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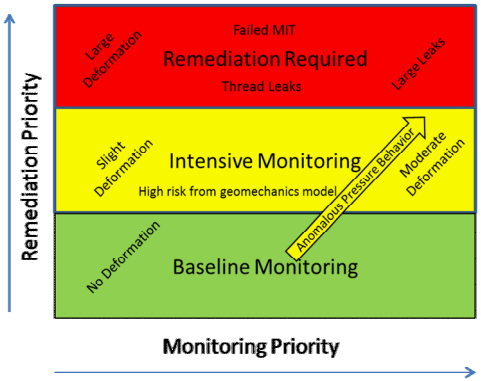

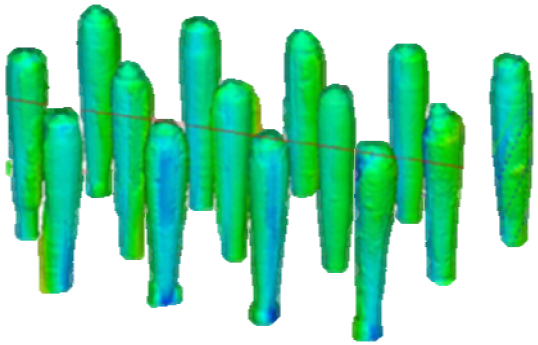

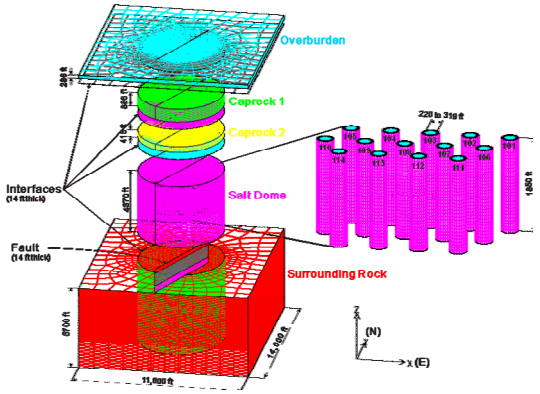

Strategic Petroleum Reserve Well Integrity Management Program

By Steven Sobolik and Barry Roberts

SMRI Technical Class - Well Integrity Management for Salt Caverns

April 23, 2017, Albuquerque, NM, USA

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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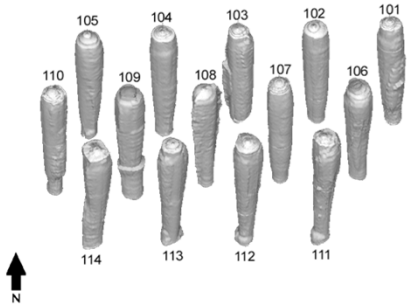
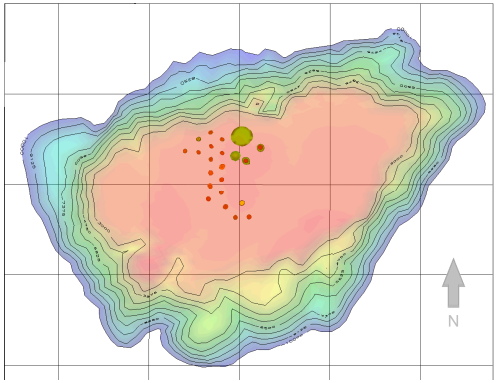
Presentation Overview

- The Strategic Petroleum Reserve
- Brief background – motivation for well grading
- General well grading framework
- Components in current well grading
- Summary

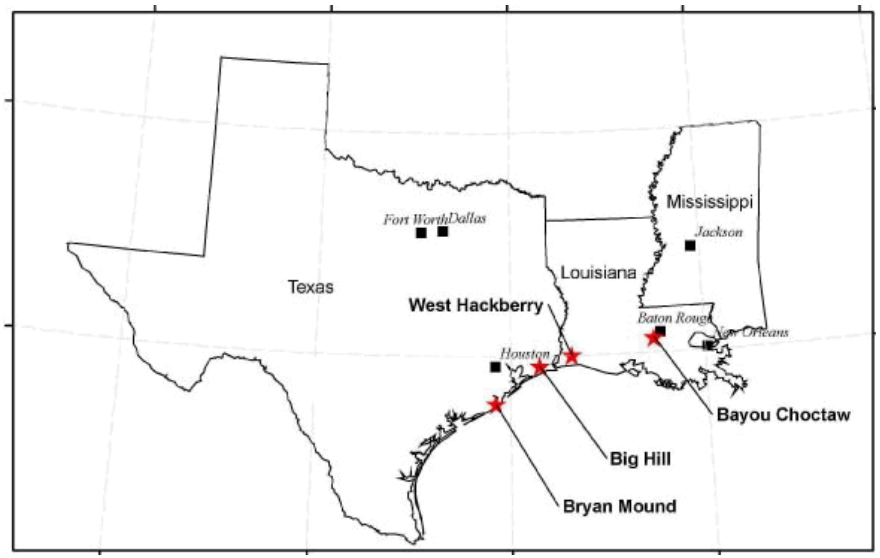




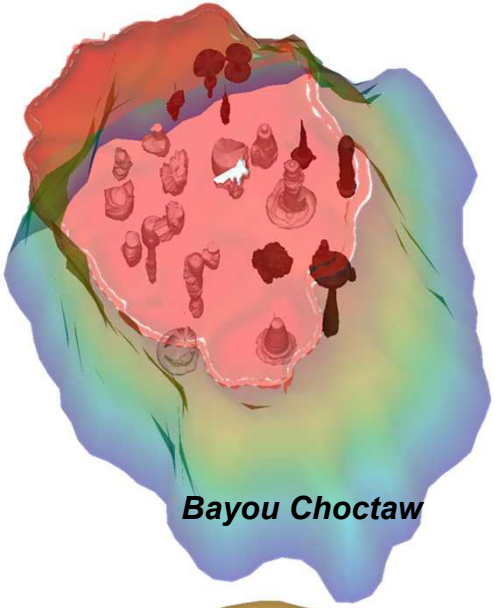
Background on SPR Sites

The Department of Energy Strategic Petroleum Reserve

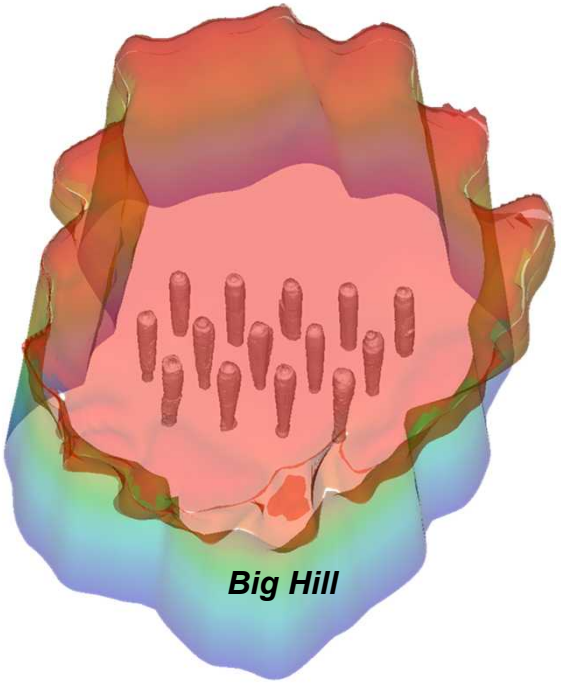
- SPR is spread across 4 Gulf Coast site locations
- Current oil inventory of about 700 million barrels
- Composed of 62 solution mined caverns
- About 120 cavern access wells – differing completions
- Length of cased well sections range from ~1400 to ~2500 feet
- Mixture of pre-existing and purpose built caverns
- SPR – owned by DOE
  - Managed/operated by FFPO
  - SNL geotechnical advisors



