

# Strategic Petroleum Reserve Well Integrity Management Program

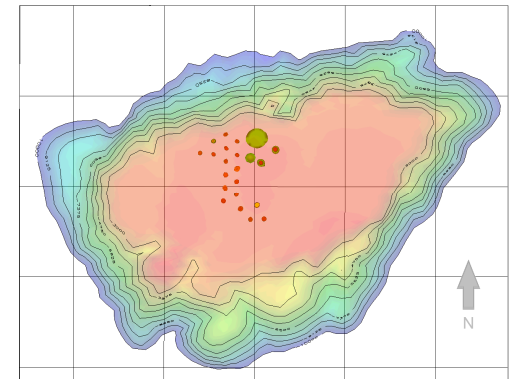
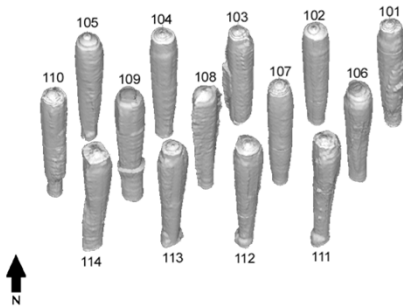
By Steven Sobolik and Barry Roberts

SMRI Technical Class - Well Integrity Management for Salt Caverns

September 24, 2017, Münster, Germany

# Presentation Overview

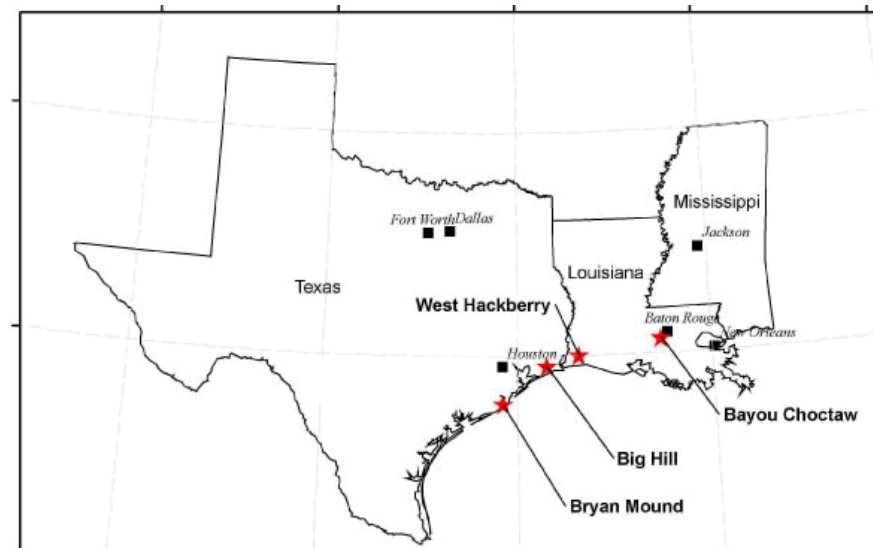
- The Strategic Petroleum Reserve
- Brief background – motivation for well grading
- General well grading framework
- Components in current well grading
- Summary



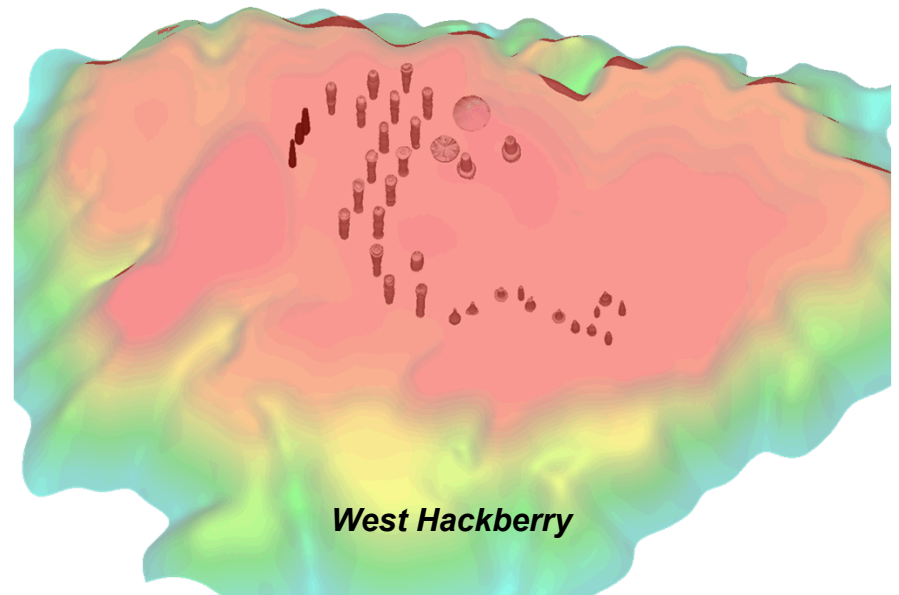
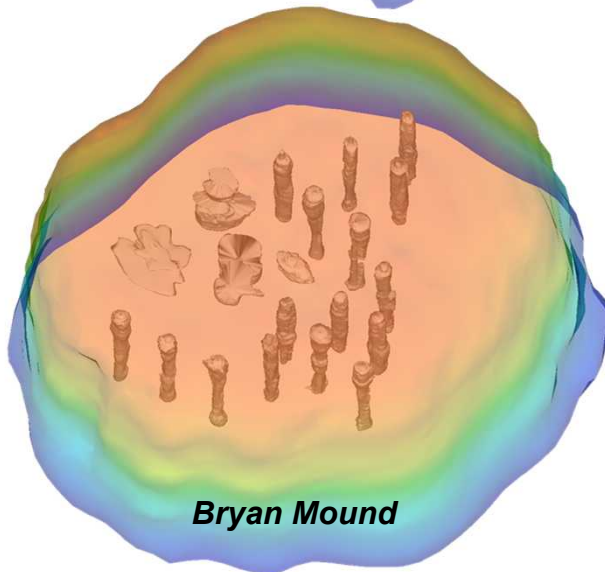
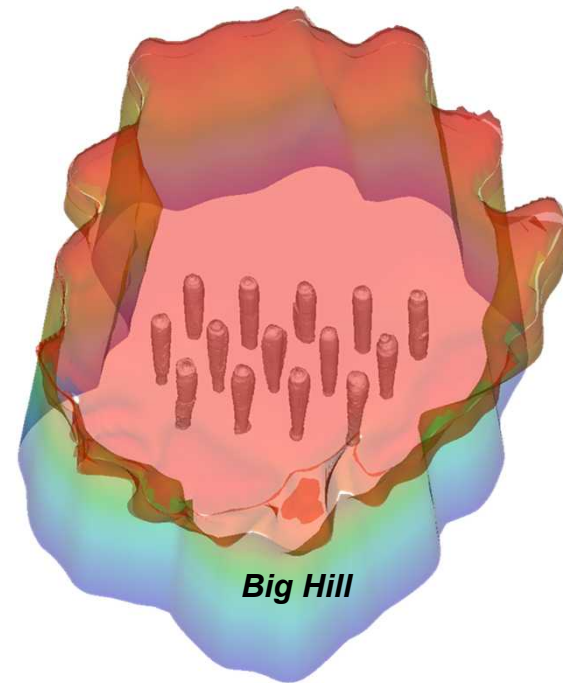
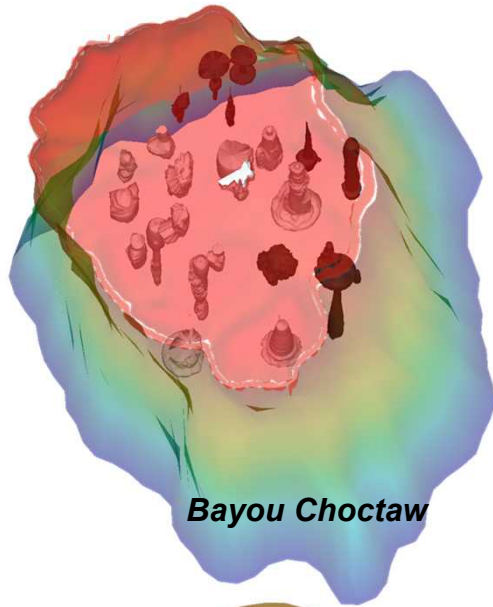
# Background on SPR Sites

