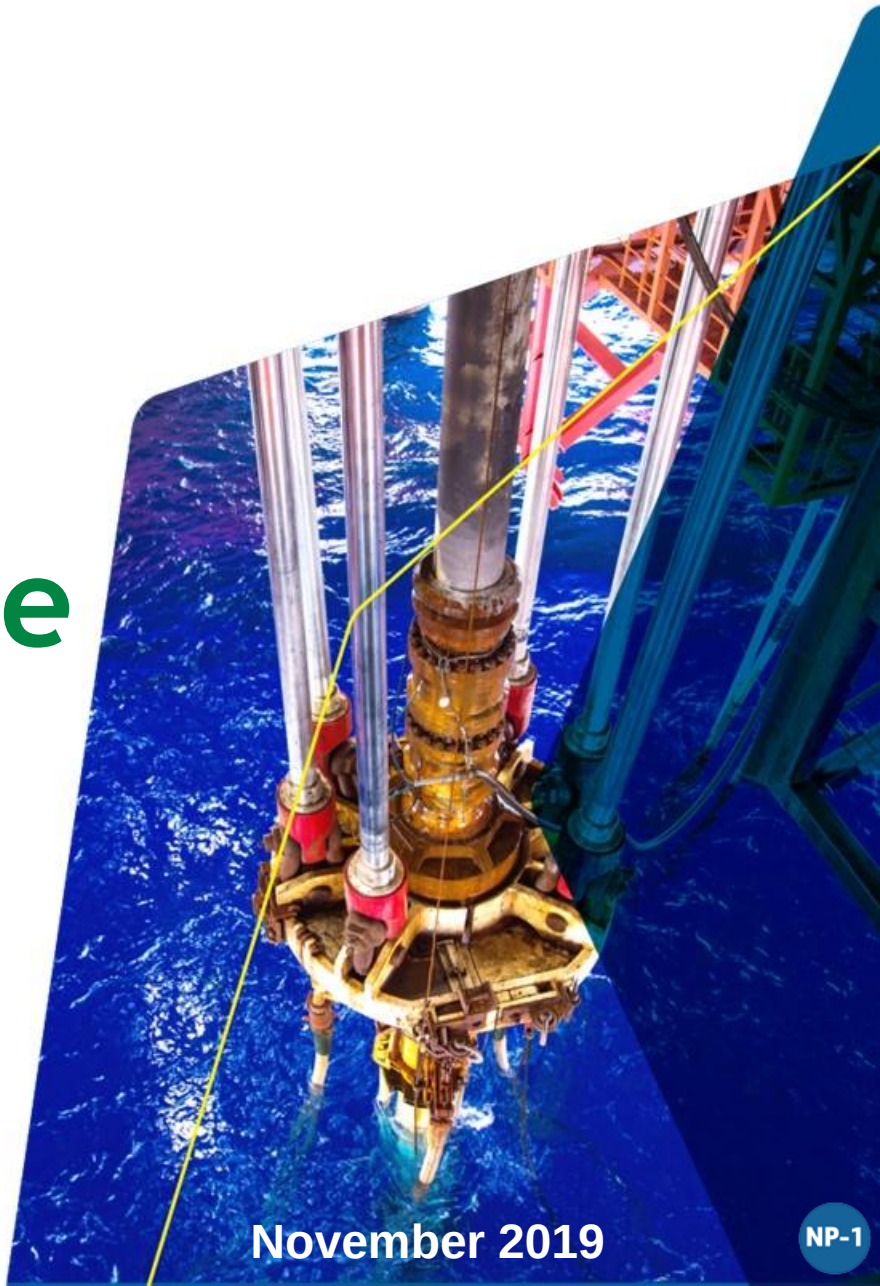
IADC Subsea and Drilling Brazil Conference 2019

PETROBRAS

Well Failure Model for the Production Phase



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(Technical Competencies on Well Integrity and Compliance)

November 2019

OUTLINE

- ✓ Well Integrity Practices during Production Phase
- ✓ Well Failure Model Reasoning
- ✓ Philosophy for Well Failure Model
- ✓ Elements Acceptance Criteria for Production Phase
- ✓ Standard Description
- ✓ Case Studies
- ✓ Conclusions