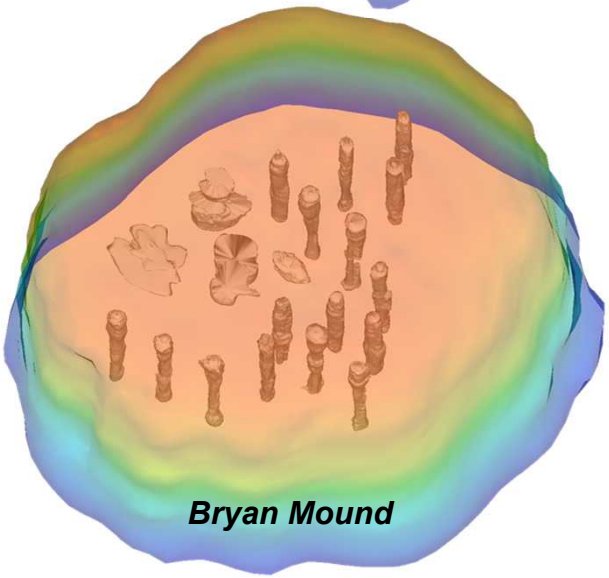
SPR Sites



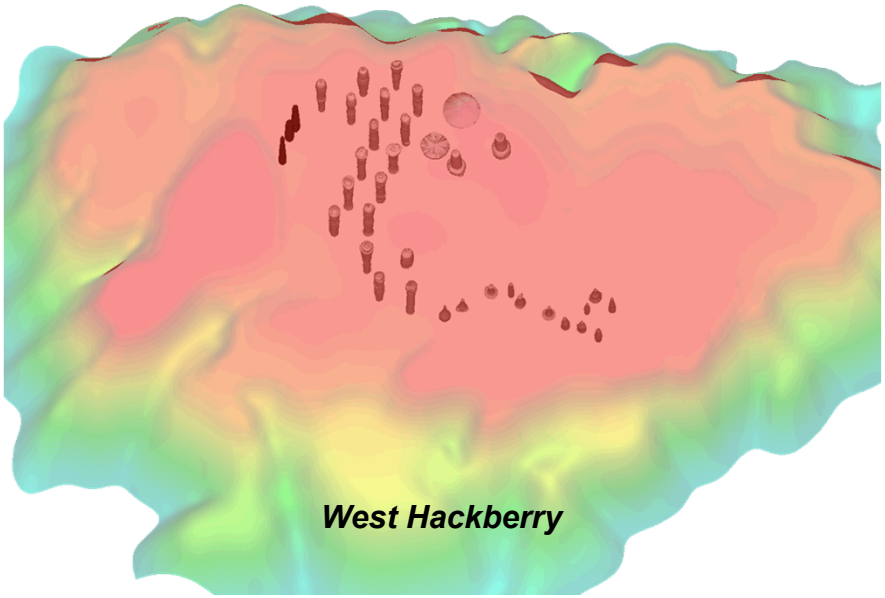
Bayou Choctaw



Big Hill



Bryan Mound

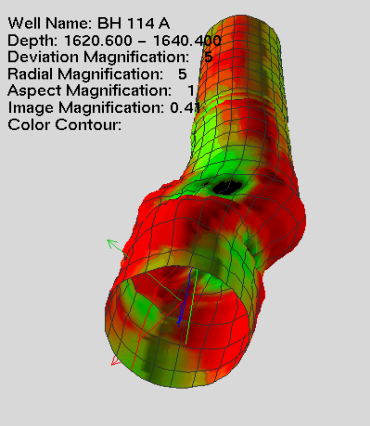


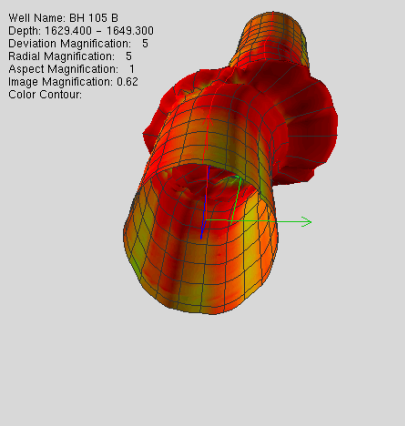
West Hackberry

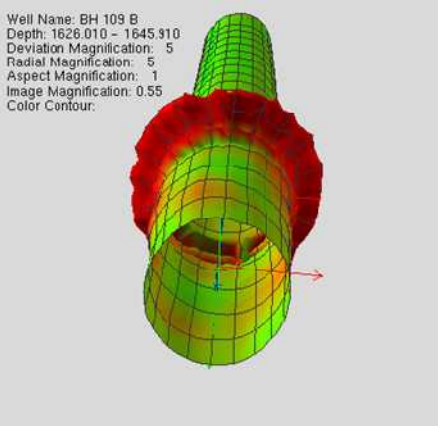
Background - Motivation

- The SPR must maintain the integrity of cavern access wells to meet drawdown requirements
  - Wells occur in differing geologic settings
  - Differing well completions
  - A multitude of cavern geometries
- Experiencing a number of well failures at some SPR sites
- Evidence from multi-arm caliper logs of accumulating casing deformation
- Need to prioritize remediation/monitoring resources

DOE requests development of a well remediation prioritization system







WELL GRADING FRAMEWORK DEVELOPMENT PROCESS

Goal

Establish a well grading system that will provide a remediation/monitoring priority based on all available, relevant information and is applicable to all SPR sites.

Process

1. Establish processes/information pertinent to well integrity
2. Develop a framework for integration of information
3. Populate framework with values for each grading parameter for each well
4. Aggregate this grading parameter values into a single value
    1. Remediation grade
    2. Monitoring grade
5. Update grading values as necessary

Well Grading Framework Development Meeting

- Considerations:
  - Geology
  - Geomechanics
  - MAC grading
  - Remedial workovers
  - Cavern pressure history
  - Regulatory requirements
  - Cavern histories
- Interactive, group development (Sandia, DOE, FFPO) of grading framework spreadsheet
- Well-by-well assignment of grading parameter values (parameter ranges 1-5, weighing factors applied)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		GRADE STATUS	MAC-FINAL	PRESS	REMED	Pressure for Monitoring	MAC for Monitoring	Geomech.	Well Info.	Geology	Cavern Geo.	Offsite Act.	Monitor Axis
2					(MAC, Press)	0.20	0.20	0.20	0.15	0.10	0.10	0.05	1.00
3													
4	BH101A	1	2.5	2	2.5	2	4	1	1.83	2.40	1.33	1	2.10
5	BH101B	1	3	2	3	2	2	1	1.55	2.40	1.33	1	1.66
6	BH102A	1	2	2	2	2	3	4	1.84	2.40	1.33	1	2.50
7	BH102B	1	1.25	2	2	2	3	4	1.55	2.40	1.33	1	2.46
8	BH103A	1	1.25	2	2	2	1.5	1	2.27	3.20	1.67	1	1.78
9	BH103B	1	3.25	2	3.25	2	1.5	1	2.27	3.20	1.67	1	1.78
10	BH104A	1	3.5	1	3.5	1	4	2	2.12	2.40	1.33	1	2.14
11	BH104B	1	1	1	1	1	1	2	1.55	2.40	1.33	1	1.46
12	BH105A	1	3	1	3	1	4	5	2.58	2.40	1.33	1	2.81
13	BH105B	1	1.25	1	1.25	1	1.5	5	2.27	2.40	1.33	1	2.26
14	BH106A	1	2.25	1	2.25	1	3	3	2.14	2.40	1.67	1	2.18
15	BH106B	1	1	1	1	1	1	3	1.57	2.40	1.67	1	1.69
16	BH107A	1	2.5	1	2.5	1	3.5	4	2.45	2.00	1.33	1	2.45
17	BH107B	1	4.25	1	4.25	1	3.5	4	1.88	2.00	1.33	1	2.36
18	BH108A	1	3	1	3	1	3.5	1	2.01	2.60	1.67	1	1.88
19	BH108B	1	3.5	1	3.5	1	3.5	1	1.72	2.60	1.67	1	1.83
20	BH109A	1	3	1	3	1	3	5	2.44	2.60	1.67	1	2.64
21	BH109B	1	1	1	1	1	1	5	1.96	2.60	1.67	1	2.17
22	BH110A	1	1.75	1	1.75	1	2.5	3	1.86	2.60	1.33	1	2.02
23	BH110B	1	1.5	1	1.5	1	3	3	1.57	2.60	1.33	1	2.08
24	BH111A	1	4	1	4	1	4	3	2.42	1.60	1.67	2	2.39
25	BH111B	1	3.25	1	3.25	1	3.5	3	1.84	1.60	1.67	2	2.20
26	BH112A	1	4.25	2	4.25	2	4	4	2.54	2.20	1.67	1	2.82
27	BH112B	1	3.5	2	3.5	2	4	4	2.26	2.20	1.67	1	2.78
28	BH113A	1	3	4	4	4	1.5	3	2.11	2.40	1.67	1	2.47
29	BH113B	1	3.75	3	3.75	3	3.5	3	1.54	2.40	1.67	1	2.59
30	BH114A	1	1	1	1	1	1	4	1.64	3.20	1.67	2	2.03
31	BH114B	1	1	1	1	1	1	4	1.93	3.20	1.67	2	2.08

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GRADING FRAMEWORK COMPONENTS

Well Grading Components

Discussions amongst subject matter experts resulted in the inclusion of the following main well grading components:

1. Geological elements
2. Geomechanical simulation results
3. Cavern pressure history
4. Multi-arm caliper survey results
5. Well history
6. Cavern Geometry
7. Offsite activities

Well ID	Remediation Grade	Monitoring Grade
19	4	2.29
15A	2.5	1.51
20	2	1.67
101A	2	1.89
15	1.75	1.55
17A	1.75	1.57
102A	1.75	1.47
18	1.25	1.58
19A	1.25	1.41
101B	1.25	1.90
17	1	1.42
18A	1	1.53
20A	1	1.60
102B	1	1.27
4**	-	3.22

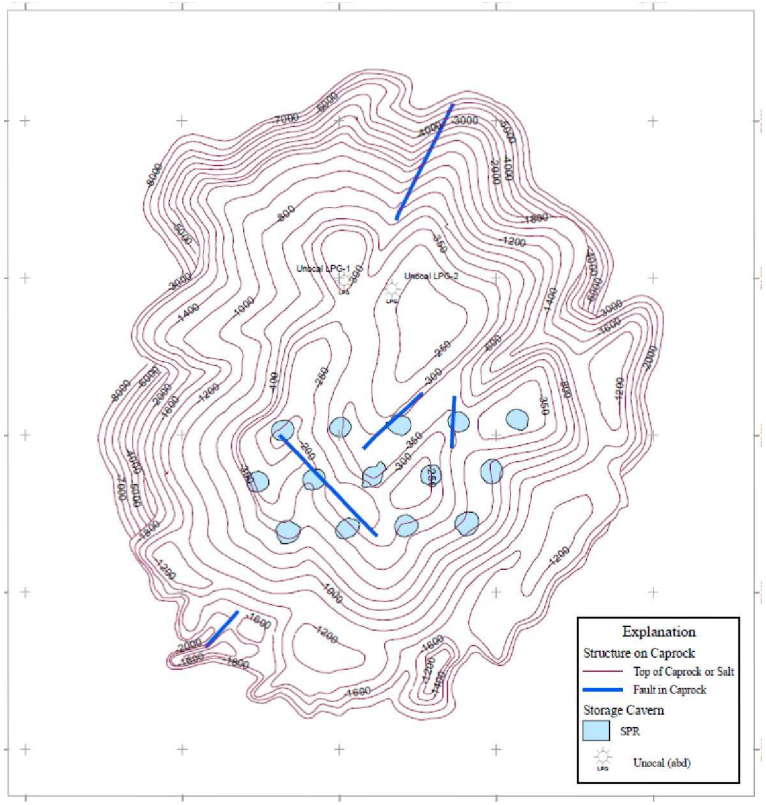
Each main component may then have various sub-components.