## 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

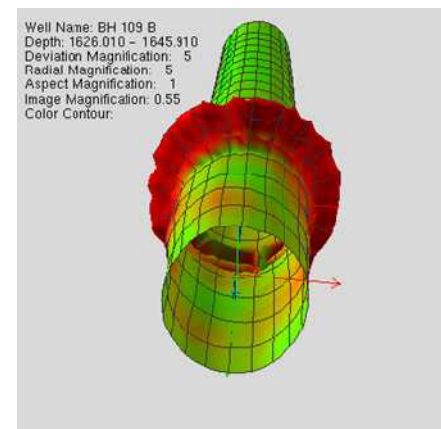
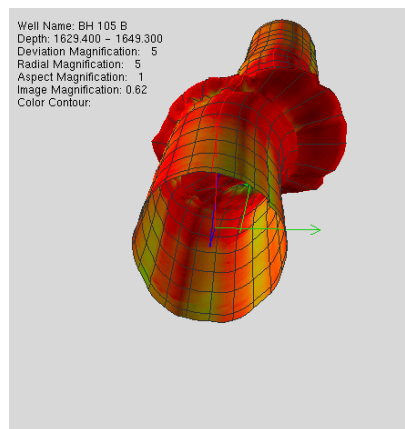
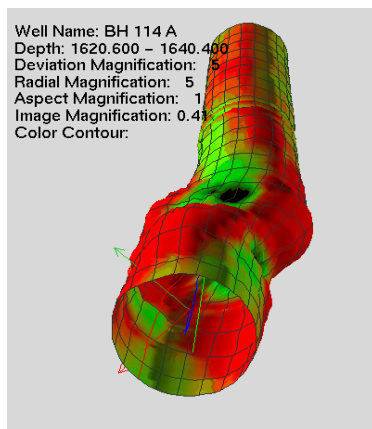




# Background - Motivation

- 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
		GRADE STATUS	MAC-FINAL	PRESS	REMED	Pressure for Monitoring	MAC for Monitoring	Geomech.	Well Info.	Geology	Cavern Geo.	Offsite Act.	Monitor Axis
					(MAC, Press)	0.20	0.20	0.20	0.15	0.10	0.10	0.05	1.00
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
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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

# 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.

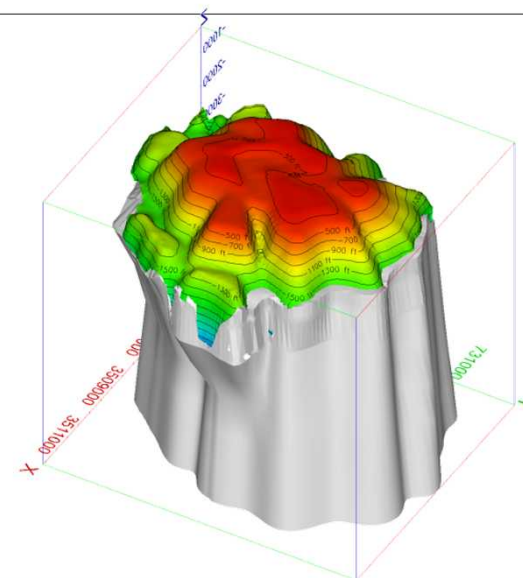
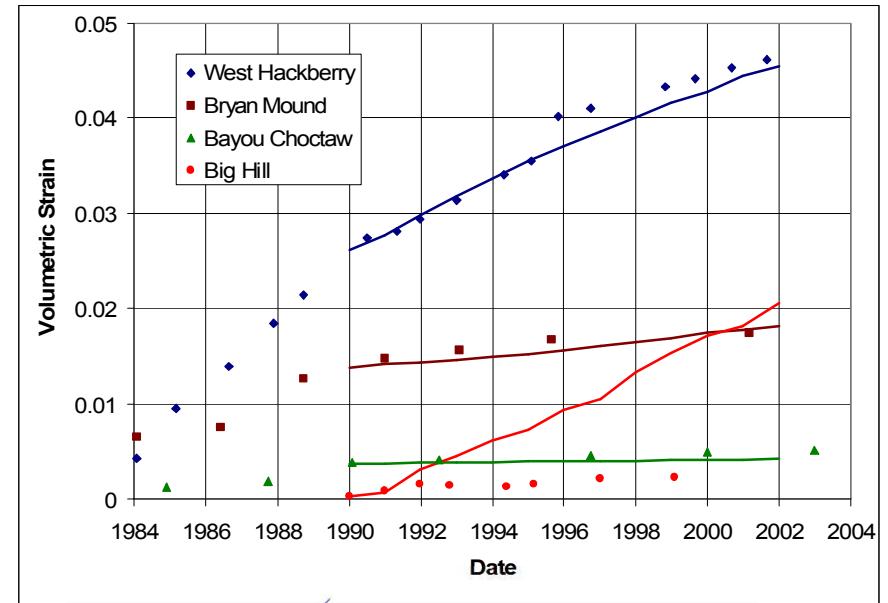
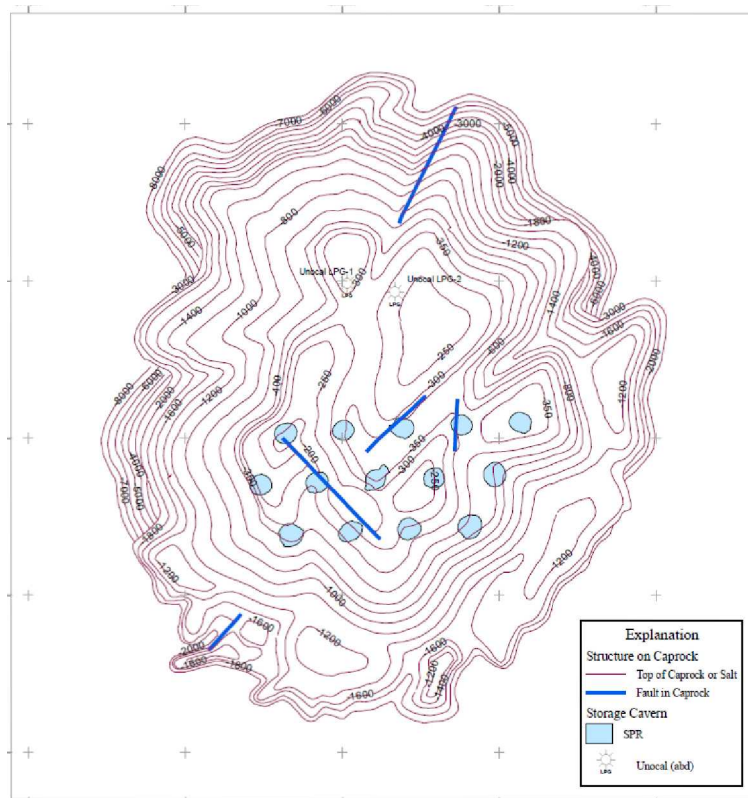