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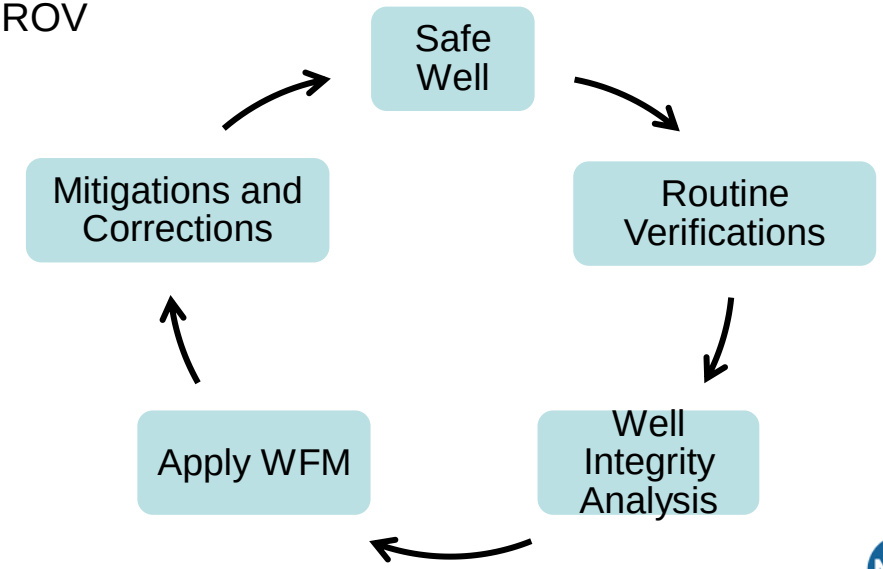
Well Integrity Practices during Production Phase

- 2 WB (Well Safety Barriers Envelope) → healthy, independents and verified
- Verifications:
  - ✓ Subsea Tree Valves → functional tests and cycling
  - ✓ DHSV → leakage rate test
  - ✓ Annulus pressure management → subsea well → annulus A
  - ✓ Wellhead Inspections → subsea well → ROV
- Well Integrity Analysis
- Apply WFM (Well Failure Model)
- Mitigation / correction



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Well Failure Model Reasoning

- Brazilian Regulatory Agency WIMS → SGIP → PG Nº 13 (well integrity management practice) → 13.2.4

"estabelecer, implementar e documentar ações corretivas e preventivas para tratamento dos desvios identificados durante a execução dos planos e procedimentos"

Establish, implement and document corrections and mitigations to deal with non compliances w.r.t. WIMS.

- Based upon international norms, standards, regulations and best practices

✓ Norwegian Oil and Gas Association Recommended Guidelines for Well Integrity Nº 117, rev. 5

✓ Well Integrity Management Manual (WS 38.80.31.30-Gen)

✓ ISO TS 16530-1: Well Integrity – Part 1: Life Cycle Governance

- Consistent with definitions and regulations of industry

✓ DNV: degradation corresponds to any reduction of functionality of a determined element, whereas failure means an event which affects an element leading to loss of functionality

✓ API RP 14-B: 0,43 Sm^3/min (gas) e 400 ml/min (liquid)

✓ Incident Communication Manual (ANP): gas leakage (to environment) > 0,1 kg/s must be notified. Any liquid leakage is not allowed (well must be shut in)

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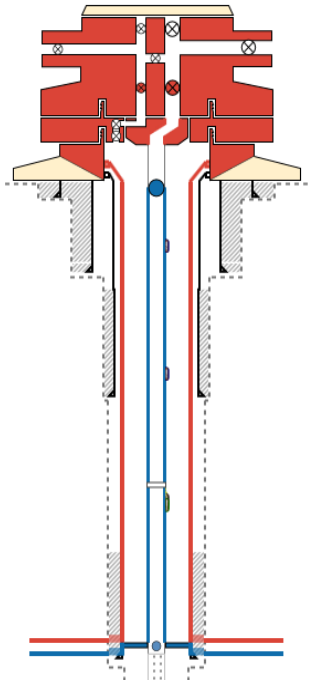
Philosophy for Well Failure Model

Well Barrier Element (WBE)

