Well Containment Screening Tool

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Well Containment Screening Tool

- A joint industry task force was established to develop an evaluation tool to demonstrate if a well design and equipment is adequate for Well Containment.
- The WCST analyzes the well's mechanical and geologic integrity to determine which of the 3 following categories the well falls into:
  - Full mechanical and geologic integrity
  - Mechanical or geologic integrity not intact, but consequence of failure is acceptable
  - Wellbore integrity does not exist and well cannot be shut-in without hydrocarbons escaping/broaching to sea

Level 1 Screening Tool

- Level 1 is designed to expedite approval for wells that can be fully shut-in without causing underground flow using very conservative assumptions and simple calculations

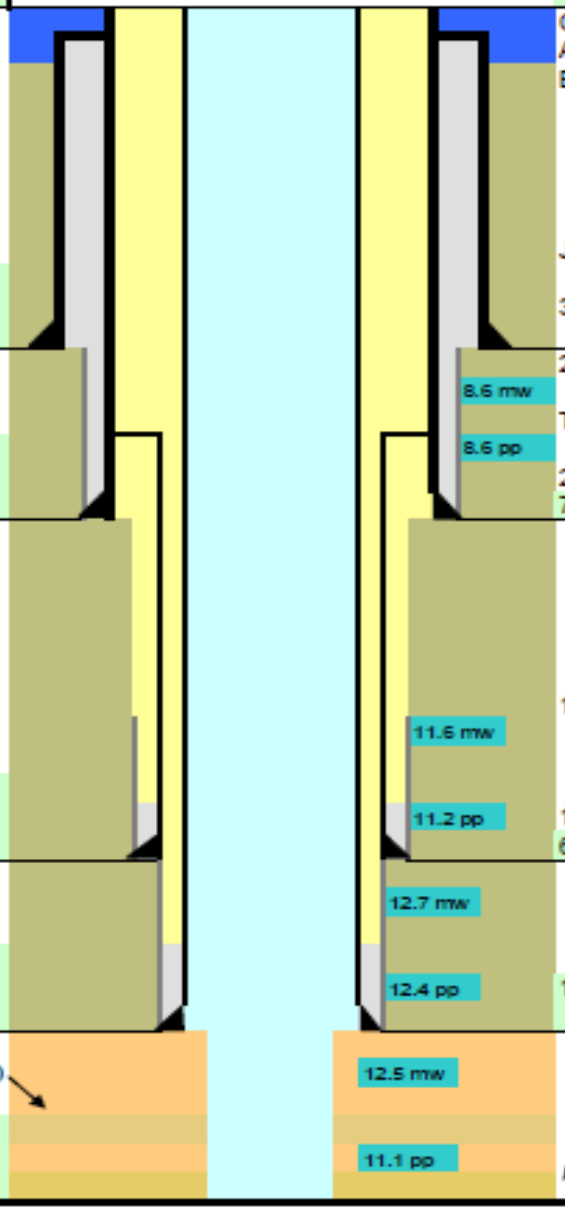
- The WCST analyzes 2 load cases:
  - Collapse during uncontrolled flow to seafloor.
  - Burst after shut-in with a full hydrocarbon gradient.

BOEMRE Well Containment Screening Tool Example Well
Wellbore Schematic

18-3/4" HP housing @ 5167' RKB (12' AML)
36" LP housing @ 5170' RKB (9' AML)
Mudline @ 5179' RKB (est)

RKB: 81'
Water Depth: 5098'

Top	(angle)	Bottom	CASING Burst	Collapse	MUD PP	MW	FG	CEMENT
			Capping Stack Rating = 15,000 psi Annular (below LMRP) = 10,000 psi BOP = 10,000 psi					
5170' TVD 5170' MD	0 degrees	5479' TVD 5479' MD	Jetted 36" 1.50" WT X80 552.69#			Seawater-Gel		Jet
5167' TVD 5167' MD	0 degrees	7880' TVD 7880' MD	26" hole TOL 16" 7338' MD 22" 1.25" WT X80 277.27#			Seawater-Gel 8.6-13 ppg mudline returns		TOC - Mudline 100% excess
			7950 psi	6670 psi	8.6	8.6	12.5	
7338' TVD 7338' MD	0 degrees	14400' TVD 14400' MD	16.5" x 20" hole 16" 0.715" WT HC N-80 118#			Synthetic		TOC - 13417' MD HID - 13909' TVD
			6260 psi	5750 psi	11.2	11.6	13.7	
5170' TVD 5170' MD	0 degrees	17438' TVD 17438' MD	14.25" x 17" hole 13-5/8" 0.625" WT Q125 88.20# cross over at 11500' TVD 13-3/8" 0.514" WT Q125 72.20#			Synthetic		TOC - 16672' MD HID - 17055' TVD
			10030 psi 13-5/8"	4800 psi				
			8410 psi 13-3/8"	2880 psi	12.4	12.7	14.65	
Weak Zone @ 20589' TVD/MD			12.25" hole			Synthetic		
17438' TVD 17438' MD	0 degrees	23790' TVD 23790' MD	Reservoir 1 - 23246' TVD Pore Pressure = 11.1 ppg Flowing = 0.280 psi/ft Static = 0.375 psi/ft		11.1	12.5		