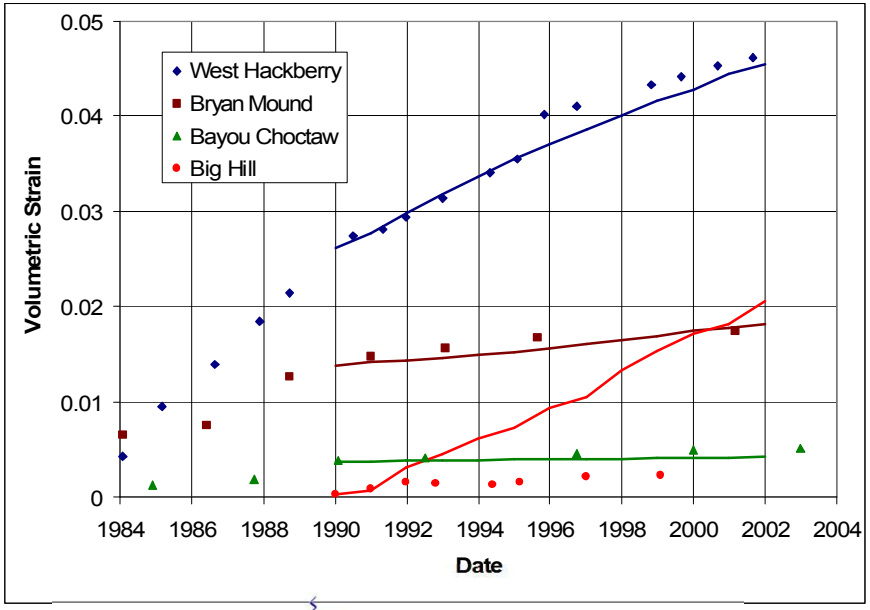
WELL GRADING COMPONENT DETAILS

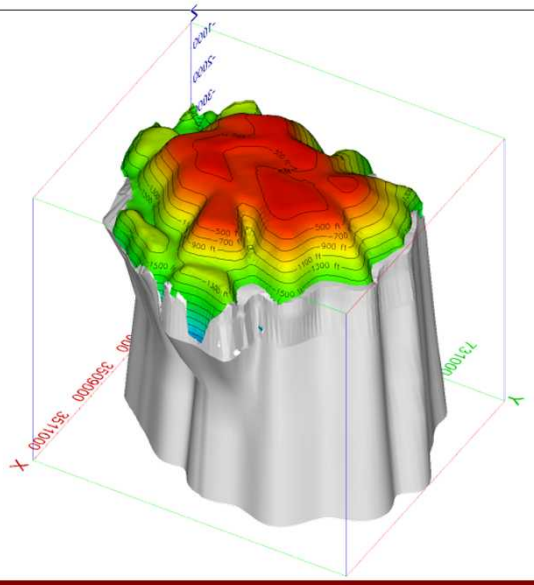
Geology Component

- Well casing stresses directly linked to surrounding geology
- Significant factors include:
  - Caprock thickness and structure
  - Relative subsidence
  - Distance to salt dome overhangs
  - Internal faults or shear zones
- Site specific traits
  - Bayou Choctaw – overhanging salt margin, close proximity of caverns to salt dome
  - Big Hill – unusually thick caprock, impact on subsidence, well strains at salt/caprock interface
  - Bryan Mound – caprock mined for sulfur, latent heat signature; highly variable salt creep
  - West Hackberry – very homogeneous salt, fast creep rate, greatest subsidence

Big Hill Geology







Bryan Mound Geology

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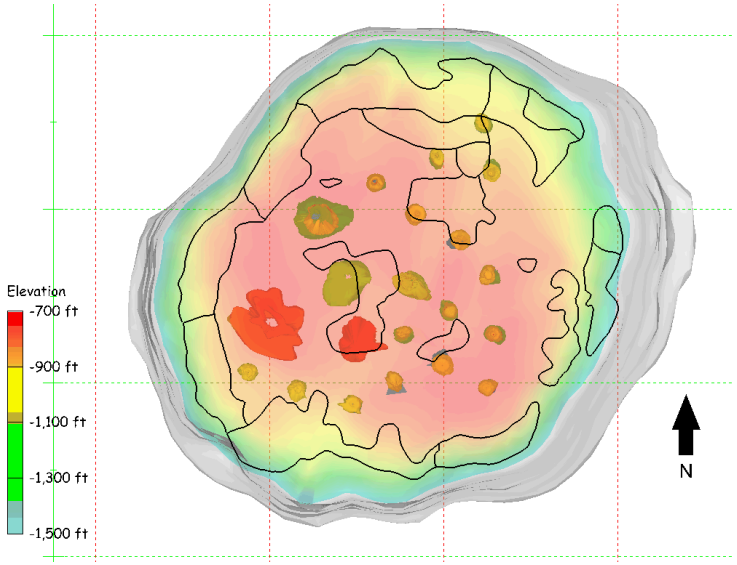
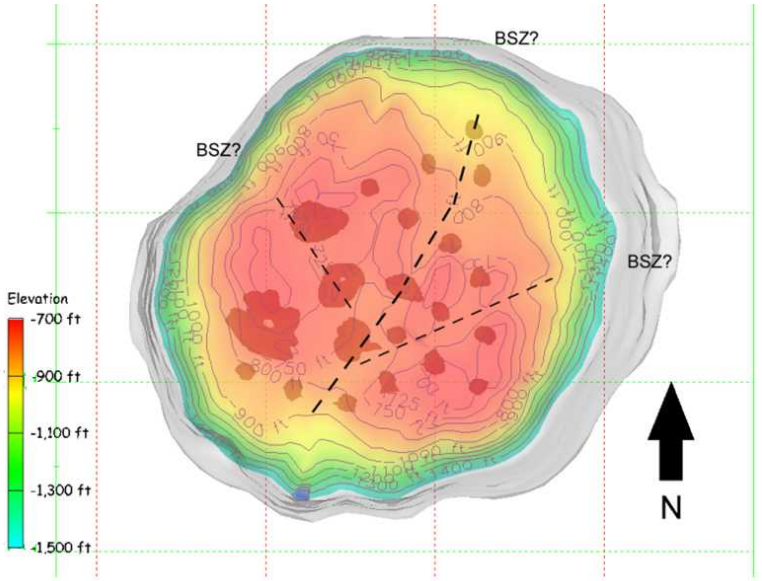
Sulfur Mining, 1910s-1920s

Heterogeneity of Salt

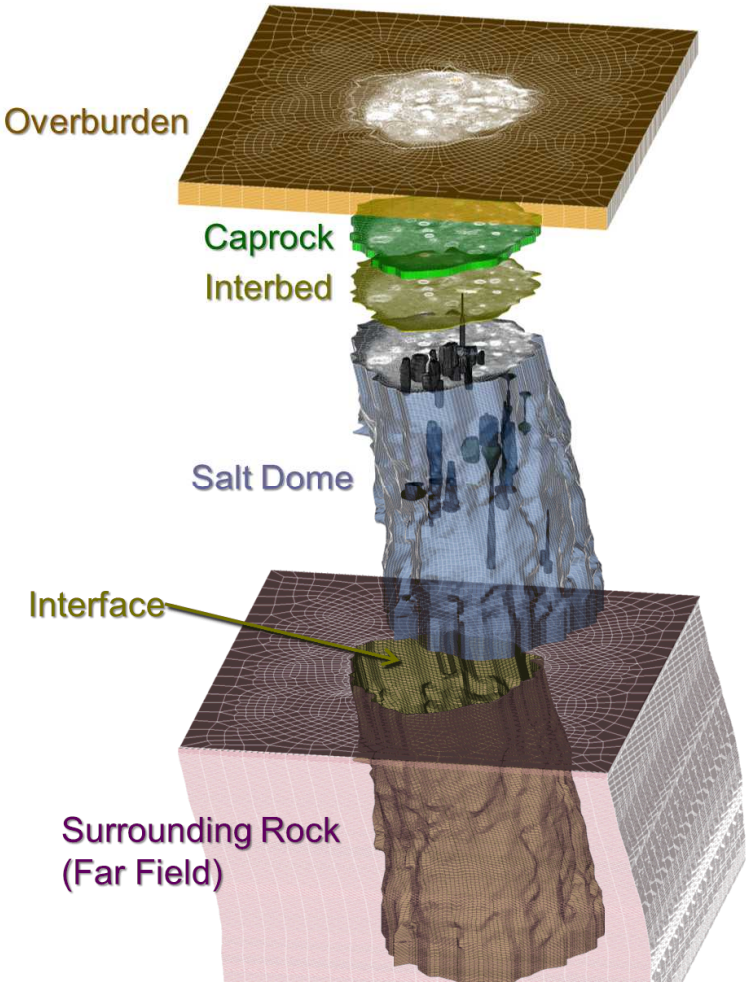
Cavern	Closure, BBL/yr	Cavern	Closure, BBL/yr
BM101	5,365	BM109	8,543
BM102	4,944	BM110	3,150
BM103	11,680	BM111	7,813
BM104	2,948	BM112	6,858
BM105	3,683	BM113	10,223
BM106	10,460	BM114	21,304
BM107	4,061	BM115	21,034
BM108	2,702	BM116	6,135