WBE	WB	Failure Impact	Functionality
Active WBE: packer + tubing	Primary	Internal Leak	Annulus “A” isolation, preventing contact of production casing with formation fluids
Potential WBE: DHSV	Primary	Internal Leak	Shut the well in when a catastrophic event in wellhead happens
Subsurface Active WBE: casing + packoff	Secondary	External Leak	Contingency well containment (in case of leakage through Primary Active WB leakage)
Surface Active WBE: WH + Subsea Tree	Secondary	External Leak	Contingency well containment (in case of leakage through Primary Active WB leakage)
Potential WBE: Subsea Tree Valves	Secondary	External Leak	Contingency shut in the well (in case of production riser / flowline leakage)

Leakage	Tolerability to Gas Leakage	Tolerability to Liquid Leakage
Internal	API RP 14-B (0,43 Sm^3/min)	API RP 14-B (400 mL/min)
External	ANP Incident Communication Manual (< 0,1 kg/s)	No Leak

Well Barrier Envelopes (WB)



WBE active
vs.
WBE potential

Philosophy for Well Failure Model

WELL INTEGRITY STATUS	NATURALLY FLOWING WELL	SUB-HYDROSTATIC WELL	ACTION
GREEN (HEALTHY)	2 healthy WELL BARRIER ENVELOPES (WB)	Non-flowing condition + 1 healthy WB	Keep on performing routine maintenance plans. Correct small deviations, when applicable.
YELLOW (DEGRADED)	1 healthy WB + 1 degraded WB 2 degraded WB, w/o communication btw. pay-zone and environment	Non-flowing condition + 1 degraded WB	Implement higher frequency inspections or verifications, according to wich WBE is degraded.
ORANGE (FAILED)	1 failed WB + 1 healthy WB, w/o lift-gas leakage to environment (> 0.1 kg/s) 2 degraded WB, with communication btw. pay-zone and environment 1 degraded WB + 1 failed WB, w/o communication btw. pay-zone and environment and w/o lift-gas leakage to environment (> 0.1 kg/s)	Non-flowing condition + 1 failed WB, w/o communication btw. pay-zone and environment and w/o lift-gas leakage to environment (> 0.1 kg/s)	Define a grace period to restablish WB's integrity.
RED (LEAKAGE POSSIBILITY)	1 failed WB + 1 degraded WB or not verified, with communication btw. pay-zone and environment or with lift-gas leakage to environment (> 0.1 kg/s)	Non-flowing condition + 1 failed WB, with communication btw. pay-zone and environment and with lift-gas leakage to environment (> 0.1 kg/s)	Secure imediatly well safety and integrity.
BLACK (BLOWOUT POSSIBILITY)	BlowOut	Not Applicable	Verify need for starting up emergency plans.

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Elements Acceptance Criteria for Production Phase

Example: EAC Subsea Well.

WBE		HOW	HEALTHY	DEGRADED	FAILED
DHSV	Potential WBE (Primary WB)	Leak Test	< 400 mL/min (L) **or** < 0,43 Sm^3/min (G)	400 - 800 mL/min (L) **or** 0,43 to 0,86 Sm^3/min (G)	> 800 mL/min (L) **or** > 0,86 Sm^3/min (G)
Subsea Tree Valves	Potential WBE (Secondary WB)	Functional Test	2 Production Bore and 1 Annulus Bore Valve Functional Test w/o any tubing leak **or** < 400 mL/min (L) **or** < 0,43 Sm^3/min (G)	400 - 800 mL/min (L) **or** 0,43 to 0,86 Sm^3/min (G)	> 800 mL/min (L) **or** > 0,86 Sm^3/min (G)
Production Casing, Wellhead, Subsea Tree Body	Active WBE (Secondary WB)	Visual Inspection (ROV)	Leaktight (L) **and** < 0,43 Sm^3/min (G)	Leaktight (L) **and** 0,43 Sm^3/min to 0,1 kg/s (G)	Any Leak (L) **or** > 0,1 kg/s (G)
GLV	Active WBE (Primary WB)	Annulus Pressure Management	< 400 mL/min (L) **or** < 0,43 Sm^3/min (G)	400 to 800 mL/min (L) **or** 0,43 to 0,86 Sm^3/min (G)	> 800 mL/min (L) **or** > 0,86 Sm^3/min (G)
Tubing	Active WBE (Primary WB)	Annulus Pressure Management	Leaktight (L) **and** < 0,43 Sm^3/min (G)	< 800 mL/min (L) **or** 0,43 to 0,86 Sm^3/min (G)	> 800 mL/min (L) **and** > 0,86 Sm^3/min (G)

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Standard Description

Step 1: classify well integrity (alphanumeric code specification).