# WELL GRADING COMPONENT DETAILS

# Geology Component

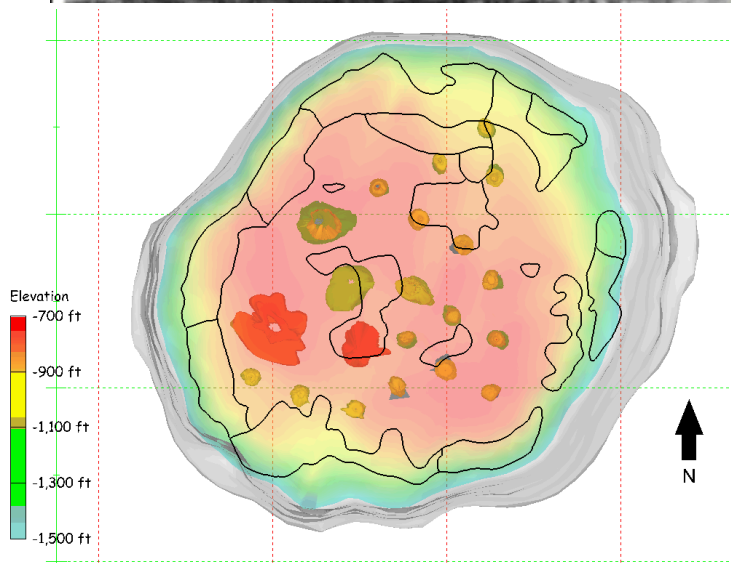
- Well casing stresses directly linked to surrounding geology
- Significant factors include:
  - Caprock thickness and structure
  - Relative subsidence
  - Distance to salt dome overhangs
  - Internal faults or shear zones
- Site specific traits
  - Bayou Choctaw – overhanging salt margin, close proximity 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