General Well Information

THIS WORKSHEET IS VALID FOR WELLS WITH SUBSEA BOP STACKS ONLY.

1) General Well Information

Well Name:	Appraisal Well #1
Lease/Block:	Block XXX
Water Depth (ft):	6,941
RKB to Mudline Depth (ft):	7,047
Location (lat/long):	XXX Lat, YYY Long
Planned TD (ft):	20,500 ft -MD/TVD
Planned Spud Date:	MM/DD/YYYY

2) Offset Well Information

	Well	Distance/Direction
1)	Exploration Well 1	X.X miles SE
2)	Exploration Well 2	Y.Y miles SE
3)	Exploration Well 3	Z.Z miles SW
4)	Exploration Well 4	A.A miles NE
5)	Exploration Well 5	B.B miles NW
6)	Exploration Well 6	C.C miles NW

Casing Design Information

3) Well Design

Wellhead Description	GE Vetco DMS-700 Fullbore 2; 15,000 psi
Capping Stack Description	1 x NOV Ram Preventer; 15,000 psi

Casing Plan

Size/Weight/Grade/Connection	Top (ft-TVD)	Bottom (ft-TVD)
36", 552#, X56, RL-2HCX	7,047	7,347
22", 224.3#, X80, RL-4S	7,047	9,650
13-5/8", 88.2#, Q125, Hydril 513	7,047	12,700

Productive Formation Information

4) Productive Formation Information

HOLE SECTION: 12-1/4" SHOE DEPTH(FT-TVD): 12,700

Name	Depth (ft-TVD)	Reservoir Fluid	Reservoir Pressure (ppg)	Reservoir Pressure (psi)	Assumed fluid gradient for calc (psi/ft)	Mud Line Shut in Pressure (psi)	Shut in ppg @ shoe	Comments
Reservoir 1	16,210	Gas	9.43	7,949	0.15	6,574	11.24	
Reservoir 2	16,976	Oil	9.44	8,333	0.23	6,050	11.13	
Reservoir 3	18,408	Oil	10.78	10,319	0.23	7,706	13.64	
Reservoir 4				-		-	-	
Reservoir 5				-		-	-	
Reservoir 6				-		-	-	
Reservoir 7				-		-	-	

Level 1 assumptions are as follows:

- Gas fluid gradient = .1 - .15 psi/ft
- Fluid gradient of any mixture of oil, water or gas = .23 psi/ft

Formation Integrity Analysis

5) Formation Integrity Analysis Zone of interest	Depth	Frac gradient at depth (ppg)	Max pressure (ppge)	Is shut-in ppge< FG at depth?	Comments
Deepest exposed shoe	12,700	13.80	13.64	YES	
Other (e.g. base of salt or depleted zone)	15,400	12.80	12.02	YES	

- This section analyzes the deepest exposed shoe as well as any other potential loss zones in open hole to determine if there will be underground flow when the well is shut-in