1	Tubing	Pressure Test	< 0,43 Sm^3/min (gas) and leaktight to liquid (tubing w/o GLV) or < 400 mL/min (tubing w/ GLV)		Primary WB
2			0,43 to 0,86 Sm^3/min (gas) or 400 to 800 mL/min (liquid)		
3			> 0,86 Sm^3/min (gas) or > 800 mL/min (liquid)		
4	DHSV	Flapper Inflow Test (Leak Rate Evaluation)	< 0,43 Sm^3/min (gas) or < 400 mL/min (liquid)		
5			0,43 to 0,86 Sm^3/min (gas) or 400 to 800 mL/min (liquid)		
6			Lockdown Sleeve (mechanical override) or > 0,86 Sm^3/min (gas) or > 800 mL/min (liquid)		
A	Subsea Tree Valves	Gate Inflow Test (Leak Rate Evaluation)	Mechanical override or > 0,86 Sm^3/min (gas) or > 800 mL/min (liquid)		Secondary WB
B			0,43 to 0,86 Sm^3/min (gas) or 400 to 800 mL/min (liquid)		
C			< 0,43 Sm^3/min (gas) or < 400 mL/min (liquid)		
D	Production Casing and Packoff	Pressure Test and Visual Inspection (ROV) of Wellhead Flow-by	Any liquid leak or > 0,1 kg/s (gas through flow-by or around WH)		
E			Liquid Leaktight and < 0,1 kg/s (gas through flow-by or around WH)		
F			< 0,43 Sm^3/min (gas) and liquid leaktight		
G	Wellhead and Subsea Tree Stack (Housings and Sealings)	Pressure Test and Visual Inspection (ROV) of WH and Subsea Tree Stack	Any liquid leak or > 0,1 kg/s (gas through Subsea Tree Stack Housings and sealings)		
H			Liquid Leaktight and < 0,1 kg/s (gas through Subsea Tree Stack Housings and sealings)		
I			< 0,43 Sm^3/min (gas) and liquid leaktight		