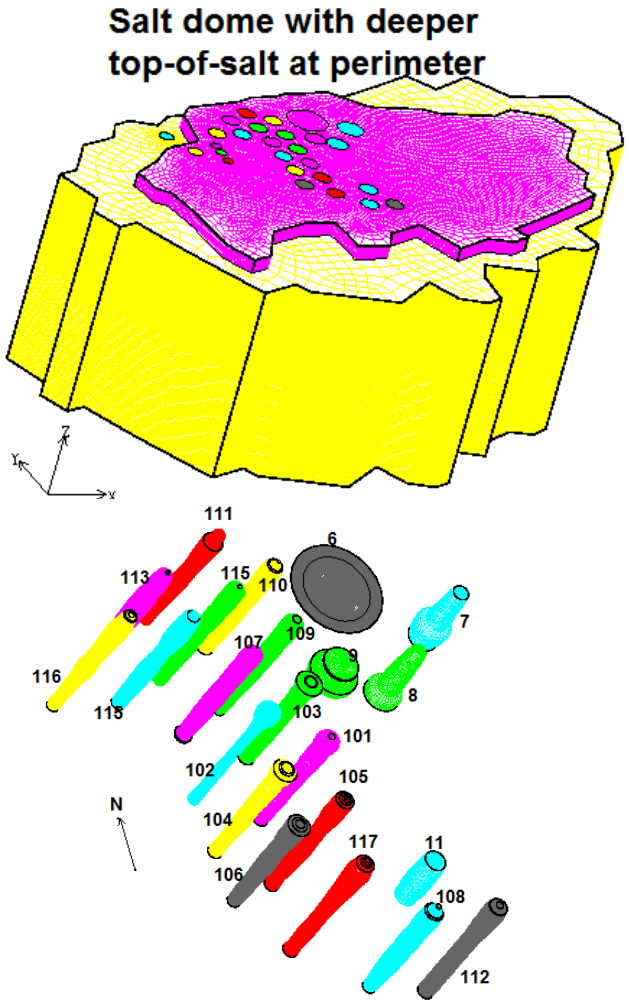
Geomechanical Simulation Component

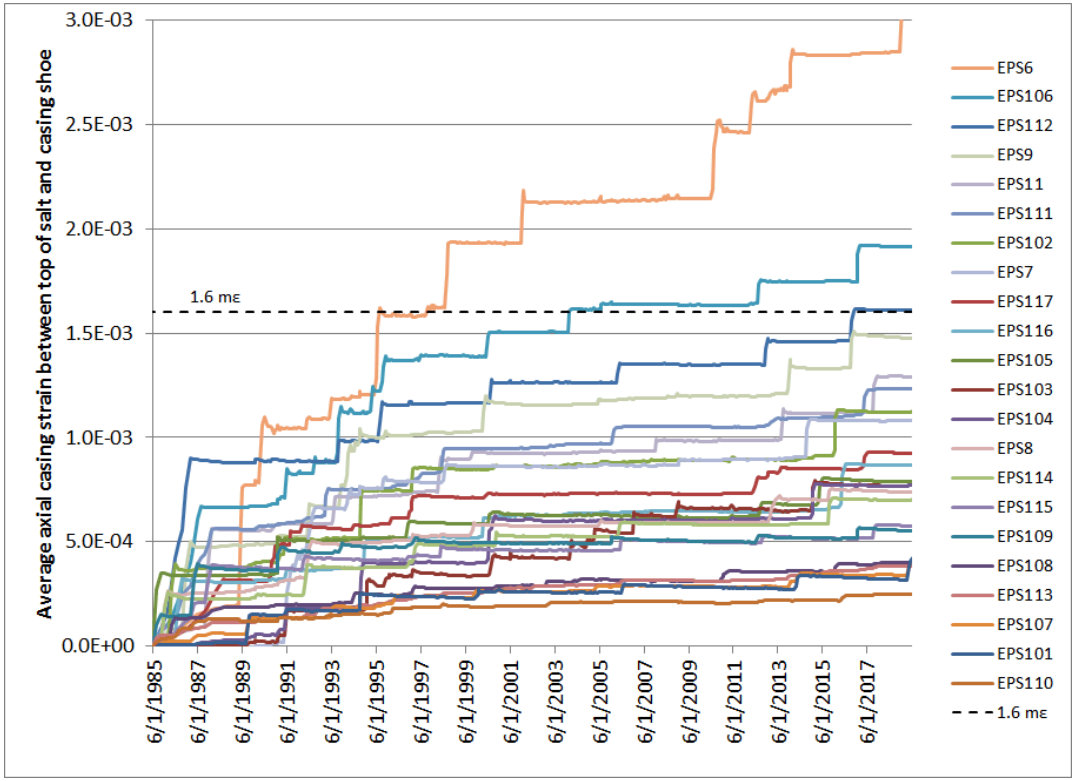
- Provides estimates of stresses and strains at millions of points within a geological region which can then be used to predict cavern closure, surface subsidence, and stresses and strains on wellbore casings.
- Models compute both tensile and shear stress which are markedly different for different regions of salt dome and cavern field.
- When coupled with actual observed well failures, computed stresses can be used to rank order wells in an estimated order of failure – this provides grading information.
- Model limitations include:
  - Simplified geometries
  - Limited parameterization/calibration information



West Hackberry Geomechanical Modeling

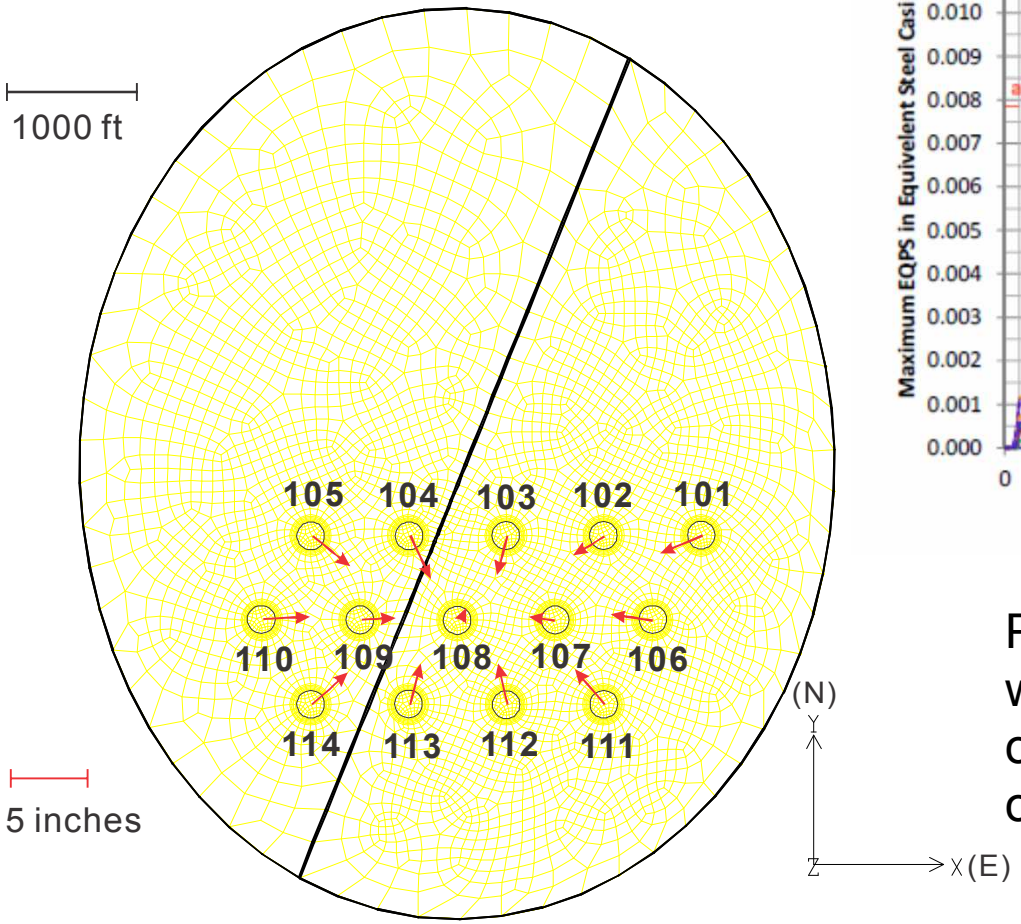
Predictive analysis show accumulation of vertical strain along casing, provide to when onset of plastic deformation of steel may occur.

