TransCanada Storage Well and Reservoir Life Cycle Integrity Management

November 2016

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In business to deliver

TransCanada's Operational Management System

Facilities Integrity-Reliability Management Program

Storage Well and Reservoir Integrity Strategies/Plans

Engineering Standards – Design(8), Drilling/Servicing(14), Well Integrity(8), Reservoir Integrity (8)

Operating Procedures and Task Packages (~20)

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Storage Integrity Management Strategies

Life cycle integrity management =

Engineering standards + Integrity plans, procedures, tasks

Safety is by design:

- Standards for design, construction, operation and abandonment, including engineering analysis procedures
- Active Control of well drilling / service work; disciplined, adaptive application of MOC across all well life cycle stages
- Integrity plans, with tasks including:
  - Data gathering and field-based monitoring
  - Mechanical integrity inspections of primary barriers
  - Engineering and geological analyses
  - Risk-informed decision making and resourcing
  - Performance tracking

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Reservoir and Well Integrity Management

Integrity plans link to 20 Operating Procedures for storage well work and data collection and to 38 well/reservoir engineering standards

Hierarchy

- Integrity Management Strategy
- Integrity Plans
- Operating Procedures and Task Packages
- Issue Log and Prioritization Model
- Risk Registers

One plan for all reservoirs and one plan for all wells…operating procedures and task packages may be specific to fields

Integrity Plans deconstruct “well” and “reservoir” into major parts…

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Well and Reservoir Integrity Plan Task Groups

WELL

1) Pressure, Flow, and Fluid Monitoring
2) Casing Integrity Assessment
3) Storage Wellhead and Valve Maintenance
4) Well-site Documentation and Security Assessment
5) Well Completion/Performance Assessment
6) Well Work Planning/Execution
7) Emergency Response Planning/Training

RESERVOIR

1) Gas Inventory Analysis and Monitoring
2) Reservoir boundary monitoring and protection
3) Reservoir performance assessment and monitoring

Tasks are listed by master task level and subtask, with timing/frequency requirement, responsibility (who), reason/driver for doing (regulatory, good practices, etc.), comments

MASTER TASK LEVEL	SUB-TASK	FREQUENCY	RESPONSIBILITY	DRIVER	COMMENTS
1.0 Well and Reservoir Integrity Monitoring	1.1 annulus pressure checks; annulus gas samples	Monthly	res engr/field op techs	Best Practice API 1171, others	Where not automated. Manual reads of monthly annulus pressure are required to discover, track, report and correct anomalies - NOTE; RESERVOIR ENGR REPORTS IMMEDIATELY TO OPERATIONS MANAGER AND RESERVOIR SERVICES MANAGEMENT ANY ANOMALOUS BEHAVIOR ON ANNULAR SPACES. Develop investigative or corrective programs; estimate or calculate gas loss.

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Time to Develop and Implement

- 2.5-3 years to develop integrity plans, procedures, engineering standards. Added knowledgeable, experienced part-time help over the duration in order to complete.
- Plus 1-2+ years to fully implement to solid foundation
- ~4-5 years to develop and implement
- Expect 1-2 years of cyclic continual improvement to feel we have foundation + maturity, 2nd version of documented integrity plans, procedures, and engineering standards
- Total time 5-7 years given extra help, motivated leadership, and total team commitment

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Task Tracking, Issue Cataloging and Prioritization

Performance Tracking

- Task Tracking – data collection, planned/preventive maintenance completion and corrective action requirements and completions
- Issues lists
  - Well: well casing, annulus pressure, valve, ESD, well site, completion interval/deliverability
  - Reservoir: gas inventory pressure/volume, boundary security, deliverability and performance reliability
- Issue prioritization based on safety, issue potential severity ranking

How do we know we have continual improvement mechanisms? What do we get out of this?