Level 1 Burst Loads

Level 1 Survival DW Well Loads – Cap and Shut In

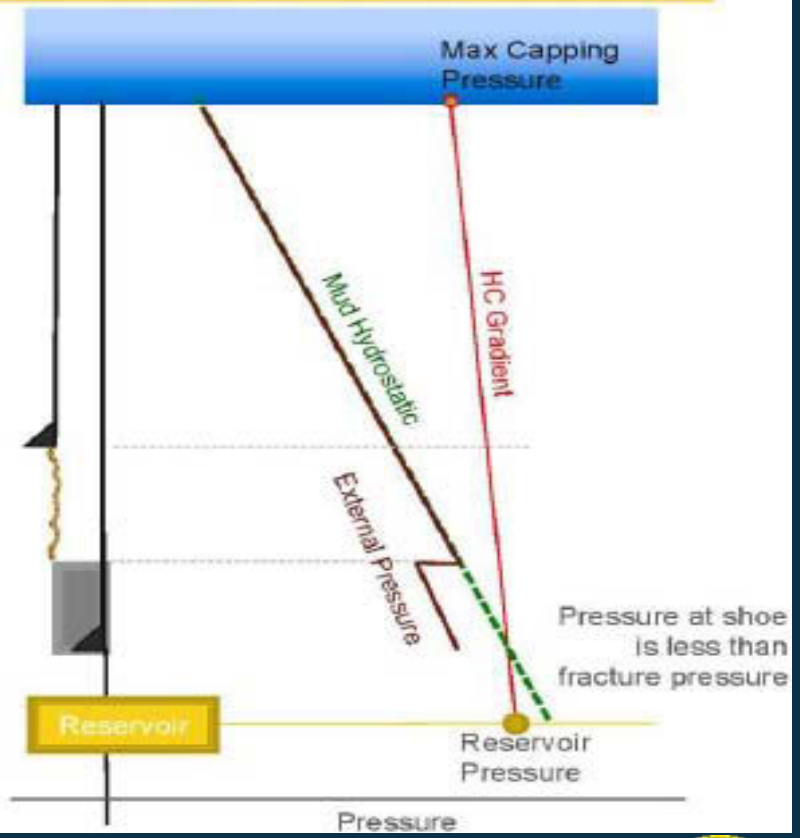
- Burst Case: Cap and Long Term Shut-In (Casing Annulus open to bleed APB to formation)

— Internal Pressure
  - At Reservoir Depth = Reservoir Pressure
  - At ML = Res Pressure – HC Gradient

— External
  - From ML to TOC = Mud Weight Casing was set in
  - In OH below top of cement = Pore Pressure

Assumptions

- Burst Rating in the Level One Screening is the eWell burst rating or the manufacturer rating for other components.
- The pressure calculated at the deepest exposed shoe does not exceed fracture gradient.
- HC gradient for gas <= 9,000', use 0.1 psi/ft. 9,000' to 11,000' linearly increase to 0.15 psi/ft. HC gradient for oil or mixed oil/gas/water use 0.23 psi/ft.
- External pressure assumes trapped pressure resulting from mud column hydrostatic when the seal was set.



Level 1 Burst Analysis

6) MECHANICAL INTEGRITY ANALYSIS

6.1 BURST ANALYSIS

Component	Burst Rating (psi)	Depth to Top of Component (ft)	Setting MW, PP or SW (ppg)	Exposed to SW? (above top hanger)	Internal Shut-in Pressure (psi)	External pressure (psi)	Burst Load (psi)	Design Factor	Comments
Capping BOP stack	15,000	7047	8.55	Y	7,706	3,086	4,620	3.24	
LMRP connector	15,000	7047	8.55	Y	7,706	3,086	4,620	3.24	
Drilling BOP stack	15,000	7047	8.55	Y	7,706	3,086	4,620	3.24	
Subsea Wellhead	15,000	7047	8.55	Y	7,706	3,086	4,620	3.24	
13-5/8" Casing Hanger/Seal Assembly	15,000	7047	10.10	N	7,706	3,701	4,005	3.74	
13-5/8" Casing	10,030	7047	10.10	N	7,706	3,701	4,005	2.50	
					-	-	-		
					-	-	-		
					-	-	-		
					-	-	-		

Trapped Annulus Screening

6.2 TRAPPED ANNULUS SCREENING Casing / Liner Strings (show all strings exposed to HC flow)	Enter string type	Is string or liner lap fully cemented?	Liner lap <= 500 ft?	Setting Depth (ft-MD)	Setting Depth (ft-TVD)	Planned TOC (ft-MD)	Planned TOC (ft-TVD)	Previous Shoe Depth (ft-MD)	Max Angle above previous shoe	Idle < 1 year?	Hydraulic Isolation Depth		Trapped Annulus?
											ft-MD	ft-TVD	
13-5/8" Casing	Casing	N	N	12,700	12,700	10,700	10,700	9,650	0	Y	11,700	11,700	NO
											-		N/A
											-		N/A
											-		N/A

- The 3 criteria are used to determine if an annulus is trapped
  - Distance between TOC and previous shoe is > 500', or cement column < 50% open hole length in measured depth
  - Hole angle is less than 30 degrees at previous shoe and above
  - Casing has not been idle for more than 1 year