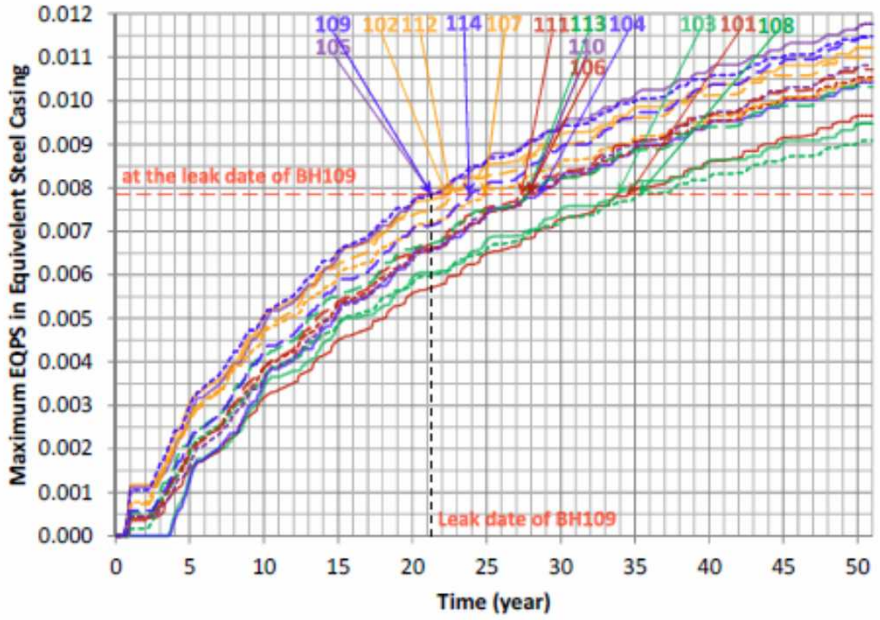




Modeling by S. Sobolik Sandia National Labs

Big Hill Geomechanical Modeling



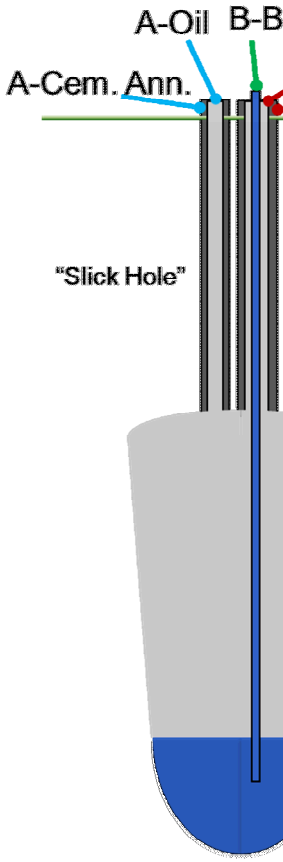


Predictive analysis showing age at which casing is likely to fail. Based on model results compared to observations.

Modeling by B. Park Sandia National Labs

Cavern Pressure History Component

- Wellhead fluid pressure is used at SPR as an indicator of cavern and well integrity
- Daily monitoring reveals long-term trends and looks for deviations from trends that may indicate leaks
- Annular pressure also considered
- Primary indictor of well integrity



BH114 Oil Pressure

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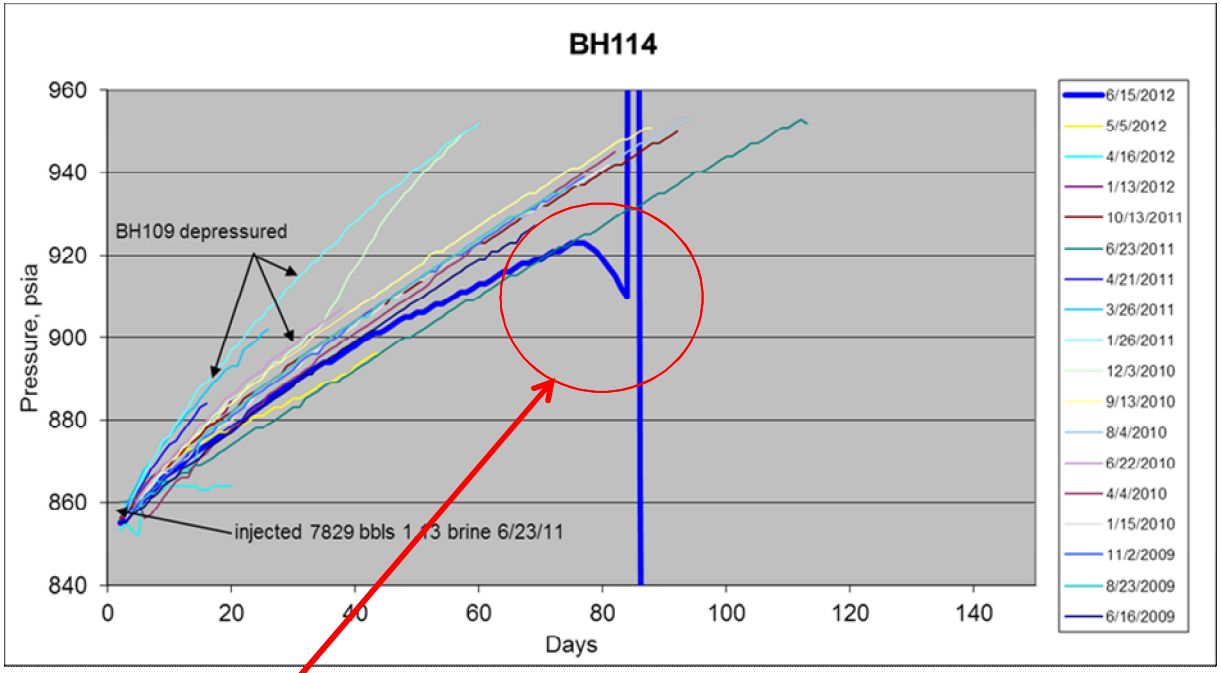
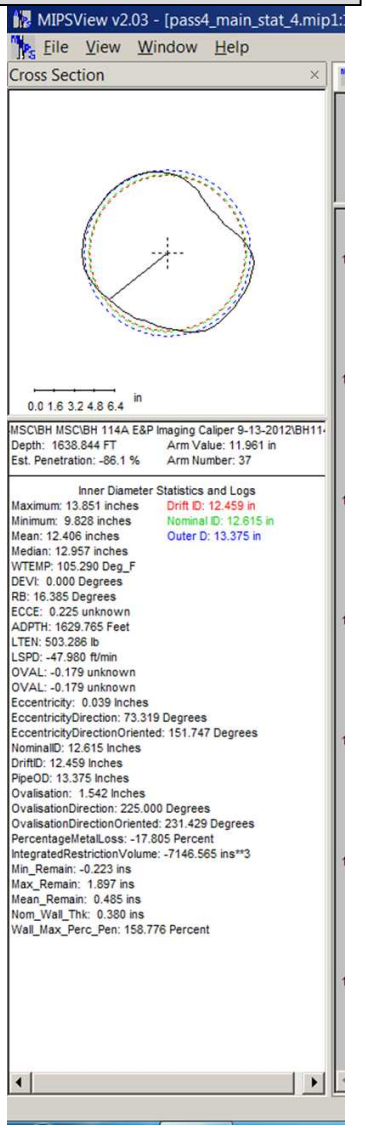


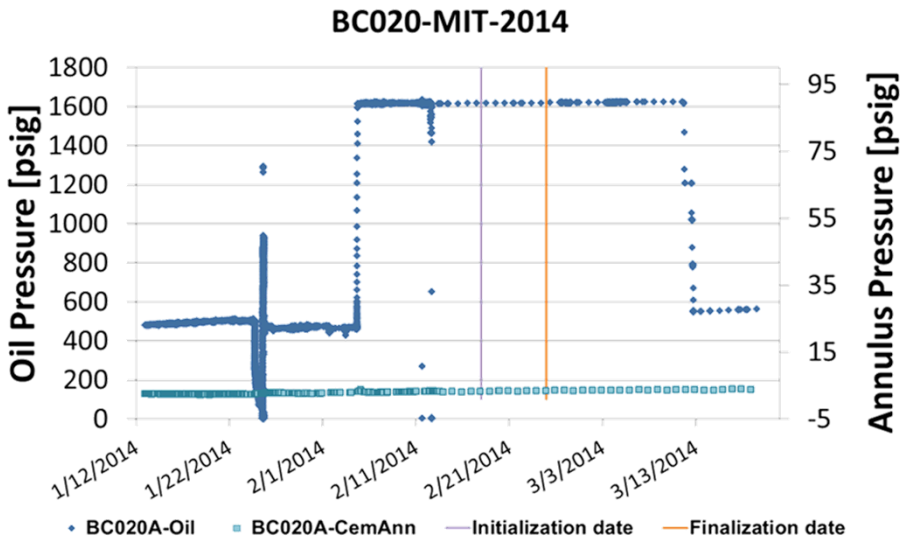
Oil pressure loss over days-weeks with no satisfactory operational explanation

Subsequent N_2 injection confirms leak location, well subsequently remediated with liner

9/13/2012 MSC



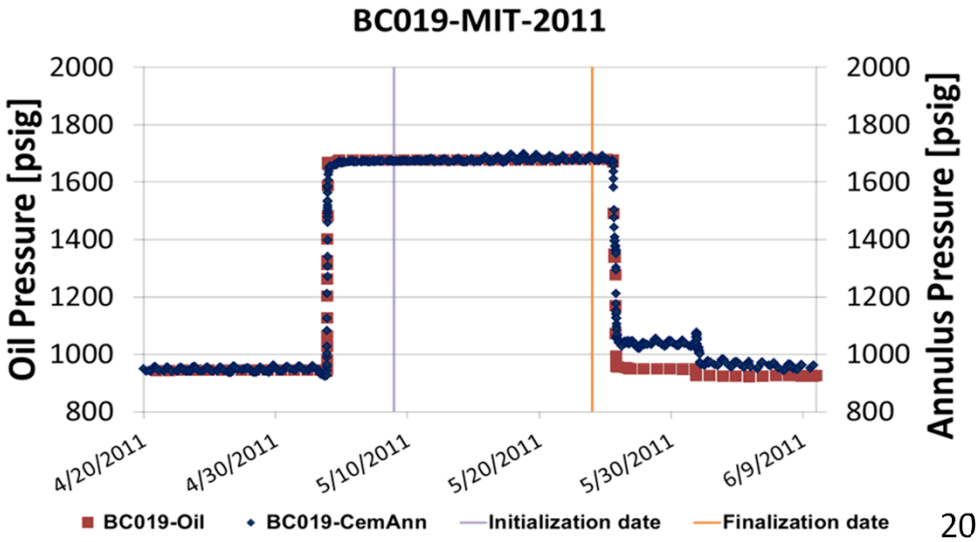
Annular Pressure



Grade	Conditions
5	Confirmed hydraulic leak through cemented casing or around shoe in excess of what can be offset by nitrogen injection. Failed MIT.
4	Pressure trending anomalies such as flattening or loss of pressure. Apparent nitrogen leak yet leak zone may or may not be identified. Cemented annulus pressure tracks with oil pressure. Leak can be contained with nitrogen.
3	Pressure trending anomalies such as flattening or loss of pressure. No problems under last MIT or nitrogen test with detailed pressure trending analysis.
2	Some discrepancy in the pressure history curves.
1	No known problems with pressure trending analysis, or under nitrogen/MIT.