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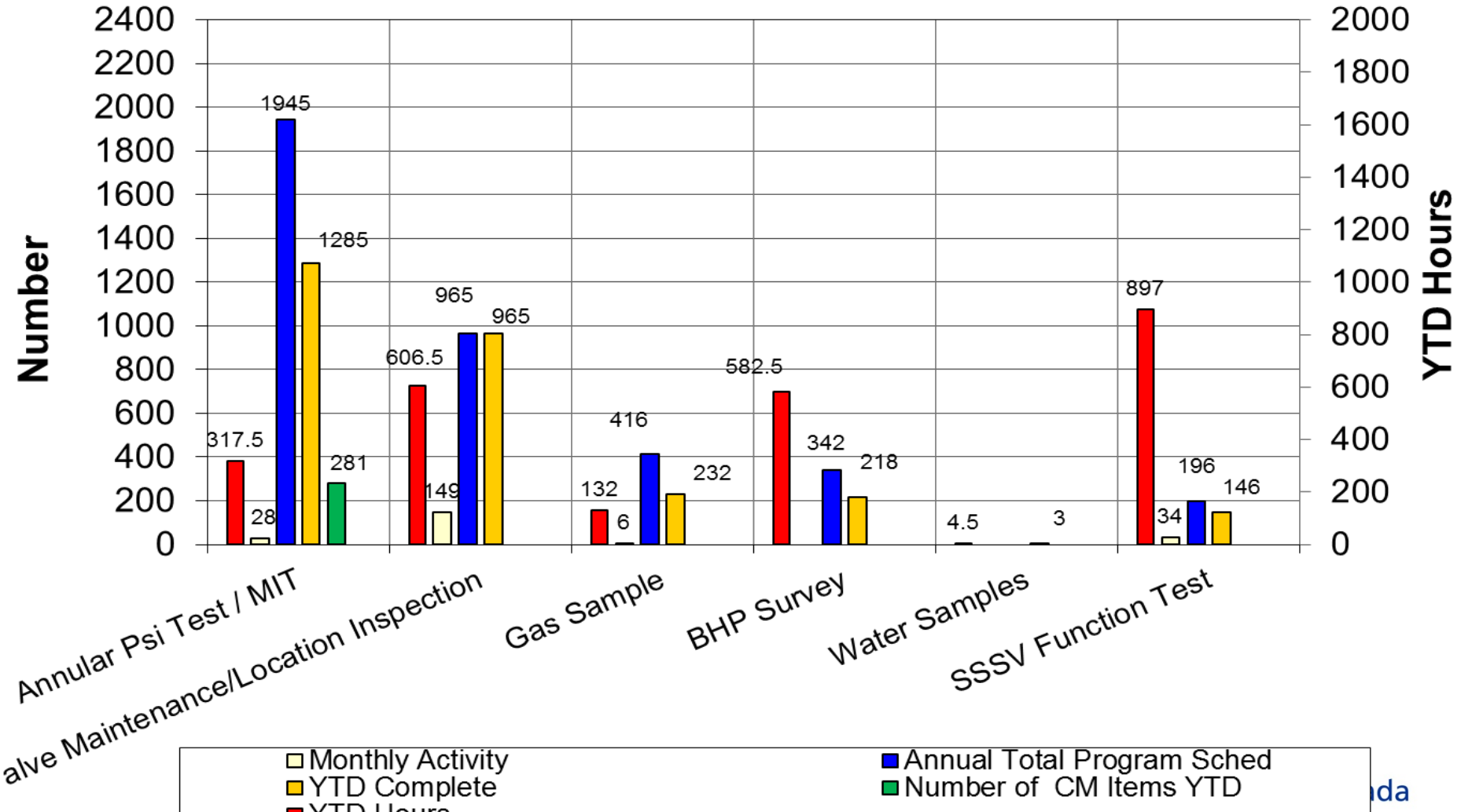