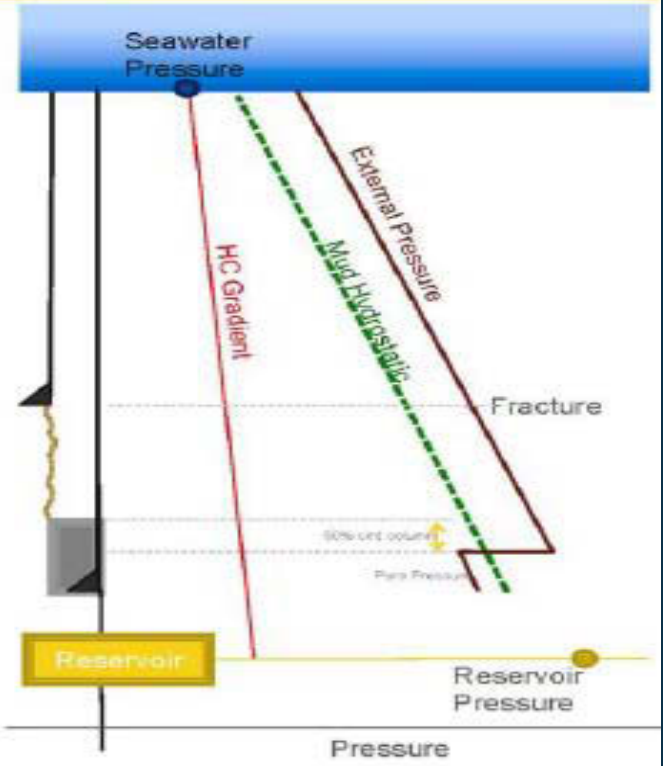
Level 1 Collapse Loads

Level 1 Survival Well Loads – WCD Collapse Loads

- Collapse Case for WCD to Sea Floor (Casing Annulus open to bleed APB to formation)
  - Internal Pressure
    - At Mudline = Seawater Hydrostatic Pressure
    - At Reservoir Depth = extrapolate to the deepest shoe using HC Gradient
  - External Pressure Profile
    - Above HID: Fracture pressure at previous shoe or weak formation in open hole above HID; project to other depths using as mud weight casing was run in.
    - Below HID: Local Pore Pressure

Assumptions:

- Hydraulic Isolation Depth (HID) = Shoe depth minus 50% of planned cement height
- Collapse Rating in the Level One Screening is the eWell collapse rating or the manufacturer rating for other components.
- HC gradient for gas <= 9,000', use 0.1 psi/ft. 9,000' to 11,000' linearly increase to 0.15 psi/ft. HC gradient for oil or mixed oil/gas/water use 0.23 psi/ft.
- Annular Pressure Buildup limited by Fracture Gradient at the previous shoe (unsealed case)
- Fracture gradient (including salt) based on PPFG submitted in APD



Screening based on Design Factor >= 1

Level 1 Collapse Analysis

6C) COLLAPSE ANALYSIS				Below HID	Above Hydr Isolation Depth				Un-trapped Annulus Calcs			
Component	Collapse rating (psi)	Depth of interest (ft TVD)	Hydraulic Isolation Depth (ft-TVD)	Pore Pressure @ Depth (ppg)	Previous Shoe Depth (ft-TVD)	Fracture Gradient @ Previous Shoe (ppg)	Setting Mud Weight (ppg)	Internal Pressure (psi)	External Pressure (psi)	Collapse Load (psi)	Design Factor	Comment
13-5/8" Casing	6370	12474	12,474		10,911.00	15.5	14.3	3,800	9,957	6,156	1.03	
14" Casing	11350	19622	18,675	12.3	10,911	15.5	14.3	5,444	12,550	7,106	1.59	
14" Casing	11350	18675	18,675		10,911	15.5	14.3	5,226	14,568	9,341	1.21	
								-	-	-		
								-	-	-		
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								-	-	-		

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Level 1 Acceptance Criteria

Screening tool results	
5. Shut in Pressure below formation integrity when well shut-in	PASS
6.1 Burst Integrity	PASS
6.2 Trapped annuli check	PASS
6.3 Collapse Integrity	PASS

- If a well does not pass all 4 of the above level 1 criteria than a level 2 is required for that hole interval

Level 2 Screening Tool

Level 2 WCST:

- Uses field/offset data and more advanced calculations to mitigate the probability of the failures identified in level 1.
- If the failure cannot be mitigated/eliminated then a consequence analysis is performed to see if failure is acceptable

Level 2 is based on the Level 1 WCST, with the following modified/additional calculations:

- Annulus pressure buildup for trapped annuli
- Secondary string collapse and burst verification
- Formation strength verification for failed strings