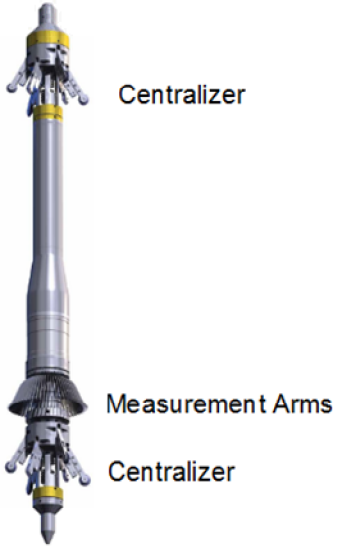
Annular pressure low or zero and no response during MIT

Significant annular pressure and response during MIT



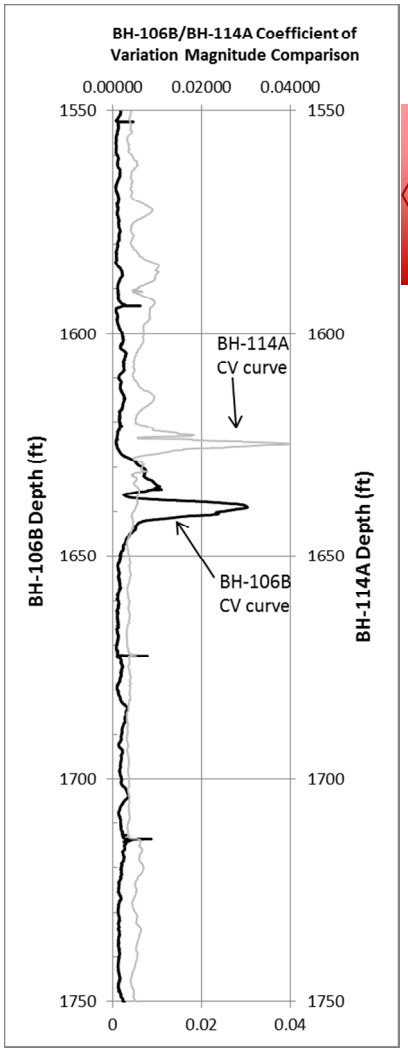
Multi-arm Caliper Survey Component

- Provides direct measurement of casing deformation as an indicator of potential casing failure
- Can be used for semi-quantitative, well-to-well comparisons
- Available for virtually all SPR cavern wells
- With multiple surveys, can provide a time-dependent analysis of casing deformation rates



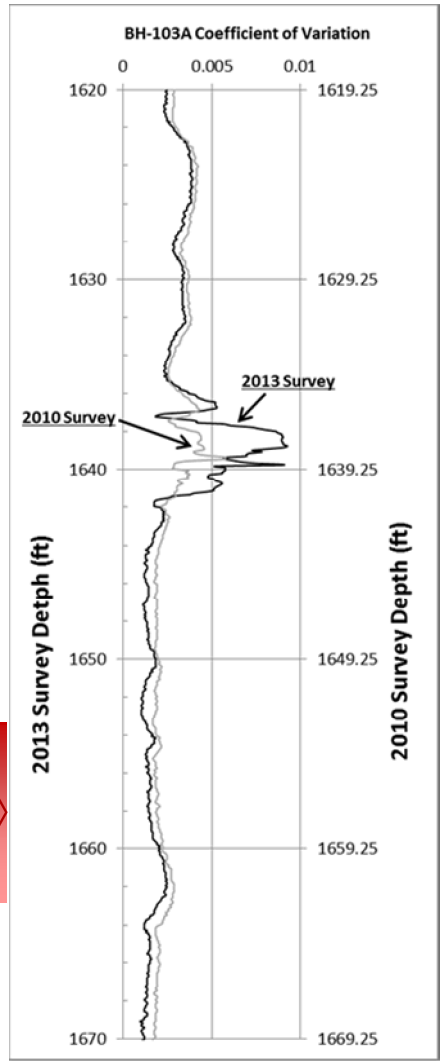

Measurement Arm Detail

MAC Survey



Well-to-well comparison supports ranking and grading based on relative deformation values

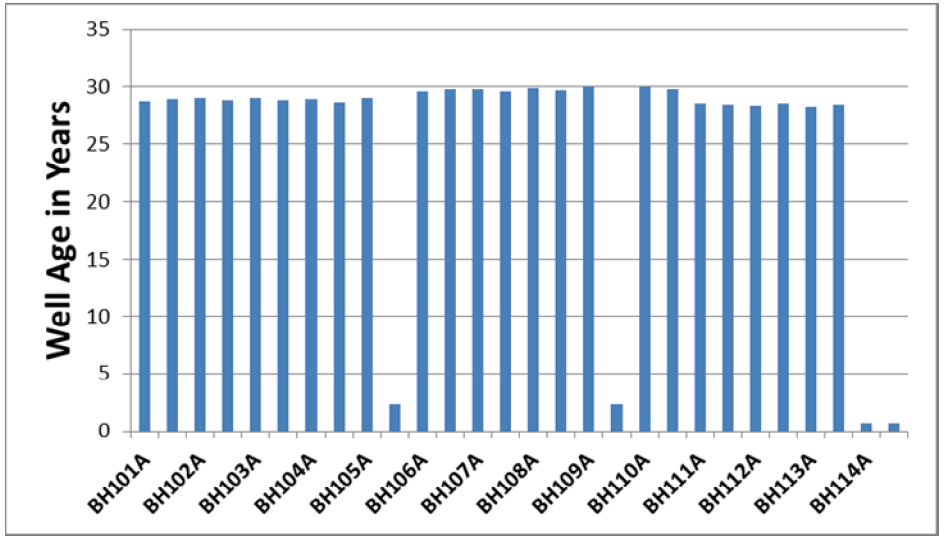
Time dependent analysis provides relative deformation rates



SMRI Paper – "Casing Analysis for Well Integrity Investigation", Spring 2014 Meeting

Well History Component

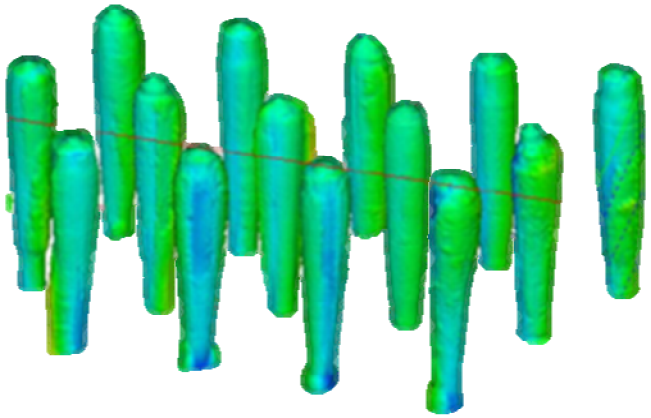
- This component captures significant information and events from the well's lifetime from installation/remediation to present
- Components included:
  - Well age
  - Gas regain
  - Fluid in cemented annulus
  - Well deviation
  - Leak history
  - Well pair history
  - Time since last MAC survey



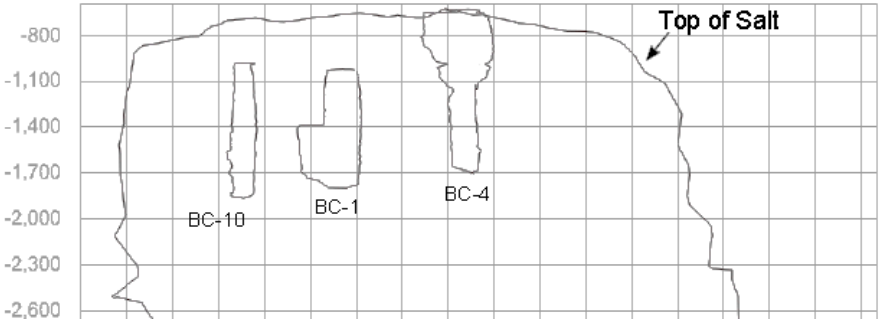
Actual time since installation or remediation

Cavern Geometry Component

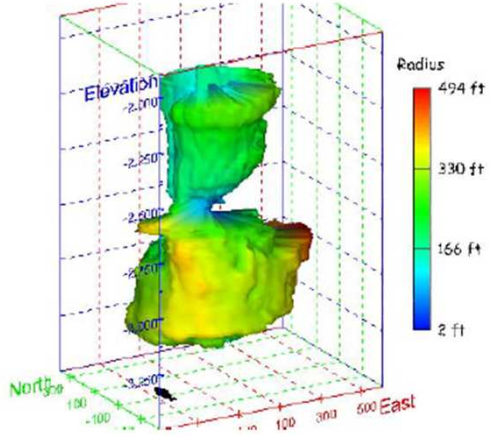
- Cavern geometry and relative position have stability which in turn, affects well integrity
- Components included:
  - Cavern shape
  - Pillar-to-diameter ratio
  - Thickness of salt above cavern roof (salt back)