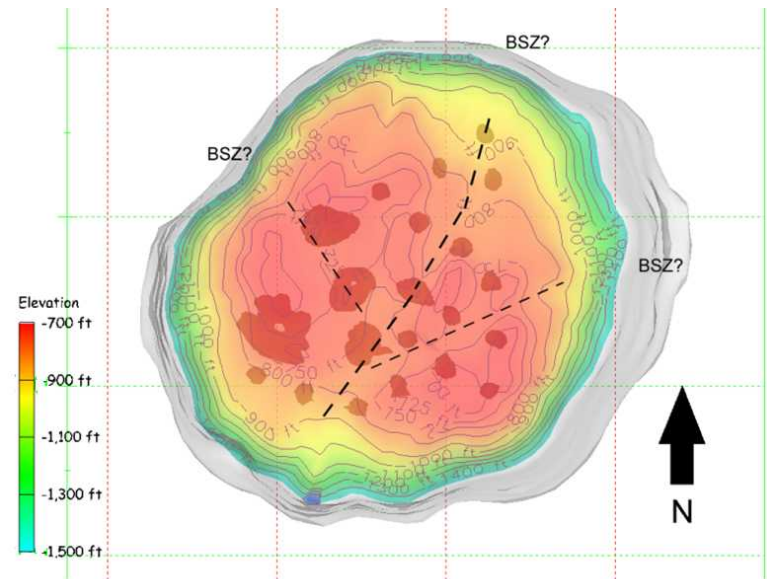
# Bryan Mound Geology

## Sulfur Mining, 1910s-1920s



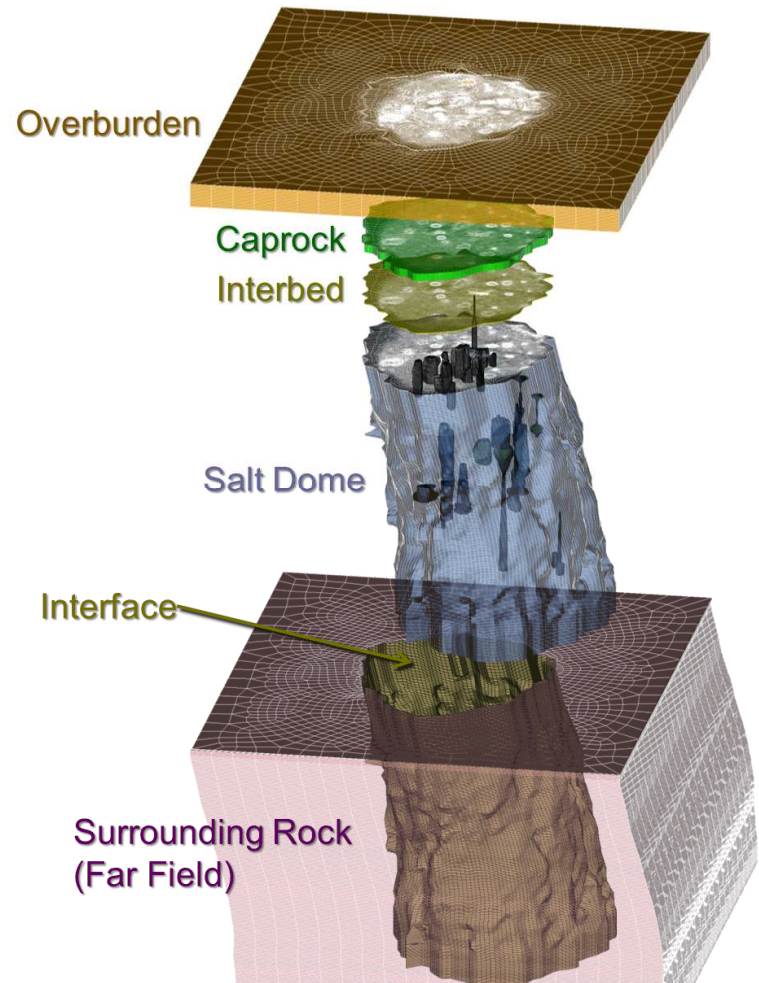
## Heterogeneity of Salt

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

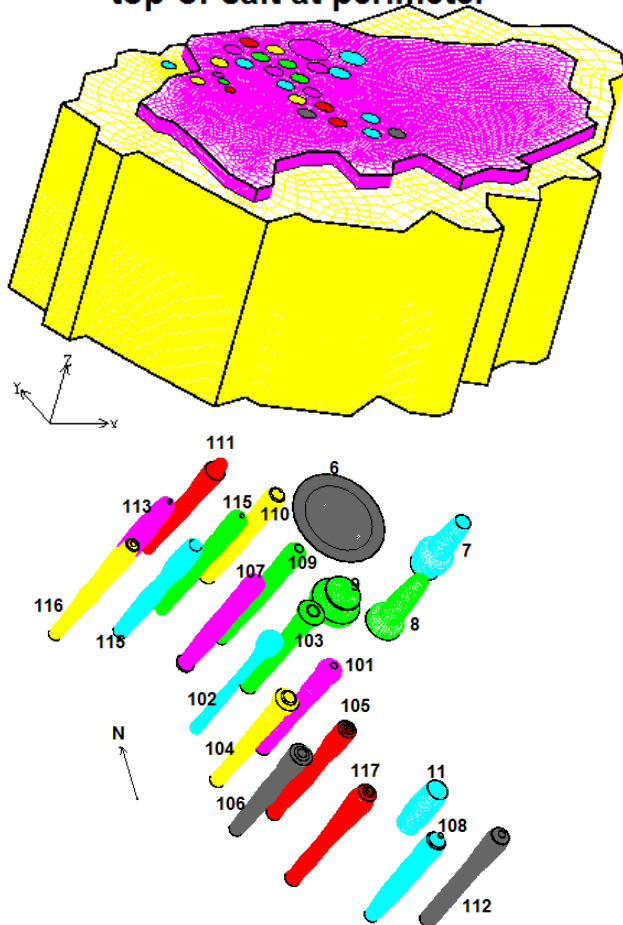
- Provides estimates of stresses and strains at millions of points within a geological region which can then be used to predict cavern closure, surface subsidence, and stresses and strains on wellbore casings.
- Models compute both tensile and shear stress which are markedly different for different regions 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