Primary and Secondary Casings

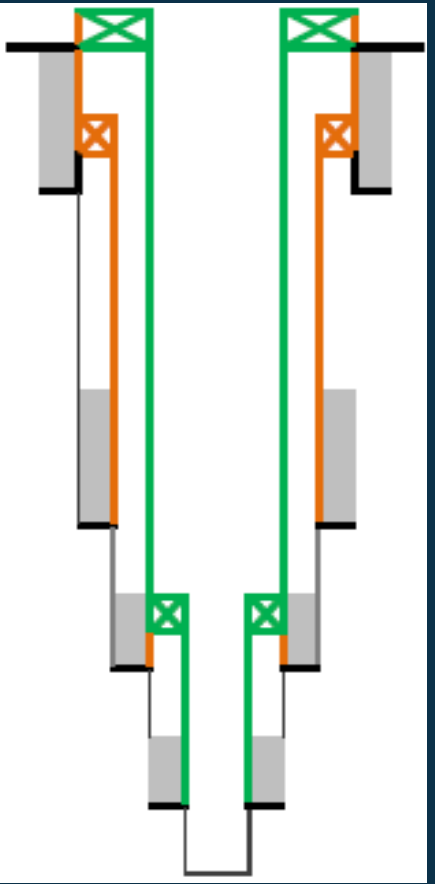
The Level 2 analysis tool and Summary Table use the terms "primary string" and "secondary string". Refer to the illustration on the right.

Primary strings (green) are strings that are exposed to the flow from the reservoir, assuming no strings have failed.

A secondary string is a string that becomes exposed when a primary string fails. Potential secondary strings are colored orange on the illustration.

The BOEMRE requires an analysis of secondary strings and of the formation that becomes exposed to wellbore pressure when a primary string fails.

In some cases, only a short cemented piece of the previous string becomes exposed. If the lap into the previous string is 500-ft MD long or less, and there is no weak zone within 500-ft MD above the previous shoe (e.g., TOS, faults, or other weaker zones), a secondary string verification is not required.



Level 2 Productive Formations

4) Productive Formation Information

HOLE SECTION: 12 1/4" SHOE DEPTH(FT-TVD): 17,438

Name	Depth (ft-TVD)	Reservoir Fluid	Reservoir Pressure or Bottom hole Flowing Pressure (ppg)	Reservoir Pressure or Bottom hole Flowing Pressure (psi)	Assumed fluid gradient for calc (psi/ft)	Mud Line Shut in Pressure (psi)	Shut in ppg @ shoe	Comments
Reservoir 1 - Shutin condition	23,246	Oil	11.1	13,418	0.375	6,642	12.40	Justification for gradient is provided as attachment.
Reservoir 2 - Shutin condirion				-		-	-	
Reservoir 3 - Shutin condition				-		-	-	
Reservoir 4 - Shutin condition				-		-	-	
Reservoir 5 - Shutin condition				-		-	-	
Reservoir 6 - Shutin condition				-		-	-	
Reservoir 7 - Shutin condition				-		-	-	
Lowest UNRESTRICTED FLOWING gradient (any combination of reservoirs)					0.28			Justifcation for gradient is provided as attachment

- Since the fluid gradients are different for Shut-in and Flowing conditions, separate gradients are entered, for each.

Level 2 Burst Loads

6) MECHANICAL INTEGRITY ANALYSIS
6.1 BURST MECHANICAL INTEGRITY AT GIVEN DEPTH

Component	Burst Rating (psi)	Depth to Top of Component (ft)	Setting MW, PP or SW (ppg)	Exposed to SW? (above top hanger)	Internal Shut in Pressure (psi)	External pressure (psi)	Burst Load (psi)	Design Factor	Comment
Capping BOP stack	15,000	5,100	8.60	Y	6,613	2,244	4,368	3.43	
LMRP connector	15,000	5,124	8.60	Y	6,622	2,255	4,367	3.43	
Drilling BOP stack	15,000	5,127	8.60	Y	6,623	2,257	4,366	3.43	
Subsea Wellhead	15,000	5,167	8.60	Y	6,638	2,274	4,364	3.43	
13 5/8" hanger & seal assy	15,000	5,170	12.70	N	6,639	3,414	3,225	4.65	
13 5/8" Casing	10,030	5,170	12.70	N	6,639	3,414	3,225	3.11	
13 5/8" Casing (at cross over)	10,030	11,500	12.70	N	9,013	7,595	1,418	7.07	at 13-5/8" x 13-3/8" crossover
13 3/8" Casing (at cross over)	8,410	11,500	12.70	N	9,013	7,595	1,418	5.92	at 13-5/8" x 13-3/8" crossover
13 3/8" Casing Shoe	8,410	17,438	12.70	N	11,240	11,516	(276)	>100	

- The same table and formulas are used as in the Level 1 WCST.
- The operator may chose to use burst ratings that differ from the standard burst values in eWell, e.g., ratings based on triaxial methods.
  - A justification must be provided if burst ratings higher than the standard eWell ratings are used.