Big Hill Cavern Field



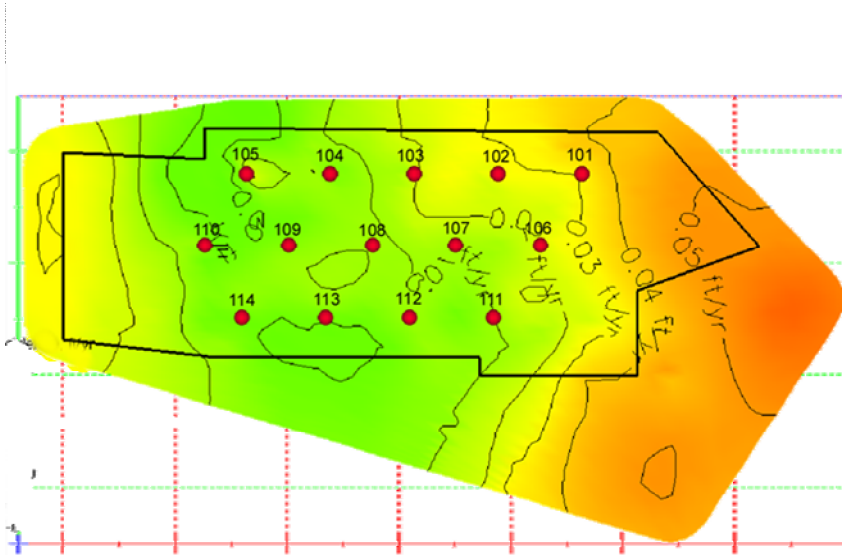
Differences in salt back



Less Desirable Cavern Shape

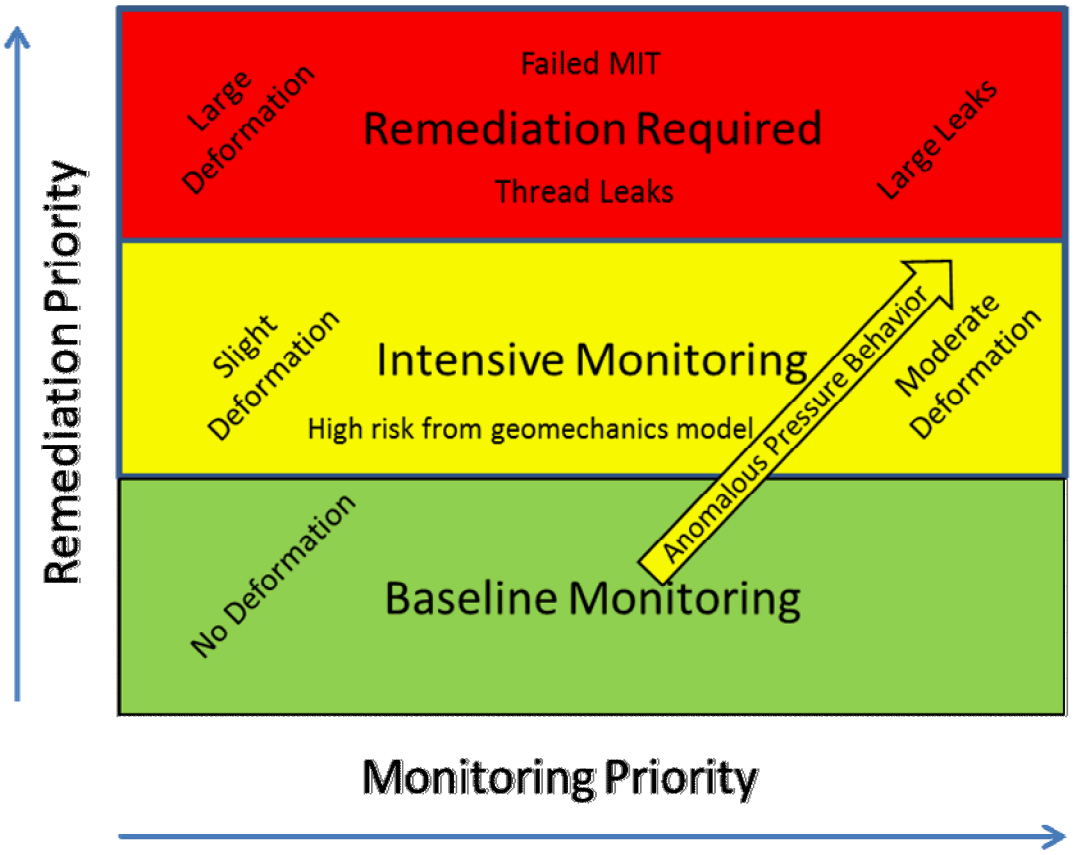
Offsite Activities

- Captures any non-SPR activities which could have a detrimental impact on SPR cavern well integrity
- Big Hill example - reflects offsite injection activities (?)
  - May or may not be an issue, but important enough to include



ROLL-UP OF GRADING COMPONENTS

Two-Dimensional Remediation/Monitoring Space



Well Grading Framework

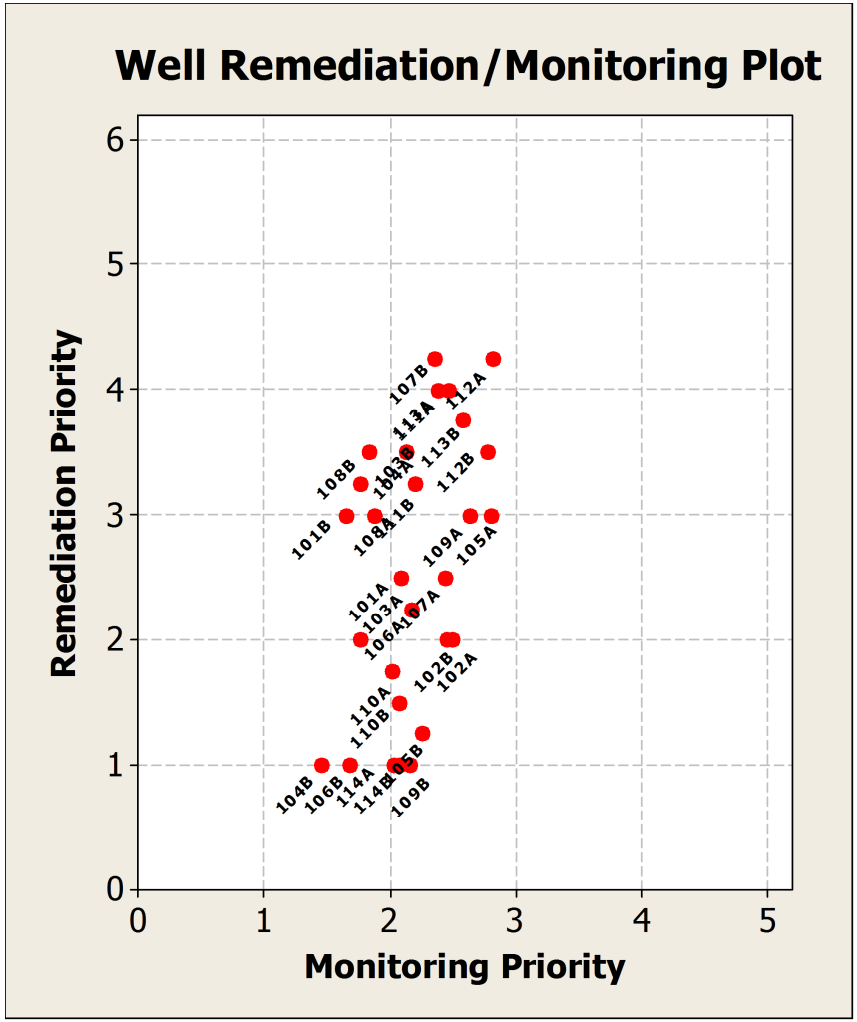
- Spreadsheet based
- Familiar format
- Easily updatable

Main Components

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		GRADE STATUS	MAC-FINAL	PRESS	REMED	Pressure for Monitoring	MAC for Monitoring	Geomech.	Well Info.	Geology	Cavern Geo.	Offsite Act	Monitor Axis
2					(MAC, Press)	0.20	0.20	0.20	0.15	0.10	0.10	0.05	1.00
3													
4	BH101A	1	2.5	2	2.5	2	4	1	1.83	2.40	1.33	1	2.10
5	BH101B	1	3	2	3	2	2	1	1.55	2.40	1.33	1	1.66
6	BH102A	1	2	2	2	2	3	4	1.84	2.40	1.33	1	2.50
7	BH102B	1	1.25	2	2	2	3	4	1.55	2.40	1.33	1	2.46
8	BH103A	1	1.25	2	2	2	1.5	1	2.27	3.20	1.67	1	1.78
9	BH103B	1	3.25	2	3.25	2	1.5	1	2.27	3.20	1.67	1	1.78
10	BH104A	1	3.5	1	3.5	1	4	2	2.12	2.40	1.33	1	2.14
11	BH104B	1	1	1	1	1	1	2	1.55	2.40	1.33	1	1.46
12	BH105A	1	3	1	3	1	4	5	2.58	2.40	1.33	1	2.81
13	BH105B	1	1.25	1	1.25	1	1.5	5	2.27	2.40	1.33	1	2.26
14	BH106A	1	2.25	1	2.25	1	3	3	2.14	2.40	1.67	1	2.18
15	BH106B	1	1	1	1	1	1	3	1.57	2.40	1.67	1	1.69
16	BH107A	1	2.5	1	2.5	1	3.5	4	2.45	2.00	1.33	1	2.45
17	BH107B	1	4.25	1	4.25	1	3.5	4	1.88	2.00	1.33	1	2.36
18	BH108A	1	3	1	3	1	3.5	1	2.01	2.60	1.67	1	1.88
19	BH108B	1	3.5	1	3.5	1	3.5	1	1.72	2.60	1.67	1	1.83
20	BH109A	1	3	1	3	1	3	5	2.44	2.60	1.67	1	2.64
21	BH109B	1	1	1	1	1	1	5	1.96	2.60	1.67	1	2.17
22	BH110A	1	1.75	1	1.75	1	2.5	3	1.86	2.60	1.33	1	2.02
23	BH110B	1	1.5	1	1.5	1	3	3	1.57	2.60	1.33	1	2.08
24	BH111A	1	4	1	4	1	4	3	2.42	1.60	1.67	2	2.39
25	BH111B	1	3.25	1	3.25	1	3.5	3	1.84	1.60	1.67	2	2.20
26	BH112A	1	4.25	2	4.25	2	4	4	2.54	2.20	1.67	1	2.82
27	BH112B	1	3.5	2	3.5	2	4	4	2.26	2.20	1.67	1	2.78
28	BH113A	1	3	4	4	4	1.5	3	2.11	2.40	1.67	1	2.47
29	BH113B	1	3.75	3	3.75	3	3.5	3	1.54	2.40	1.67	1	2.59
30	BH114A	1	1	1	1	1	1	4	1.64	3.20	1.67	2	2.03
31	BH114B	1	1	1	1	1	1	4	1.93	3.20	1.67	2	2.08