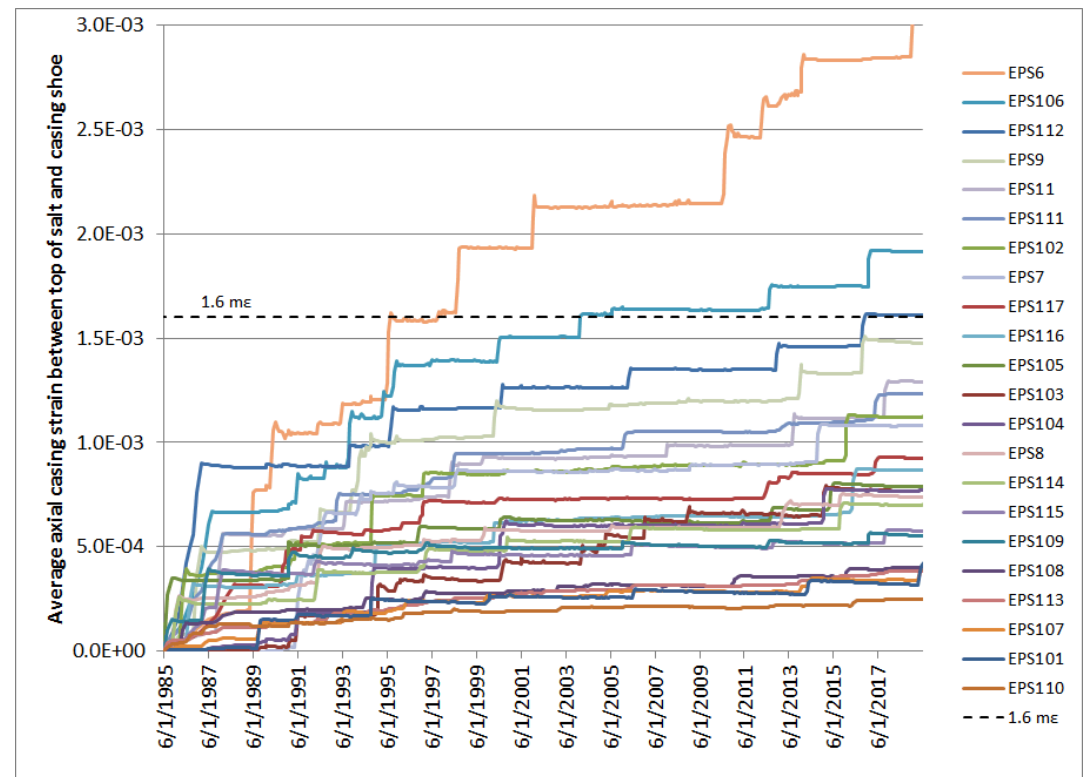
# West Hackberry Geomechanical

## Modeling

Salt dome with deeper  
top-of-salt at perimeter

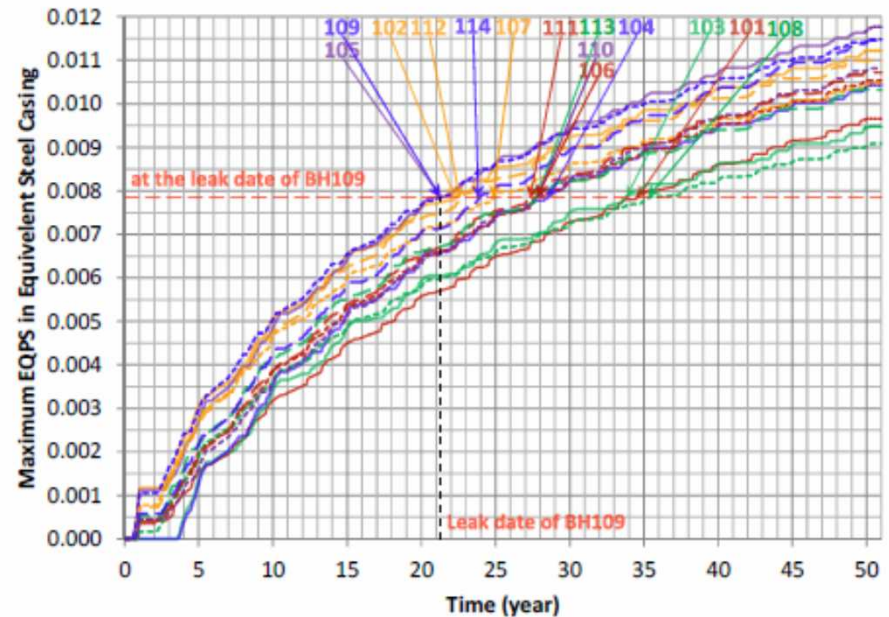
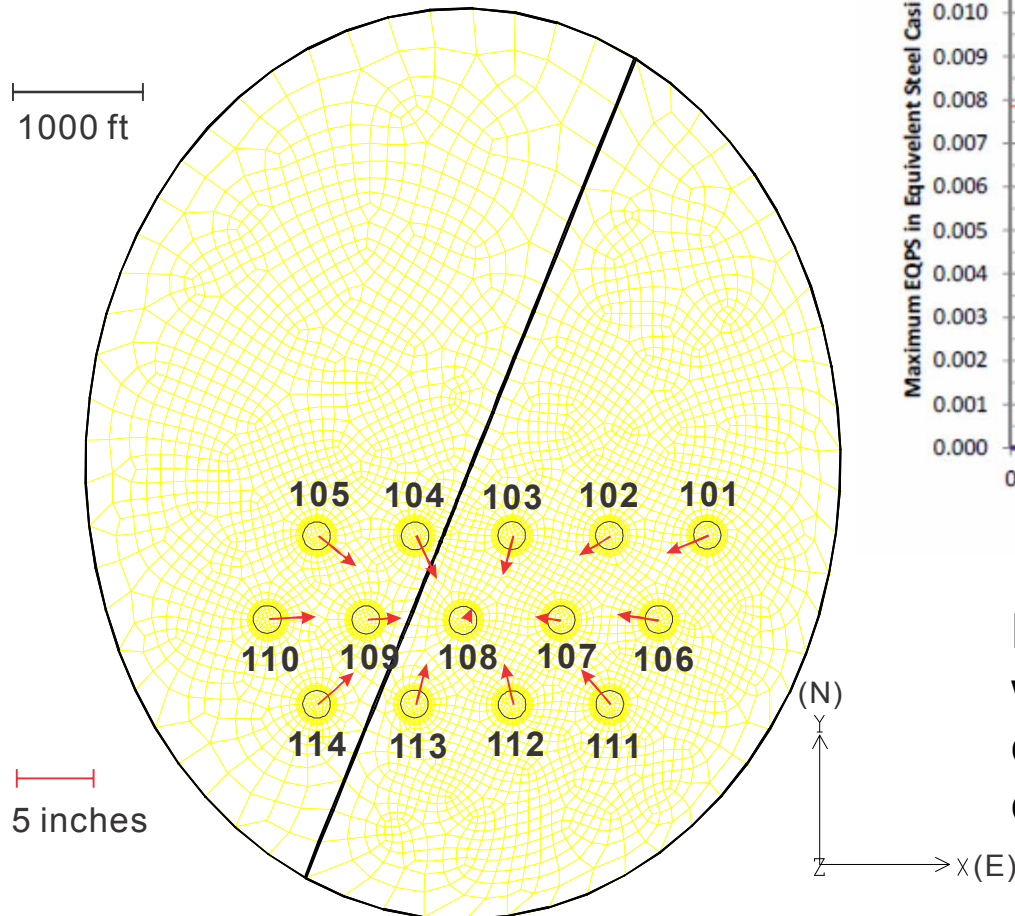


Predictive analysis show accumulation of vertical strain along casing, provide to when onset of plastic deformation of steel may occur.





# Big Hill Geomechanical Modeling



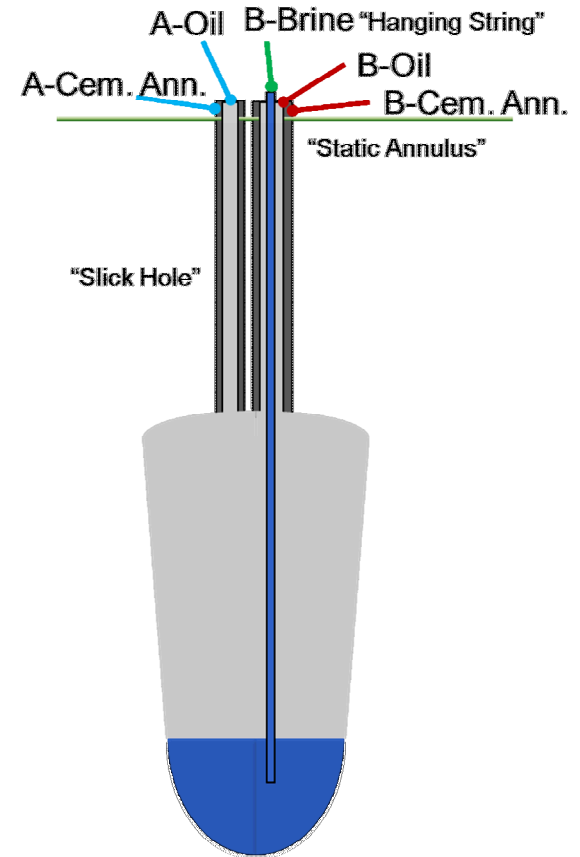
Predictive analysis showing age at which casing is likely to fail. Based on model results compared to observations.

