480	14.076	-57
Minimum Operating Density - Sequence 2 Hydraulic	2,329	7,890	NR	NR	NR

4. Calculate optimum precharge density

Optimum precharge density $\rho_0 = \rho_2$.

Use NIST fluid property references to determine gas absolute pressure based upon gas temperature and density.

Condition 0	Optimum Precharge Density (lbm/ft³)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure - Sequence 1	15.007	90	3,426	3,441
Optimum Precharge Pressure - Sequence 2	14.076	90	3,172	3,186

If sequence consists of 2 functions, then calculate the optimum precharge that satisfies both functions, otherwise use the optimum precharge for the single function. See Annex C for explanation of two function optimum precharge.

Condition 0	Optimum Precharge Density (lbm/ft³)	Temperature (°F)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)
Optimum Precharge Pressure	14.076	90	3,172	3,186

5. Determine precharge density

Actual precharge pressure can vary from optimal precharge pressure for reasons such as:

- *maintaining precharge pressure below the maximum rated working pressure*
- *preventing accumulator piston from stroking out.*
- *maintaining total discharge pressure above seawater hydrostatic pressure*
- *permitting a range of precharge pressures during operations*
- *following manufacturer's recommendations.*

NOTE: Depth Compensated accumulators are intended for use in deeper depths. If a system designed for deeper depth is used at shallower depths, calculations should be performed to verify they are sufficient for the application.

Surface precharge pressure should equal Optimum Precharge Pressure unless the volume of the accumulator supports a range of precharges

Precharge Gas Properties	User-Selected Precharge (psig)	Accumulator Pre-Charge Pressure (psig)	Accumulator Pre-Charge Pressure (psia)	Temperature (°F)	Density (lbm/ft³) ρ_0
Selected Precharge Pressure at Precharge Temperature		3,916	3,931	90	16.697
Selected Precharge Pressure at Maximum Temperature		4,226	4,241	120	16.697
Selected Precharge Pressure at Operating Temperature		3,346	3,360	35	16.697
Precharge Pressure at full stroke of piston*		3,916	3,931	90	16.697

** A check is done to ensure that piston does not reach the mechanical stop in the charged state. If it does, the pre-charge is adjusted to prevent this from occurring.*

Precharge Verification

Accumulator Precharge Pressure at Maximum Temperature	Precharge pressure (4226 psig) is less than accumulator rated working pressure (10000 psig).
Hydraulic Stroke Verification Check	Precharge pressure does not cause piston to reach full stroke.

6. Determine volumetric efficiencies

Use the NIST fluid property references to determine accumulator absolute pressure using the Condition 0 density and Condition 1 entropy

Condition 3	Density (lbm/ft³) ρ_3	Entropy S_3	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Temperature (°F)
Total Discharge - Gas	16.697	1.1722480	NR	2,841	-15
Total Discharge - Hydraulic	NR	NR	3,335	8,896	NR

Condition Summary	Temperature (°F)	Accumulator Pressure (psig)	Accumulator Pressure (psia)	Density (lbm/ft³)
Condition 0: Precharged Accumulators - Gas	90	NR	3,931	16.697
Condition 0: Precharged Accumulators - Gas (Subsea)	35	NR	3,360	16.697
Condition 1: Charged accumulators - Gas	35	NR	4,176	19.717
Condition 1: Charged accumulators - Hydraulic	NR	4,902	10,463	NR
Condition 2: Minimum Operating Pressure - Sequence 1 Gas	-42	NR	2,261	15.007
Condition 2: Minimum Operating Pressure - Sequence 1 Hyd	NR	2,654	8,215	NR
Condition 2: Minimum Operating Pressure - Sequence 2 Gas	-57	NR	1,984	14.076
Condition 2: Minimum Operating Pressure - Sequence 2 Hyd	NR	2,329	7,890	NR
Condition 3: Total Discharge - Gas	-15	NR	2,841	16.697
Condition 3: Total Discharge - Hydraulic	NR	3,335	8,896	NR

Sequence 1

Pressure Limited $VE_P = (\rho_0/\rho_2 - \rho_0/\rho_1)/(1.1*AR)$ **	0.206
Volume Limited $VE_V = (1.0-\rho_0/\rho_1)/(1.1*AR)$ **	0.119
Volumetric Efficiency $VE_1 = \min(VE_P, VE_V)$	0.119
Gas Volume Required (gal) $ACR_1 = FVR_1/VE_1$	339.7

Sequence 2

Pressure Limited $VEP = (\rho0/\rho2 - \rho0/\rho1)/(1.1*AR)$ **	0.263
Volume Limited $VEV= (1.0-\rho0/\rho1)/(1.1*AR)$ **	0.119
Volumetric Efficiency $VE_2 = \min(VE_P, VE_V)$	0.119
Gas Volume Required (gal) $ACR_2 = FVR_2/VE_2$	687.9

** The area ratio of the accumulator must be included in the efficiency calculation as shown.

Min. Accumulator Gas Volume Required (gal) = max (ACR_1, ACR_2)	687.9
Minimum Quantity of accumulators required	5

Figure D.12: *The content shall be replaced with the following:*