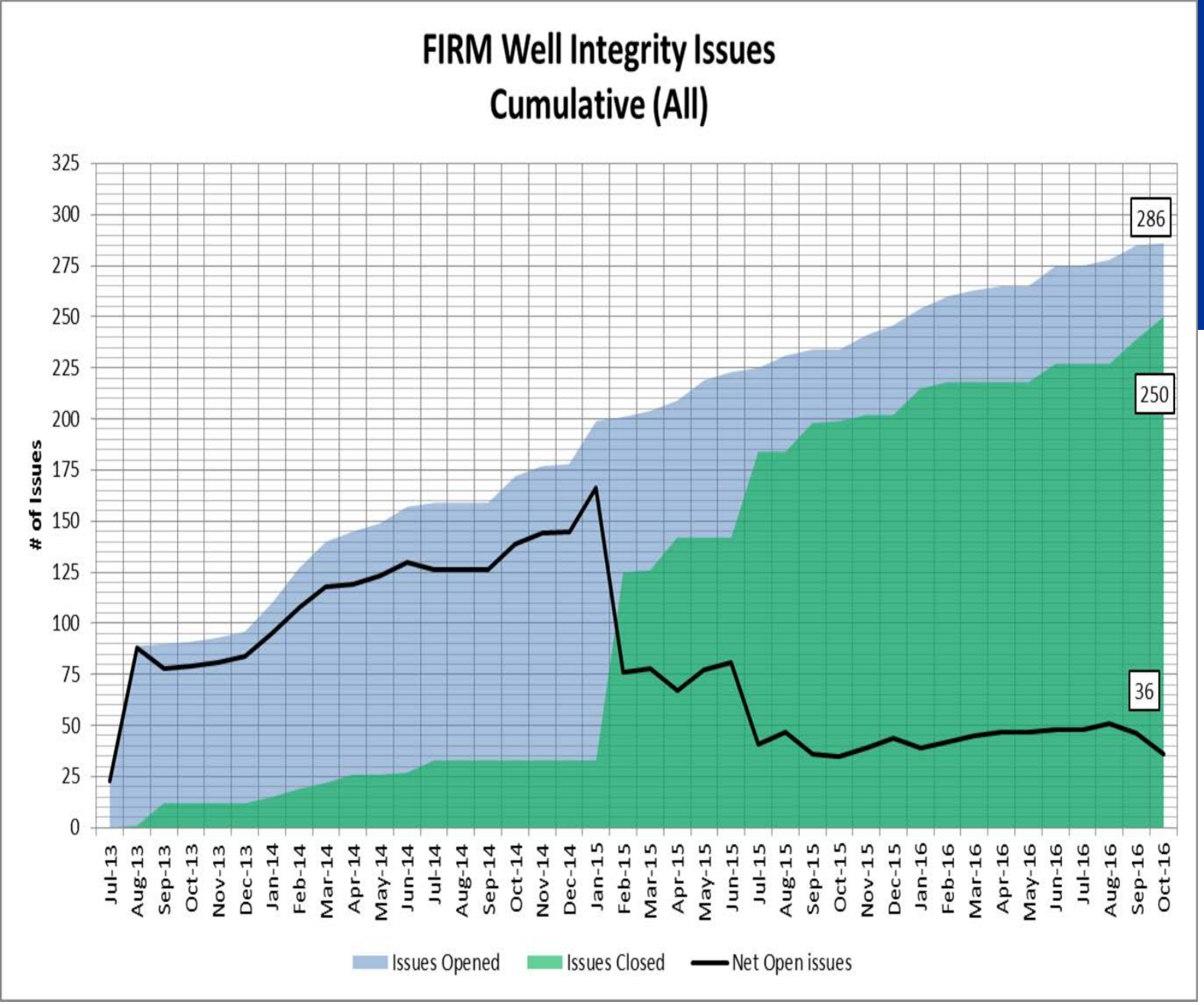
Storage Reliability / Integrity Work Tracking