Level 2 Collapse

COLLAPSE ANALYSIS Component	Collapse rating (psi)	Depth of interest (ft TVD)	Hydraulic Isolation Depth (ft-TVD)	Annulus Pressure Buildup (psi)	Setting MW, or PP (ppg)	Internal Pressure (psi)	External Pressure (psi)	Collapse Load (psi)	Design Factor	Comments
13 5/8" Casing	4,800	5,170	17,055	749	12.7	2,264	4,163	1,899	2.52	
13 5/8" Casing	4,800	11,500	17,055	749	12.7	4,036	8,344	4,307	1.11	Cossover depth between 13 5/8" and 13 3/8" casing
13 3/8" Casing	2,880	11,500	17,055	749	12.7	4,036	8,344	4,307	0.66	Cossover depth between 13 5/8" and 13 3/8" casing
13 3/8" Casing	2,880	17,055	17,055	749	12.7	5,592	12,012	6,420	0.44	HID at 17055' is most likely depth of collapse

- Level 2 collapse table has a separate column for APB. If an annulus is trapped then an APB model must be run and the results entered into APB column. If an annulus is untrapped then use the level 2 APB calculator for untrapped annulus.

APB Calculator for Untrapped Annulus

6.3 COLLAPSE ANALYSIS

APB calculator for Untrapped Annulus String	OH Weak pt (ft TVD)	Setting MW (ppg)	FG at weak pt (ppg)	Calculated APB (psi)	Level 2 Alternative APB (psi)	Comments / justification of alternative APB used
13-5/8" x 13-3/8"	14,400	12.7	13.7	749		APB limited by sand formation FG @ 16" Shoe
16"	7,880	11.6	12.5	369		APB limited by sand formation FG @ 22" Shoe

$$APB = (FG_{shoe} - MW) \times TVD_{shoe} \times 0.052$$

- This simple model assumes that APB is limited to the FG at the previous shoe, at which point any additional APB generated would just bleed off to the formation.
- APB = (FGshoe – MW) x TVDshoe x 0.052

Secondary String Collapse

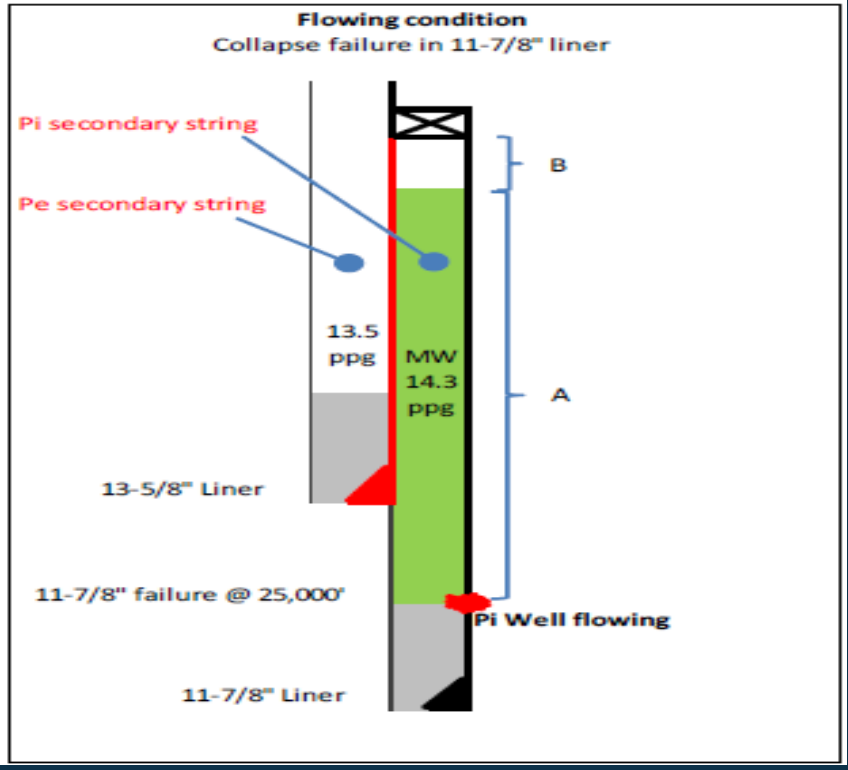
Internal pressure for the secondary string at a depth of interest (TVD) is calculated as follows:

$$P_{i\ Secondary\ String} = P_{i\ Well\ flowing} - (TVD_{Failure\ point} - TVD_{Depth\ of\ Interest}) \times MW_{annulus} \times 0.052$$