Standard Description

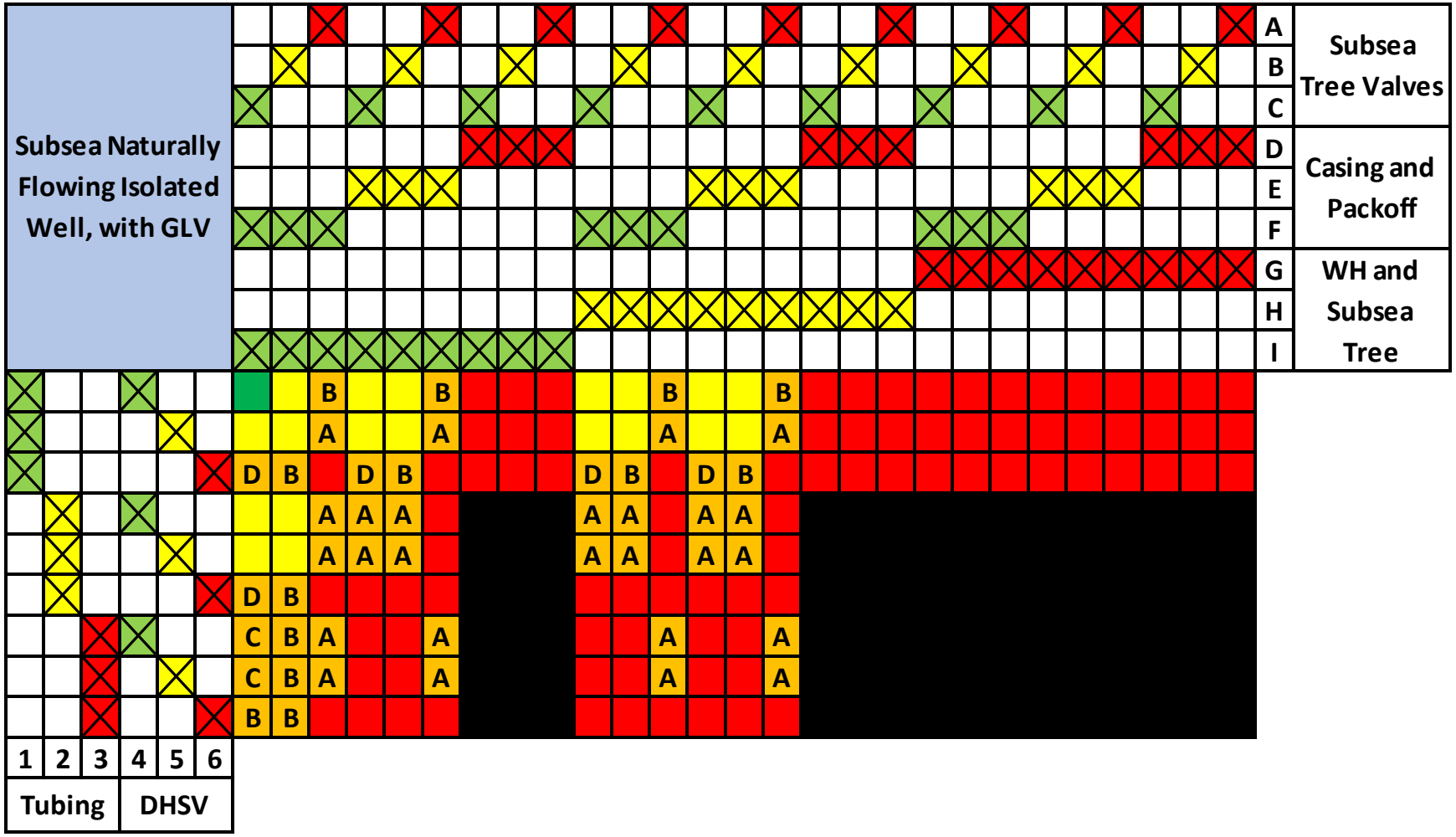
Step 2: considering exceptions.

- ✓ Visual inspection (ROV) → drilling fluid (annulus B and C) or gas leakage → secondary Active WBE well integrity classification depends upon loadings and stress analysis for failure scenarios, considering (not limited to):
  a) Possible leak paths btw. annuli;
  b) Casing friction wear estimated during drilling;
  c) Thermal effects (AFE);
  d) Loading scenarios during production phase (BSW peak, oil peak, gas peak, shut-in, etc.);
  e) Corrosion analysis of production casing due to produced formation / injected fluids, considering leak path btw. annuli A and B.
- ✓ Cement sheath in doubt of hydraulic integrity w/o external leak → operational report (primary cement job) lacks info's validating op success → classify active WBE as degraded → increase inspection frequency
- ✓ Cement sheath in doubt of hydraulic integrity w/o external leak → cement evaluation logging (primary cement job) do not validate integrity → classify active WBE as failed → schedule new cement evaluation logging to next heavy workover (and cement job if necessary)

Standard Description

Step 3: defining well integrity status (integrity matrix).

There are various matrices considering well type and configuration



Standard Description

Step 4: defining grace period whenever well integrity status is ORANGE.

Grace Period to Reestablish Well Integrity (months)	Oil Flow Rate (bpd)		
	High (> 5000 bpd)	Medium (5000 to 500 bpd)	Low (< 500 bpd)
A	6	12	18
B	12	24	36
C	18	36	48
D	36	60	Next Heavy Workover