ANR Storage Group - Well and Reservoir Integrity and Reliability Drivers, 2016 Work Program



Integrity Issue Tracking



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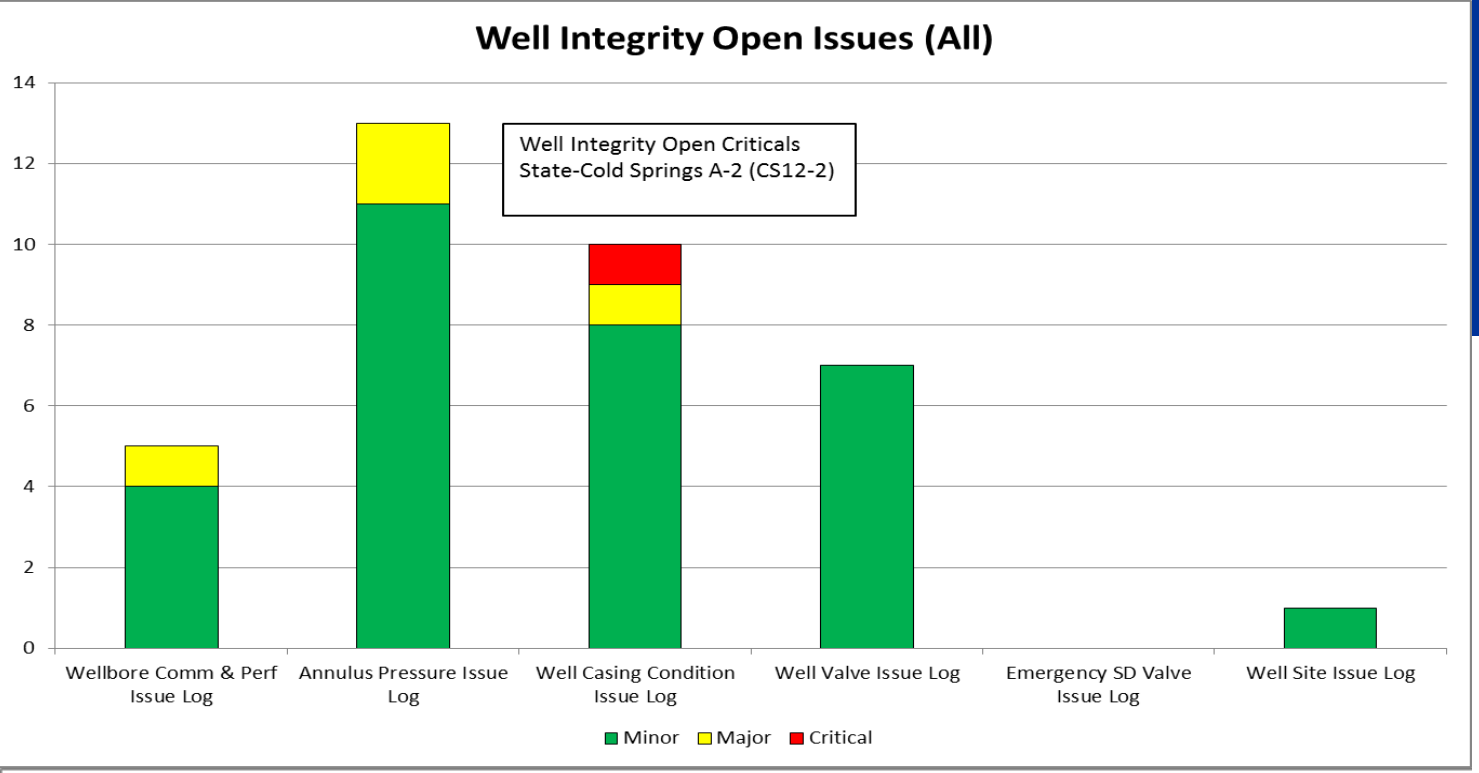
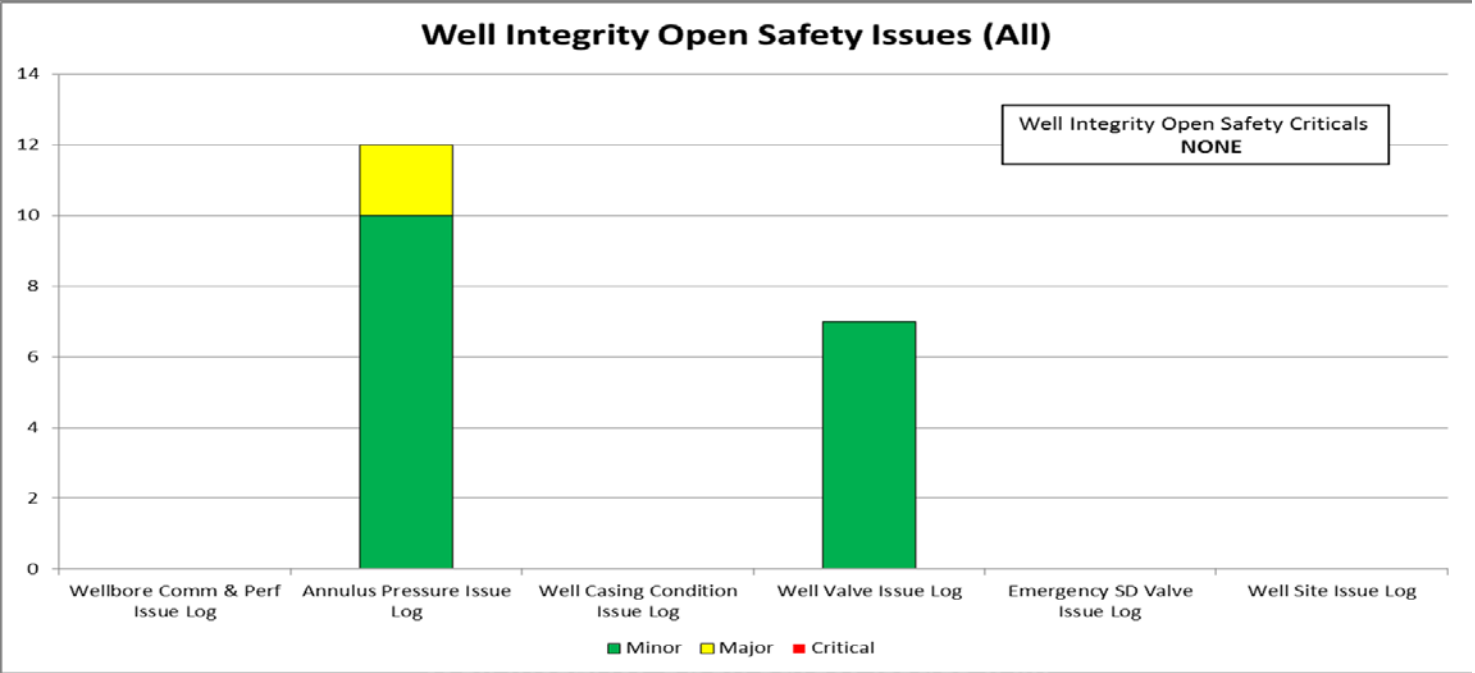
TransCanada - US Storage Reliability / Integrity Issues Listing