Modeling by B. Park Sandia National Labs

More on Geomechanical component in SMRI Fall 2017 paper, Sobolik et al.

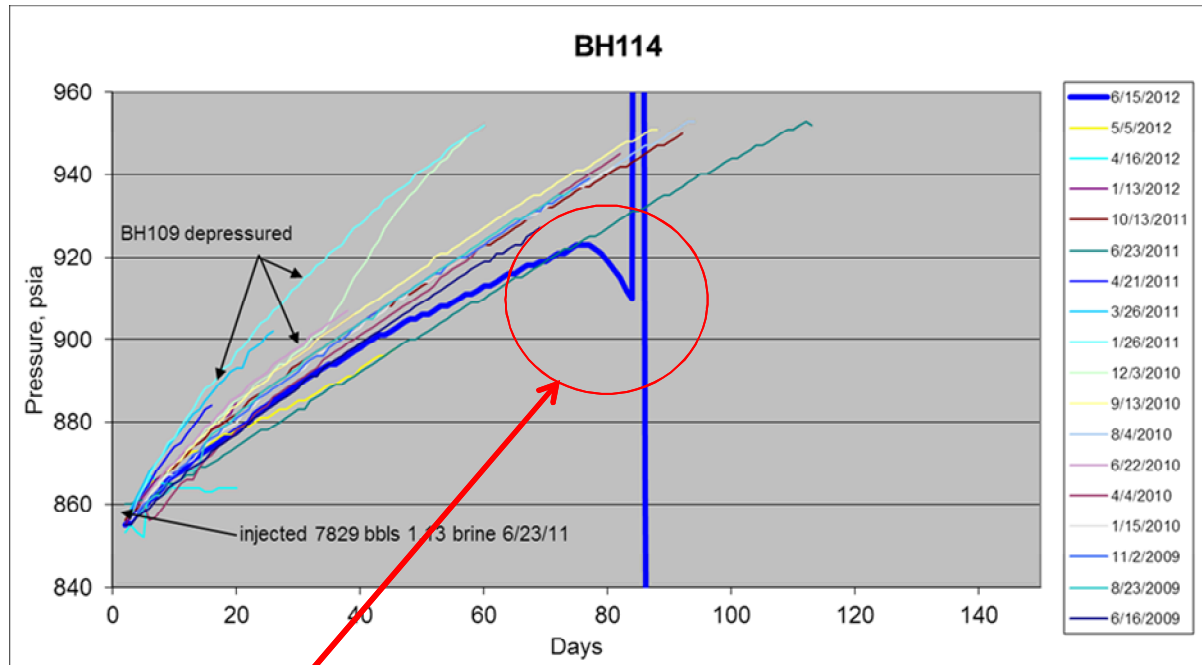
# Cavern Pressure History Component

- 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 indicator of well integrity

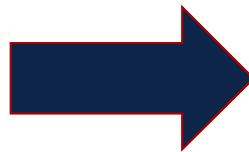


# BH114 Oil Pressure

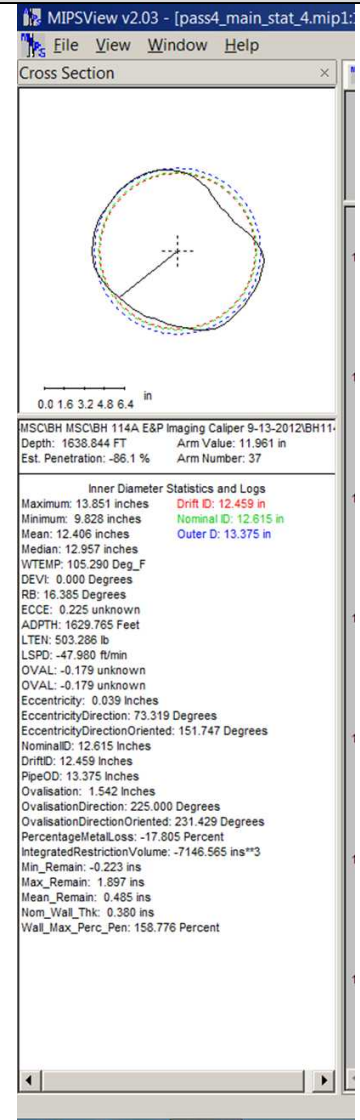
9/13/2012 MSC



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

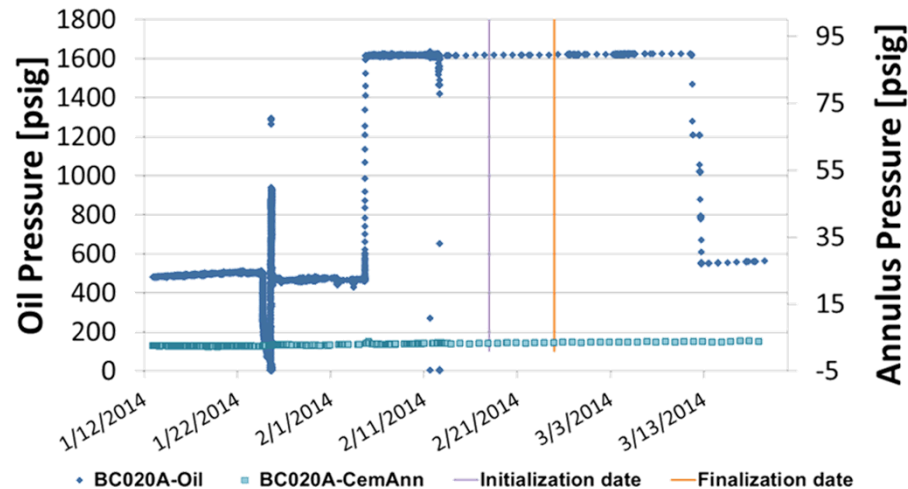


Subsequent N<sub>2</sub> injection confirms leak location, well subsequently remediated with liner