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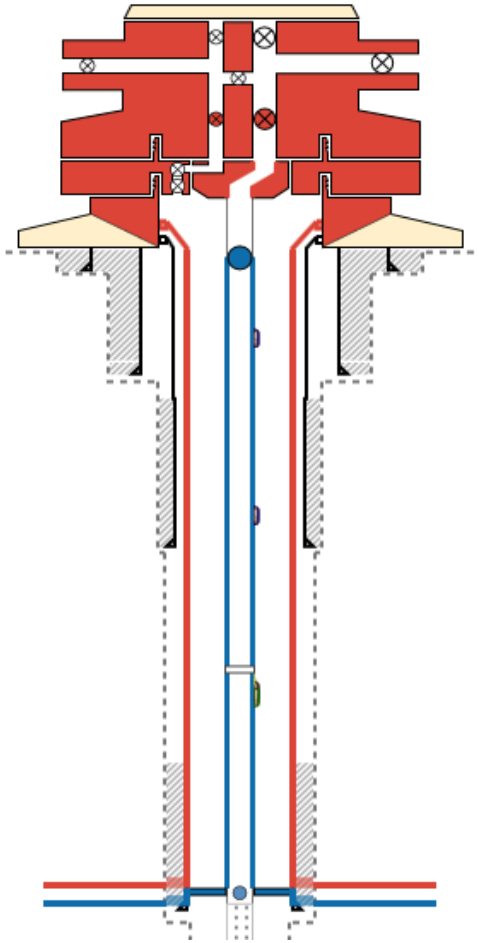
Case Studies

<u>Well # 1</u>: oil production naturally flowing well (6,000 bpd).

- ✓ Subsea isolated well
- ✓ Naturally flowing with GLV installed
- ✓ DHSV locked open (**failed**)
- ✓ Tubing leak (**failed**)
- ✓ Subsea Tree Valves → healthy
- ✓ Production Casing → healthy
- ✓ WH and Subsea Tree Stack → healthy



Case Studies

ALPHANUMERIC CODE → 3-6-C-F-I

1	Tubing	Pressure Test	< 0,43 Sm^3/min (gas) and leaktight to liquid (tubing w/o GLV) or < 400 mL/min (tubing w/ GLV)		Primary WB
2			0,43 to 0,86 Sm^3/min (gas) or 400 to 800 mL/min (liquid)		
3			> 0,86 Sm^3/min (gas) or > 800 mL/min (liquid)		
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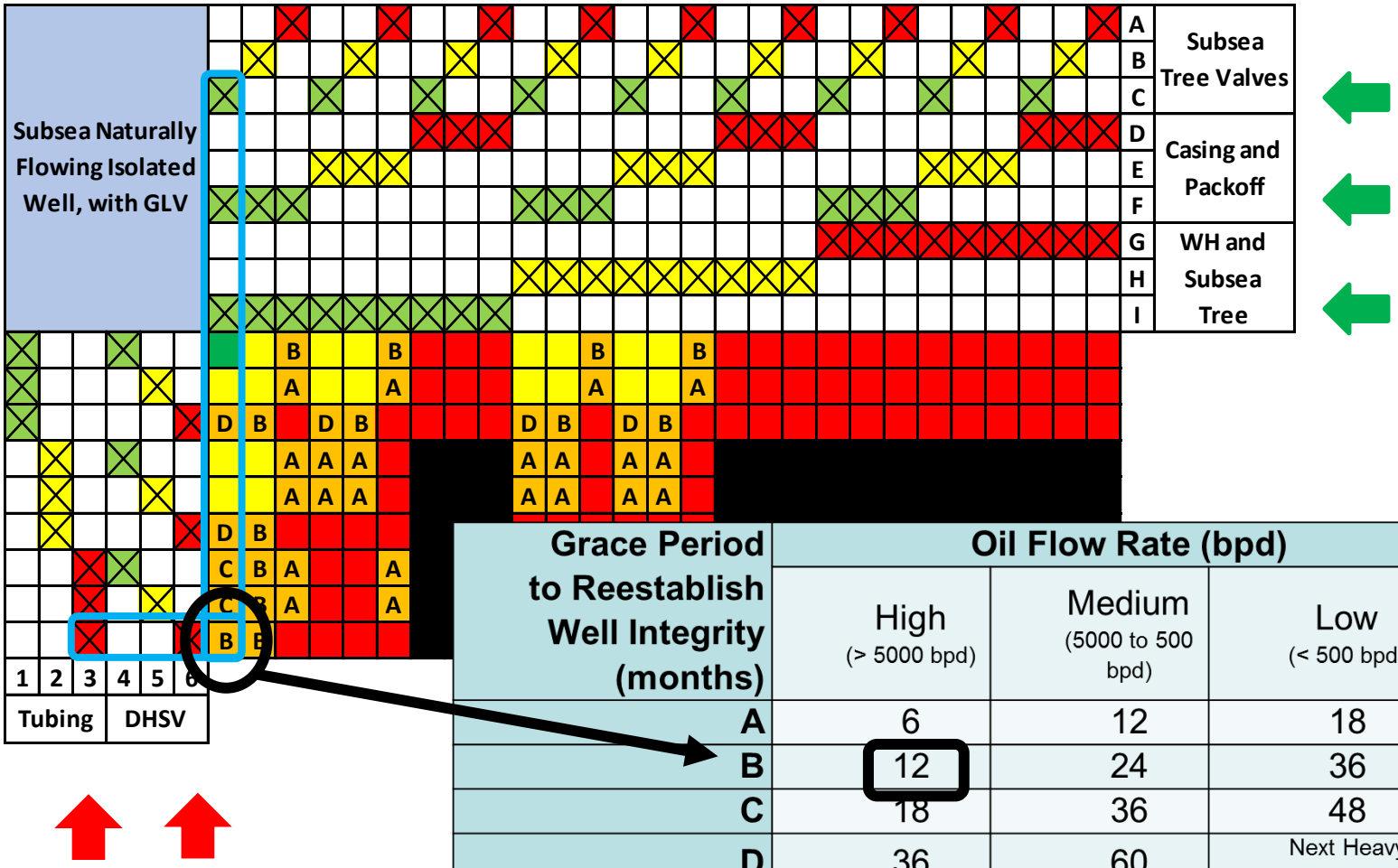
3-6-C-F-I