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Well Integrity Risk Assessment

Barrier Analysis

- Wellhead, seals, valves, pressure ratings
- Tubulars, pressure ratings, adjusted pressure ratings for condition assessments
- Other – packers, downhole equipment, pressure ratings
- Cement integrity, extent, quality
- Operating Limits
  - Maximum allowable annulus surface pressure (ISO 16530 method)
  - Maximum operating pressure and flow velocity, safety margin factors
- Operating Procedures, Inspection and Maintenance Plans
- Data documentation, well information form - ..\..\2016 Well Integrity Assessments\well profile and wellhead forms\CS1-5HD - 11 09 16.xlsx

Risk Analysis

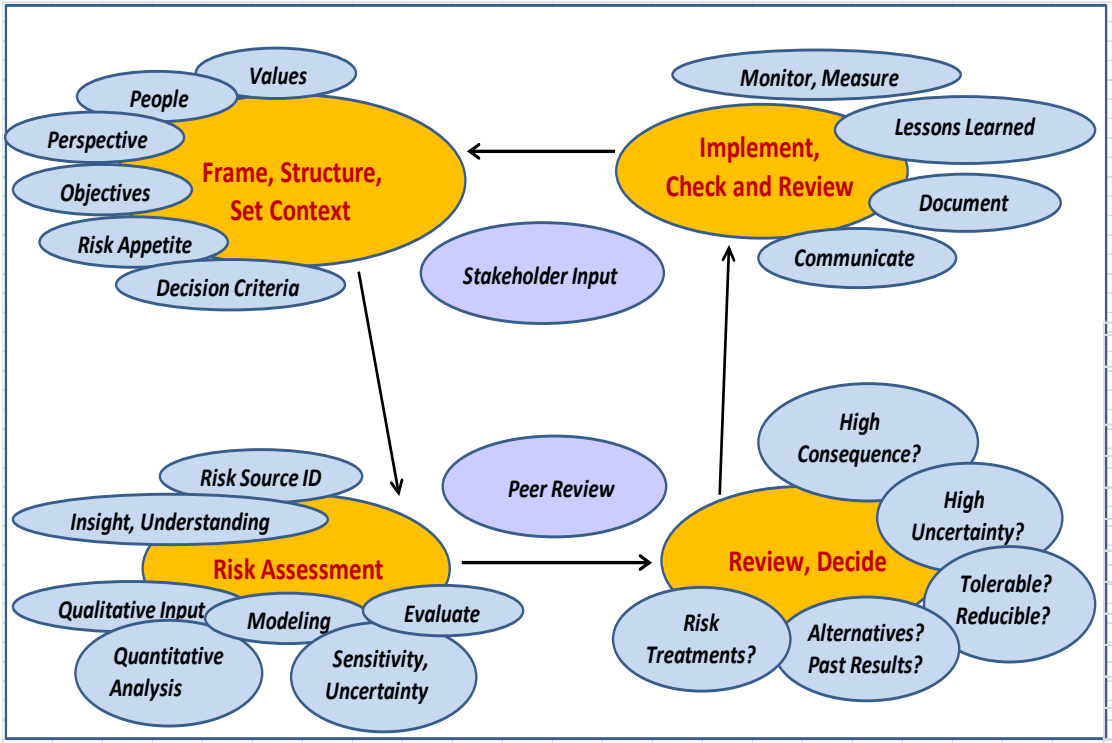
Likelihood of primary containment failure