# Annular Pressure

BC020-MIT-2014

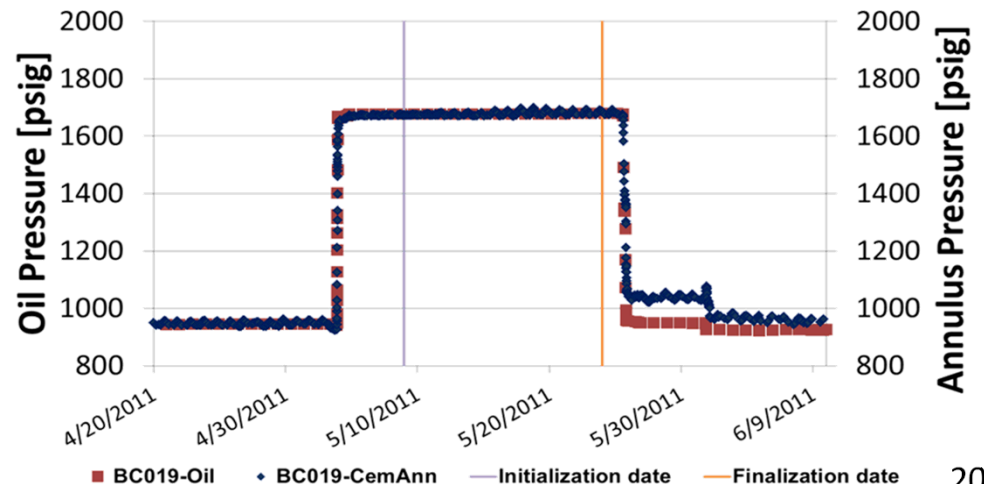


Grade	Conditions
5	Confirmed hydraulic leak through cemented casing or around shoe in excess of what can be offset by nitrogen injection. Failed MIT.
4	Pressure trending anomalies such as flattening or loss of pressure. Apparent nitrogen leak yet leak zone may or may not be identified. Cemented annulus 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

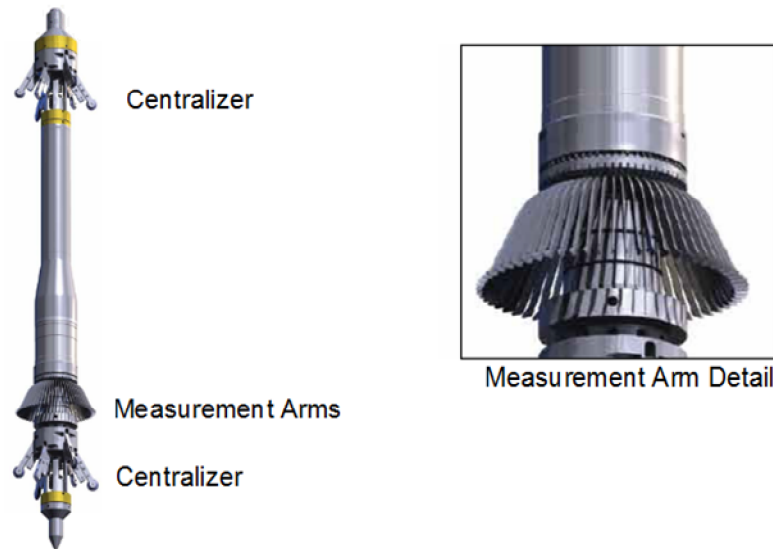
Significant annular pressure and response during MIT