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	High (> 5000 bpd)	Medium (5000 to 500 bpd)	Low (< 500 bpd)
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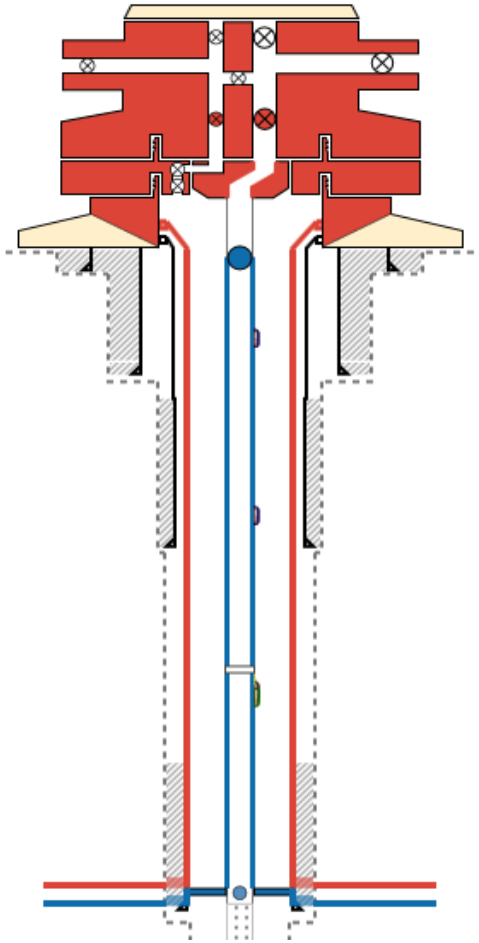
B	12	24	36
C	18	36	48
D	36	60	Next Heavy Workover

Case Studies

<u>Well # 2</u>: gas, condensate production, sub hydrostatic well (9,000 bpd).

- ✓ Subsea isolated well
- ✓ Sub hydrostatic well with GLV installed
- ✓ DHSV verified → healthy
- ✓ Subsea Tree Valves → healthy
- ✓ Production Casing → healthy
- ✓ WH and Subsea Tree Stack → healthy
- ✓ Tubing leak (**failed**)
- ✓ Drilling Fluid Leakage around WH → need simulate loadings and stresses → collapse possible → secondary active WBE well integrity status modification needed (**failed**)