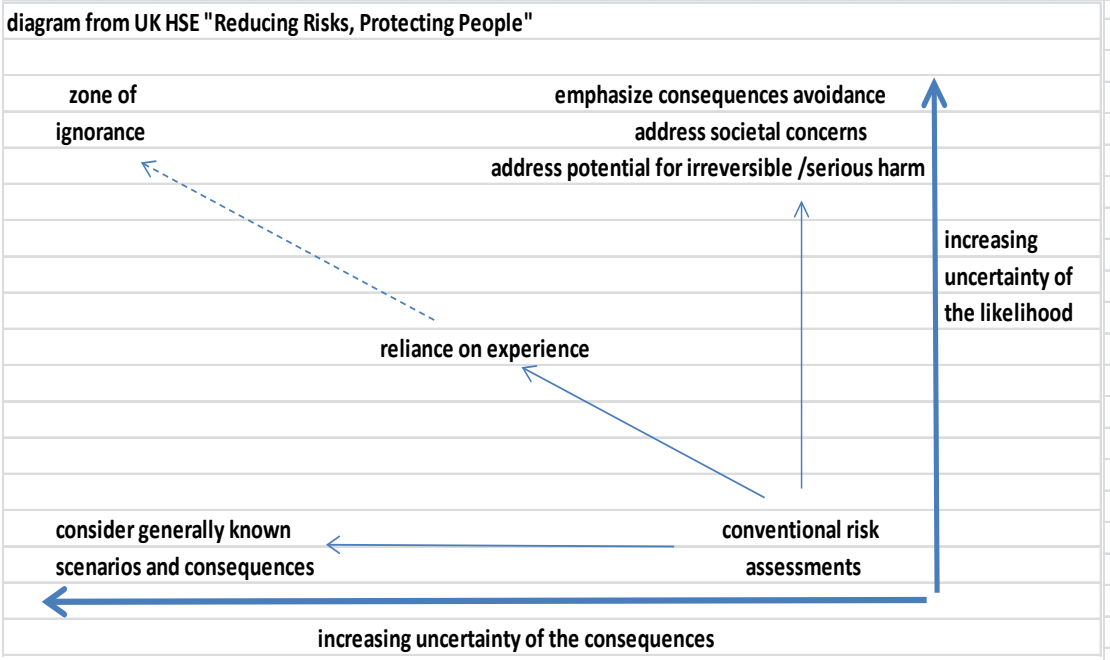
- past incidents, generic failure frequency
- condition assessment time-dependent trends, rates (corrosion and other deterioration mechanisms)
- time-independent potentials (impacts, etc.)

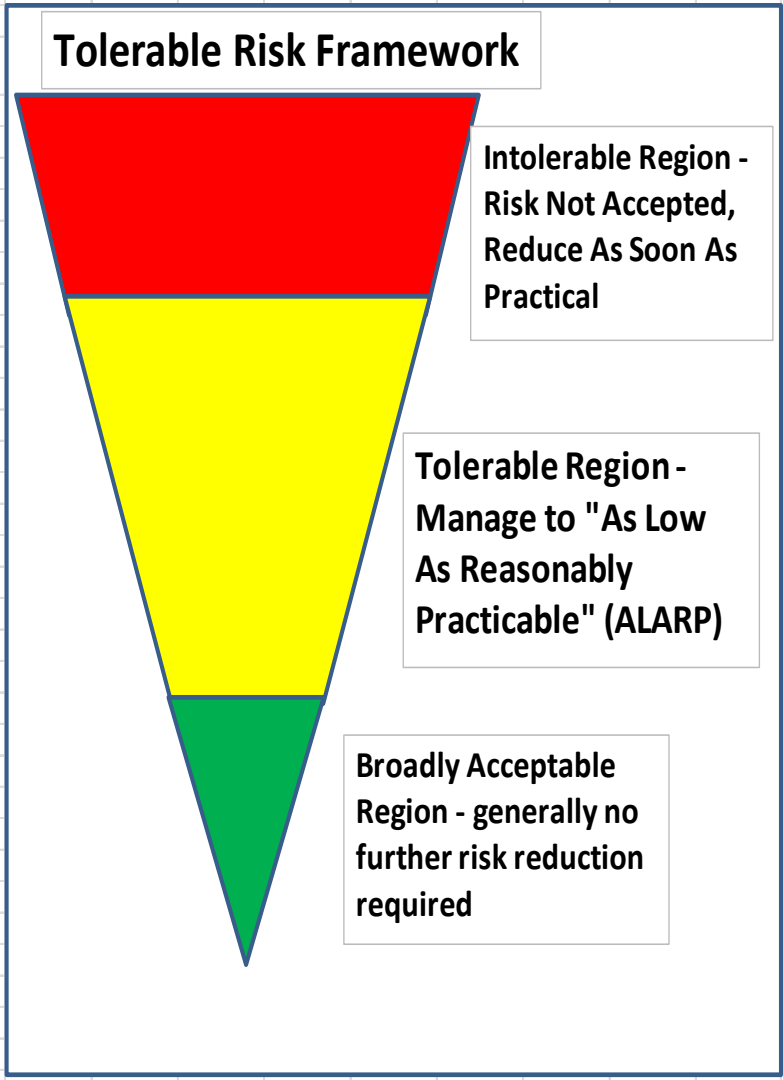
Consequence of primary containment failure

- secondary barriers: passive/technical containment, isolation, detection, control, human/organizational
- well flow capability (AOF tbg-limited at MOP)
- reservoir volume available (~15 day limit)
- population density - worker and public safety
- other: environmental, financial impact, service impact, regulatory, public perception

What is Values-Based, Risk-Informed Integrity Management?