Sub-Component Tabs

Example - Big Hill Well Grading Results

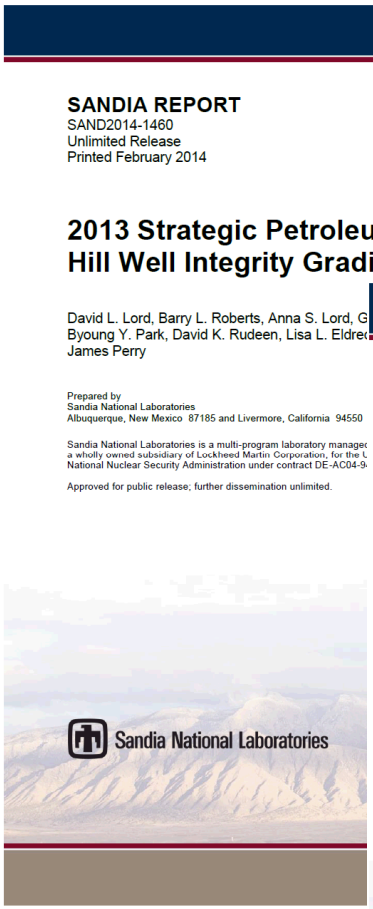


WELL ID	REMED.	MON.
BH101A	2.5	2.10
BH101B	3	1.66
BH102A	2	2.50
BH102B	2	2.46
BH103A	2	1.78
BH103B	3.25	1.78
BH104A	3.5	2.14
BH104B	1	1.46
BH105A	3	2.81
BH105B	1.25	2.26
BH106A	2.25	2.18
BH106B	1	1.69
BH107A	2.5	2.45
BH107B	4.25	2.36
BH108A	3	1.88
BH108B	3.5	1.83
BH109A	3	2.64
BH109B	1	2.17
BH110A	1.75	2.02
BH110B	1.5	2.08
BH111A	4	2.39
BH111B	3.25	2.20
BH112A	4.25	2.82
BH112B	3.5	2.78
BH113A	4	2.47
BH113B	3.75	2.59
BH114A	1	2.03
BH114B	1	2.08

Maintenance of Grading Framework

- Designed to be easily updatable by subject matter experts
- Framework spreadsheet will reside on O&M contractors shared digital storage space
  - Viewable by all
  - Updatable by only selected subject matter experts
- Spreadsheet updated as new information becomes available – metadata tracing updates
- Process applied to each SPR site
- Accompanying SAND report for each site

Well Grading SAND Reports



SANDIA REPORT
SAND2014-1460
Unlimited Release
Printed February 2014

2013 Strategic Petroleum Reserve Big Hill Well Integrity Grading Report

David L. Lord, Barry L. Roberts, Anna S. Lord, G
Byoung Y. Park, David K. Rudeen, Lisa L. Eldre
James Perry

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Albuquerque, New Mexico 87185 and Livermore, California 94550

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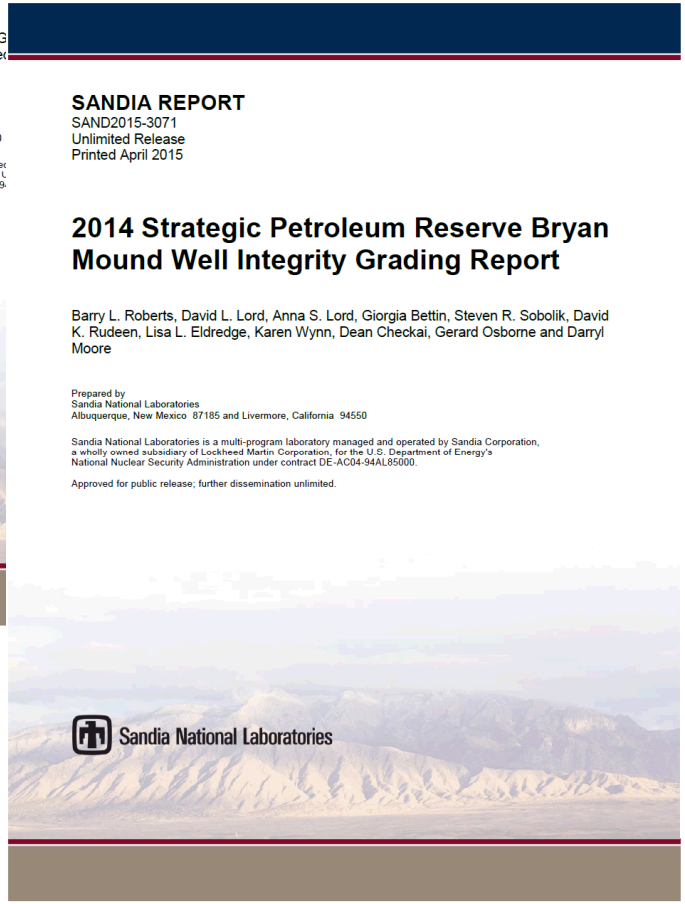

SANDIA REPORT
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2014 Strategic Petroleum Reserve Bryan Mound Well Integrity Grading Report

Barry L. Roberts, David L. Lord, Anna S. Lord, Giorgia Bettin, Steven R. Sobolik, David K. Rudeen, Lisa L. Eldredge, Karen Wynn, Dean Checkai, Gerard Osborne and Darryl Moore

Prepared by
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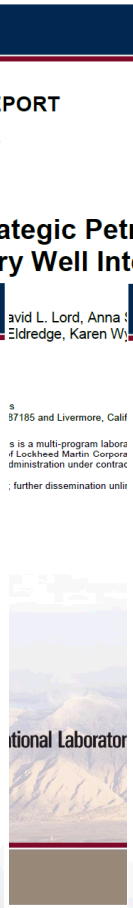

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2015 Strategic Petroleum Reserve West Hackberry Well Integrity Grading Report

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Eldredge, Karen Wy

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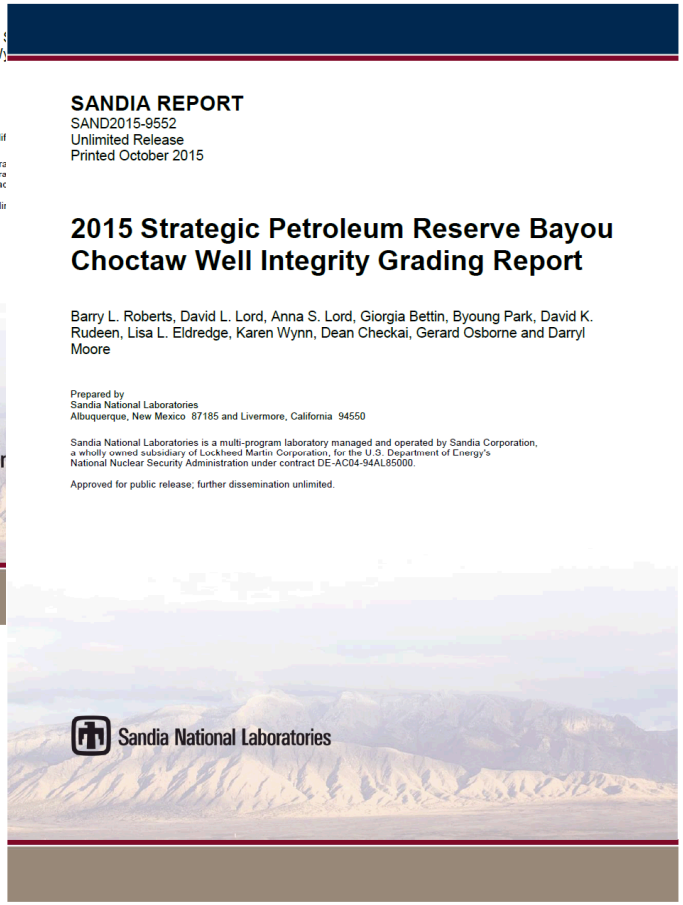

SANDIA REPORT
SAND2015-9552
Unlimited Release
Printed October 2015

2015 Strategic Petroleum Reserve Bayou Choctaw Well Integrity Grading Report

Barry L. Roberts, David L. Lord, Anna S. Lord, Giorgia Bettin, Byoung Park, David K. Rudeen, Lisa L. Eldredge, Karen Wynn, Dean Checkai, Gerard Osborne and Darryl Moore

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Summary

- SNL/OM/DOE team has a developed a process and framework for the grading of cavern wells for remediation and monitoring
- This process has been applied to all wells at all SPR sites
- We now have a priority grading for SPR wells
- Is updated as new information is available
- A SAND report documenting this process is available for each SPR site – DOE Office of Scientific and Technical Information - **www.osti.gov**

Thank You

blrober@sandia.gov srsobol@sandia.gov

This work was supported by the US DOE SPR