Case Studies

ALPHANUMERIC CODE → 3-4-C-D-I

1	Tubing	Pressure Test	< 0,43 Sm^3/min (gas) and leaktight to liquid (tubing w/o GLV) or < 400 mL/min (tubing w/ GLV)		Primary WB
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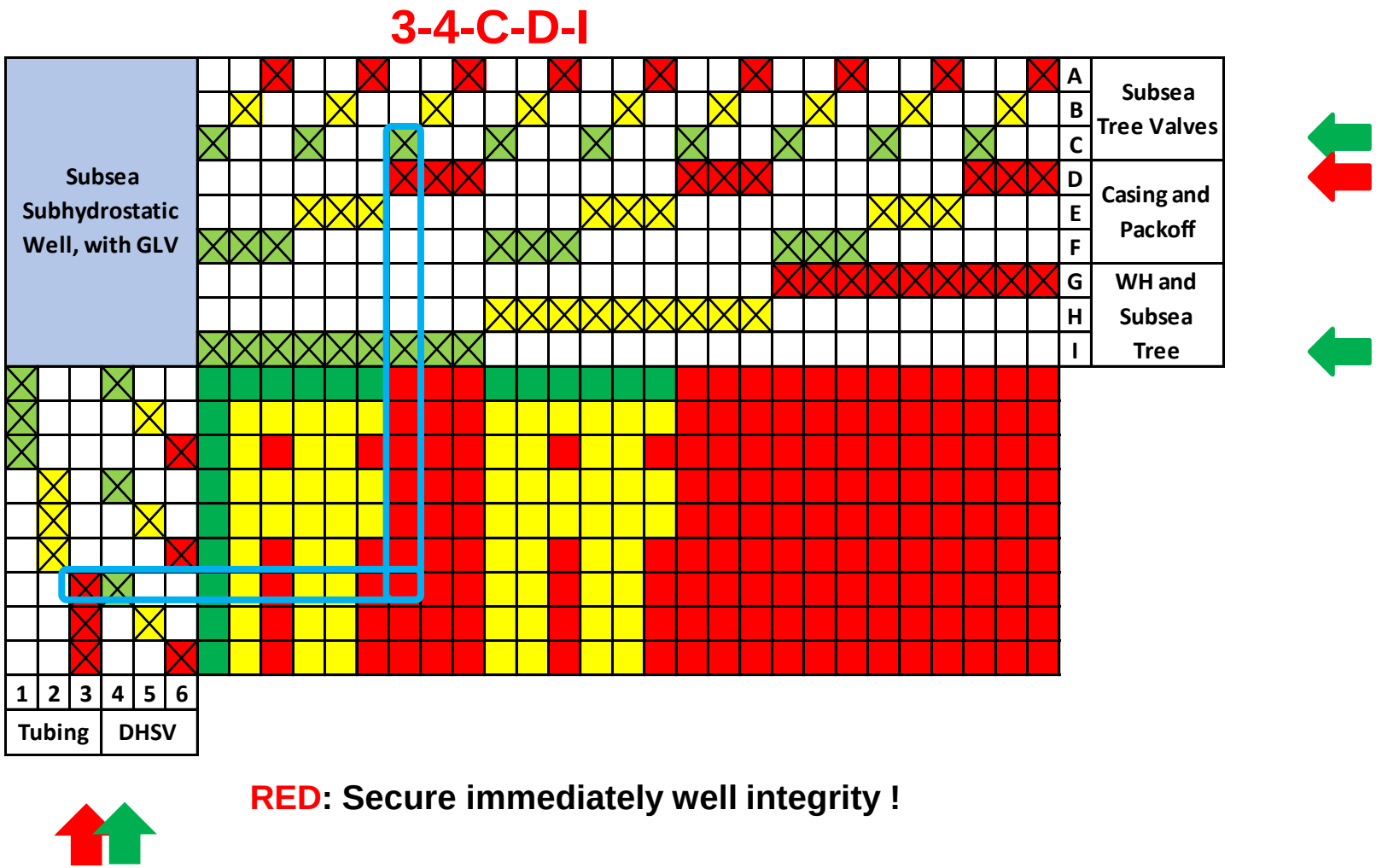

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Conclusions

- Benefits of WFM during production phase:
  - ✓ Corporate standard treatment of well integrity issues
  - ✓ Preemptive risk assessment based upon all possible failure scenarios → save highly specialized human resources (participate in well integrity risk assessments)
  - ✓ Minimizing subjectivities in well integrity risk assessments
  - ✓ Resources management → establishment of rules (need to engage to restore well integrity) → possibility of planning workovers and related contingencies