Risk Evaluation and Treatment

Tolerable Risk Framework

- thresholds for safety; safety assessed for public, workers, nearby equipment/structures
- Environmental drivers – water, air, land/soil, non-human life and vegetation
- Service reliability, customer and public reputation
- Other financial impacts
- Assessment criteria – values thresholds and/or cost-benefit

Risk Treatment Decisions

- Options library
- effectiveness assessment
- data tracking

Consequence-Driven Risk Treatment Decisions

Financial Equivalence of Consequences	.0000001 to .000001	.000001 to .00001	.00001 to .0001	.0001 to .001	.001 to .01	.01 to .1	.1 to 1
$10,000,000,000	Green/Yellow						
$1,000,000,000	Green/Yellow						
$100,000,000			safety shift one-two orders of magnitude				
$10,000,000							
$1,000,000							
$100,000							
$10,000						Green/Yellow	Green/Yellow
	surface SV failure per demand	well failure, two barriers (tbg and csg) in excellent condition, per well-yr	well failure, single barrier (casing, or casing and cement), per well-yr	workover/re-entry incident rate, per event	tbg failure, per well-yr (low end)	MTTR - SSSV systems; MTTR - tbg/pkr systems; per well-yr	
	Likelihood>>>						

Consequence>>>

NOTE: well/casing failure is generally in “very unlikely” ranges, suggesting that risk treatment should be driven by probability-severity of consequences

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Consequence Drivers and Mitigations

Drivers

- Well flow potential and flow product composition
- Reservoir volume available to a well
- Proximity of well to population
- Population Density
- Worker/temporary human exposures
- Proximity to adjacent equipment/infrastructure
- Underground gas migration potential and pathways
- Environmental Factors, proximity and sensitivity
- Service Reliability factors – well importance to field performance

Mitigations (partial list)

- Isolation/Containment: secondary physical barriers, surface and subsurface
- Technical Control: flow shut off devices, fire suppression systems
- Human/Organizational Detection and Control: emergency response preparedness; data acquisition systems, alarms, and awareness of AOC; well intervention and control

RESEARCH:

1) HUMAN/ORG FACTORS IN PROCESS SAFETY
2) DATA ACQUISITION, MONITORING, ALARM – PROTOCOLS, STANDARDIZATION, RELIABILITY
3) TECHNICAL CONTROL BARRIER RELIABILITY

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Quantitative example: Tubing/packer + casing vs. casing

analysis of LOC risk over 100 years…

Generic casing failure rate assumed 0.000023 per well/yr

Re-entry LOC rate 0.000215 per well entry

Two barriers 2-6x lower failure rate than generic casing failure rate

Tbg/pkr system MTTR is 15 to 30 years (3.3 to 6.7 re-entries in 100 yrs)

Casing MTTR assume 1-2 per 100 years

analysis of LOC risk over 100 years												
	re-entries over 100 years		re-entry LOC	wells	re-entry LOC		add Gff	total		add 0 to 1 well w/tbg for service		
	min	max			min	max		min	max			
casing	1	2	0.000215	1	0.000215	0.00043	0.000023	0.000238	0.000453			
tbg	3.3	6.7	0.000215	1	0.00071	0.001441	0.0000034	0.000713	0.001444	0.000713	0.002888	
										3.00	6.37	LOC risk ratio, tbg/pkr vs. single well casing
										3 to 6 times more LOC risk w/tbg		

Note – even if casing failure likelihood increases to .0001, well re-entry risk drives total LOC risk due to increased re-entry due to inherently shorter tbg/pkr system MTTF/MTTR

CONTINUES TO SUGGEST THE IMPORTANCE OF HUMAN FACTORS IN PROCESS SAFETY (re-entry / workover LOC more of a driver than inherent casing / tubing failure)

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Risk Treatment – Options Library