When a string fails and the annulus behind the string is exposed to internal well flowing pressure, the hydrostatic pressure of the annulus mud column at the failure point may exceed the internal well flowing pressure. The assumption is that the mud level in the annulus will fall (U-tube effect) until the hydrostatic of the remaining mud column equals the internal well flowing pressure.

If the mud level in the annulus drops, the above equation will give a negative result above the level the fluid column will drop to. When the formula turns negative, then Pi Secondary String = 0 (zero) will be used.

The external pressure is determined in a similar way as for the collapse calculations in the table in Section 6.3. For collapse, Annulus Pressure Buildup needs to be added if the Depth of Interest is above the Hydraulic Isolation Depth.

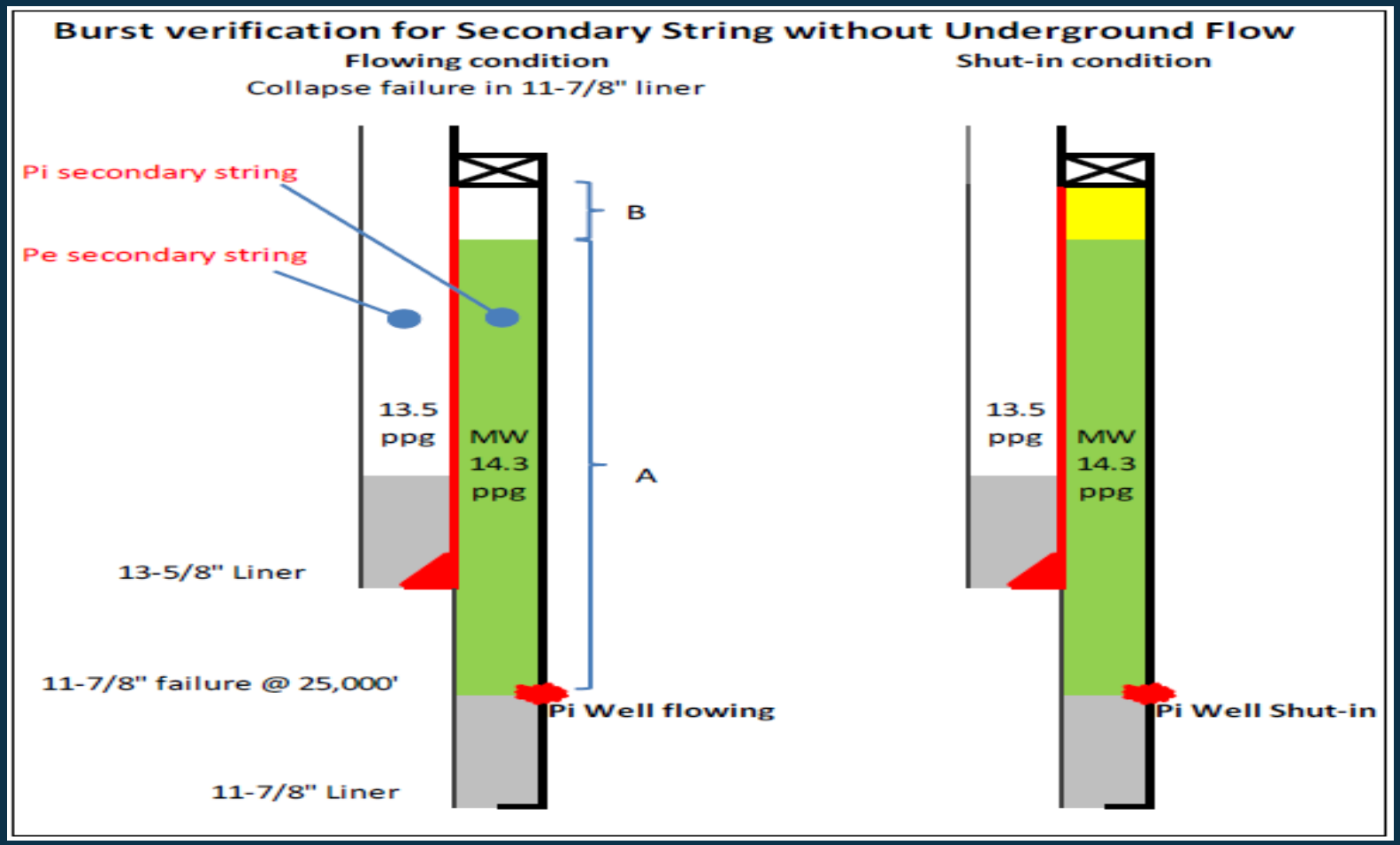


Secondary String Collapse

7) SECONDARY STRING VERIFICATION ======>	Check box if no secondary strings exposed: ☐										
7.1 COLLAPSE VERIFICATION Secondary String	Collapse rating Secondary String (psi)	Depth of interest (ft TVD)	Primary string failure depth (ft TVD)	Internal Flowing Pressure at failure pt (psi)	MW failed string was set in (ppge)	Secondary string Internal pressure (psi)	Secondary string APB buildup (psi)	Secondary string setting MW, or PP (ppg)	Secondary string External pressure (psi)	Collapse load (psi)	Collapse DF
22" Casing	6,870	7,338	17,055	5,592	12.7	-	0	8.6	3,282	3,282	2.09
16" Liner	5,750	13,909	17,055	5,592	12.7	3,514	369	11.6	8,759	5,245	1.09
				-		-			-	-	

- All secondary strings that are exposed to collapse forces have to be analyzed in this table

Secondary String Burst



Secondary String Burst

Fluid drop Secondary String (to be verified)	Failed string(s)	Primary string failure depth (ft TVD)	Hanger depth of failed string(ft TVD)	MW failed string was set in (ppge)	Internal Flowing Pressure at failure pt (psi)	Fluid drop (ft TVD)	Hydrocarbon gradient (psi/ft)	Average fluid density in annulus (ppg)	Comments
22" Casing	13-5/8" x 13-3/8"	17,055	5,170	12.7	5,592	3,418	0.375	11.1	
16" Liner	13-5/8" x 13-3/8"	17,055	5,170	12.7	5,592	3,418	0.375	11.1	

- The fluid drop table is used to calculate the average fluid density in the secondary annulus so the secondary string can be analyzed appropriately for burst