Recommendation Options	
Applicable TEPS: *Gas Storage Facility Storage Well Integrity Plan* (EDMS 008452312)	
As prescribed from the Well Integrity Flow Charts, pick all options that apply.	
All potential remediation options require an immediate update to the FIRM Storage Well Integrity Issue Log and/or an IV study.	
1	Continue to operate without restriction per well integrity plans
2	Immediate action - set-downhole bridge plug, take well out of storage service
3	Immediate action - de-rate/limit maximum operating pressure
4	Enhanced data gathering (wellhead pressure, temperature, flow rate, etc) - MONTHLY
5	Enhanced data gathering (wellhead pressure, temperature, flow rate, etc) - WEEKLY
6	Enhanced data gathering (wellhead pressure, temperature, flow rate, etc) - DAILY
7	Enhanced casing annulus testing - MONTHLY
8	Enhanced casing annulus testing - WEEKLY
9	Enhanced casing annulus testing - DAILY
10	Enhanced casing inspection logging - NO MORE THAN 5 YEARS
11	Enhanced casing inspection logging - NO MORE THAN 10 YEARS
12	Enhanced casing inspection logging - NO MORE THAN 15 YEARS
13	Enhanced casing inspection logging - NO MORE THAN 20 YEARS
14	Additional logging - run cement bond, GRN, noise, calipe, casing inspection, and/or temperature log
15	Downhole remediation option - plug and abandon well
16	Downhole remediation option - install/repair tubing and packer
17	Downhole remediation option - install cemented liner
18	Wellhead remediation option - change-out/repair/paint wellhead valves/flanges/seals/bolts
19	Wellhead remediation option - pack-off wellhead seals
20	Wellhead remediation option - replace wellhead seals
21	Enhanced wellsite security - minimize encroachments (clear brush, remove trees, re-locate equipment, etc)
22	Enhanced wellsite security - install/repair phyiscal barrier (heat shields, burms, fences, etc)
23	Enhanced wellsite security - install sub-surface safety valve
24	Downhole remediation option - install de-rate/pressure limiting downhole packer (limiting MOP)
25	Downhole remediation option - pressure test wellbore (MIT test)
26	Downhole remediation option - remedial cementing (grouting, perforate and squeeze, etc)
27	Wellhead remediation option - install/repair annulus pressure vents
28	Downhole remediation option - back-off and replace top joints of casing
29	Downhole remediation option - top-off annulus with corrosion inhibitor
30	Regional study - investigate regional geology and adjacent wells, additional logging
	(bond, GRN, noise, caliper, casing inspection, temp) on adjacent wells,
	possible remediation of adjacent/plugged wells, addition of vent/observation wells

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Additional Safety and Integrity Management

- Active Control of well drilling / service work
- Adherence to Contractor Safety Management Program and contracting qualifications and policies
- MOC adapted for all well and reservoir life cycle stages
- Conformance to Industry Standards
  - CSA Z341.1 (Canada)
  - API 1171
  - ISO 16530 (Well Integrity)
  - IADC/CAODC Drilling Practices
  - Enform safety practices

Management of Change Process for the Storage Well Life Cycle

Well Design

change is initiated after the Well Design Basis Memorandum is completed

CPMS Manage Project Changes (EDMS 006377893)

consult the CPMS Manage Project Design (EDMS 006740639)

Well Drilling and Completion

Planning: See Well Design stage

Storage Well Drilling and Servicing Practices (EDMS No. 008372584)

Execution phase:

Storage Reliability Well Drilling, Completion, and Intervention MOC Practice

pre-completion phase:

Wellsite Review and Turnover Procedure (EDMS No. 008873051) and Form (EDMS No. 008873036

Well Operation

changes to operating status / limits, process, control, methods, measures, timing, or responsibilities

Technical and Physical Change Procedure (EDMS No. 007728761))

changes to procedures:

Document Change Procedure (EDMS No. 007728670)

Well Intervention

Planning stage

Storage Well Drilling and Servicing Practices (EDMS No. 008372584)

Storage Well Work Planning Procedure for Operation and Maintenance Work (EDMS No. 008902959) and Checklist (EDMS No. 008902948)

execution phase:

Storage Reliability Well Drilling, Completion, and Intervention MOC Practice

pre-completion phase:

Wellsite Review and Turnover Procedure (EDMS No. 008873051) and Form (EDMS No. 008873036)

Well Abandonment

Planning stage

Technical and Physical Change Procedure (EDMS No. 007728761)

Storage Well Drilling and Servicing Practices (EDMS No. 008372584)

execution phase:

Storage Reliability Well Drilling, Completion, and Intervention MOC Practice

pre-completion phase:

Wellsite Review and Turnover Procedure (EDMS No. 008873051) and Form (EDMS No. 008873036)

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