7.2 BURST VERIFICATION WITHOUT UNDERGROUND FLOW Secondary String	Burst rating (psi)	Depth of interest (ft TVD)	Primary string failure depth (ft TVD)	Average fluid density in annulus (ppge)	Internal Shut-In Pressure at Primary string failure pt (psi)	Secondary String Internal pressure (psi)	Exposed to SW? (above top hanger)	MW / PP (ppg)	Secondary string External pressure (psi)	Burst load (psi)	Burst DF
22" Casing	7,950	5,167	17,055	11.1	11,096	4,234	Y	8.57	2,267	1,968	4.04
16" Liner	6,260	7,338	17,055	11.1	11,096	5,487	N	11.6	4,426	1,061	5.89
					-	-			-	-	

Level 2 Formation Integrity Analysis

8) LEVEL 2 FORMATION INTEGRITY ANALYSIS	Check box if no formation exposed behind failed strings: ☐							
Description of depth where formation checked & Strings that failed	Primary string Failure depth (ft TVD)	Depth of Previous shoe or weak point (ft TVD)	FG at previous shoe or weak point (ppg)	Average fluid density in annulus (ppge)	Internal Shut-in Pressure at Primary string failure pt (psi)	Annulus pressure at previous shoe or weak pt (psi)	Frac margin (psi)	Comments
16" Shoe	17,055	14,400	13.7	11.1	11,096	9,564	688	16" shoe survives shut in after 13 3/8" x 13 5/8" casing
					-	-		
					-	-		
					-	-		

- This section must be completed if a primary string fails and there is formation exposed behind the primary string.

Broaching Analysis

- A broaching analysis is performed if an underground flow occurs as a result of a weak formation fracturing when a well is shut-in
  - All faults are identified in area for potential conduit for hydrocarbons to broach to sea floor
  - Salt canopy will help prevent underground flow from broaching
  - All sands mapped in field that could act as a tank
  - Known seafloor anomalies are mapped identifying ongoing venting
- A determination is then made on the probability of broaching

Level 2 Results

Level 2 results	
5. Formation strength verification below deepest shoe	PASS
6.1 Burst Integrity - Primary strings	PASS
6.3 Collapse Integrity - Primary strings	L2 FORMATION INTEGRITY AND/OR SECONDARY STRING VERIFICATION REQUIRED
7. Secondary string verification	PASS
8. Formation strength verification for failed strings	PASS

Thank you