BC019-MIT-2011

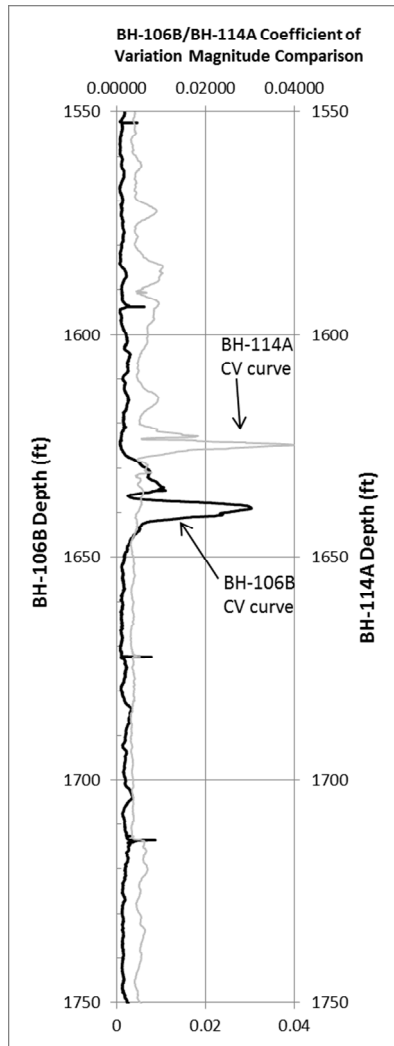


# Multi-arm Caliper Survey Component Sandia National Laboratories

- 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

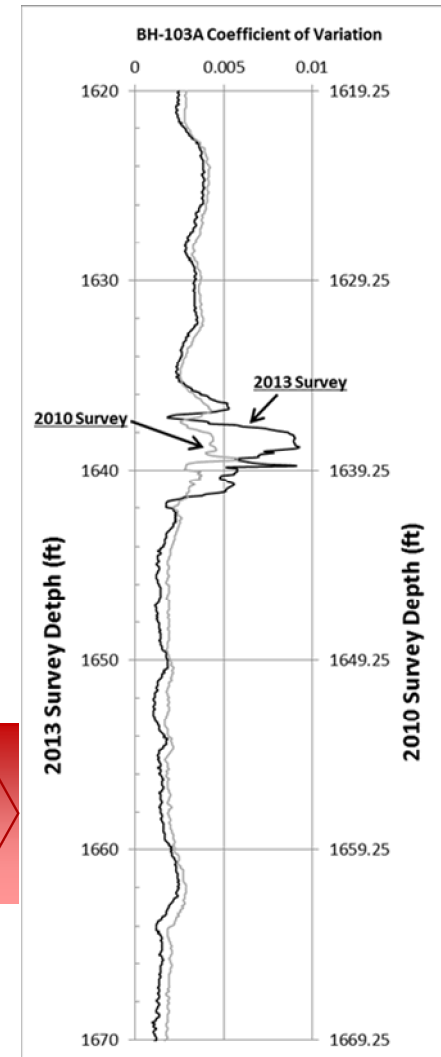


# MAC Survey



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

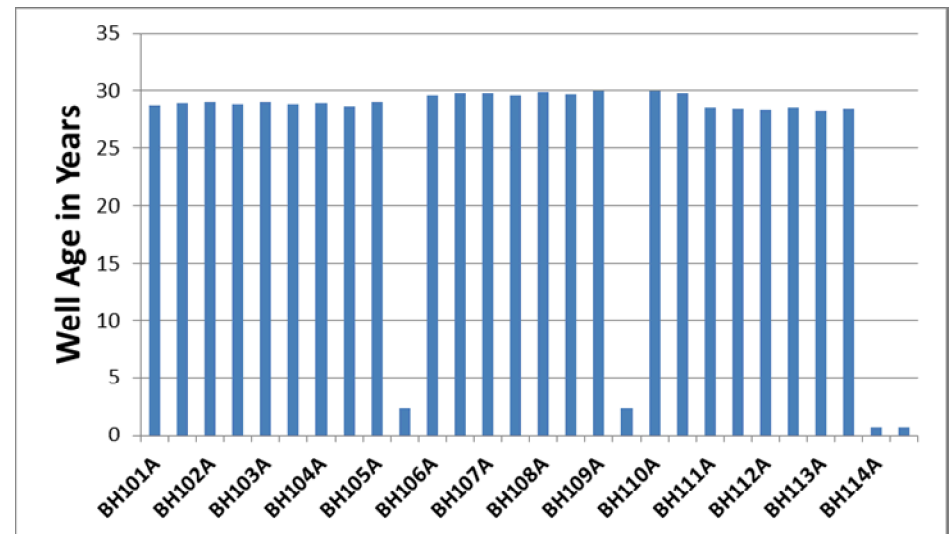
Time dependent  
analysis provides  
relative deformation  
rates





# Well History Component

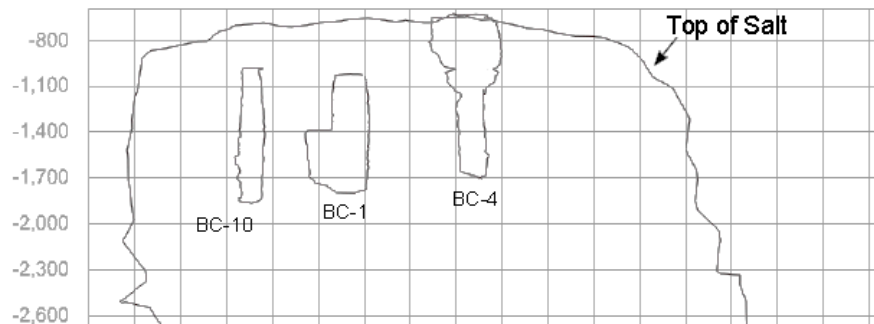
- This component captures significant information and events from the well's lifetime from installation/remediation to present
- Components included:
  - Well age
  - Gas regain
  - Fluid in cemented annulus
  - Well deviation
  - Leak history
  - Well pair history
  - Time since last MAC survey



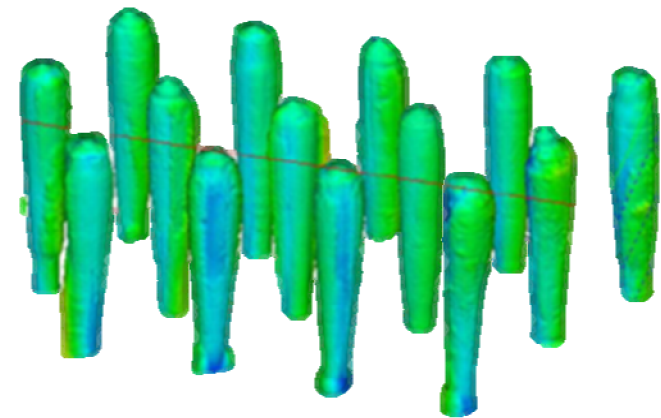
Actual time  
since installation  
or remediation

# Cavern Geometry Component

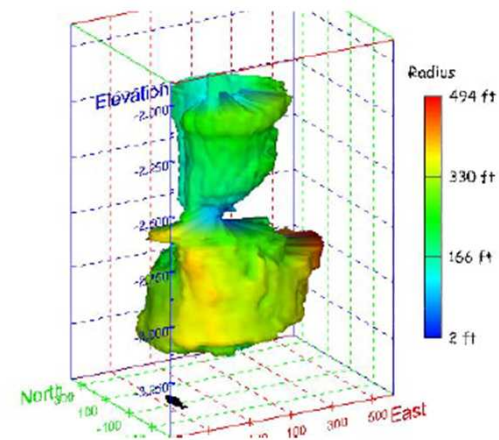
- Cavern geometry and relative position have stability which in turn, affects well integrity
- Components included:
  - Cavern shape
  - Pillar-to-diameter ratio
  - Thickness of salt above cavern roof (salt back)



Differences in salt back



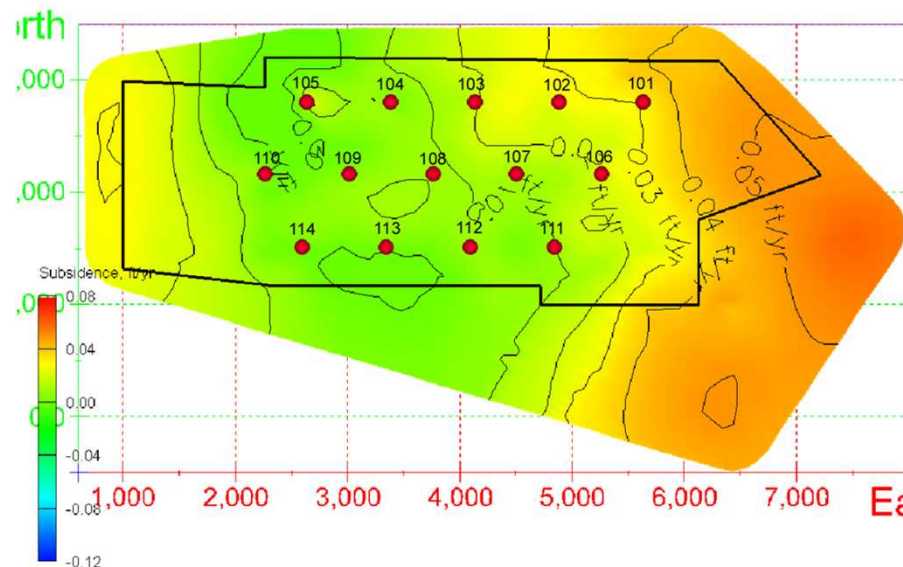
Big Hill Cavern Field



Less Desirable Cavern Shape

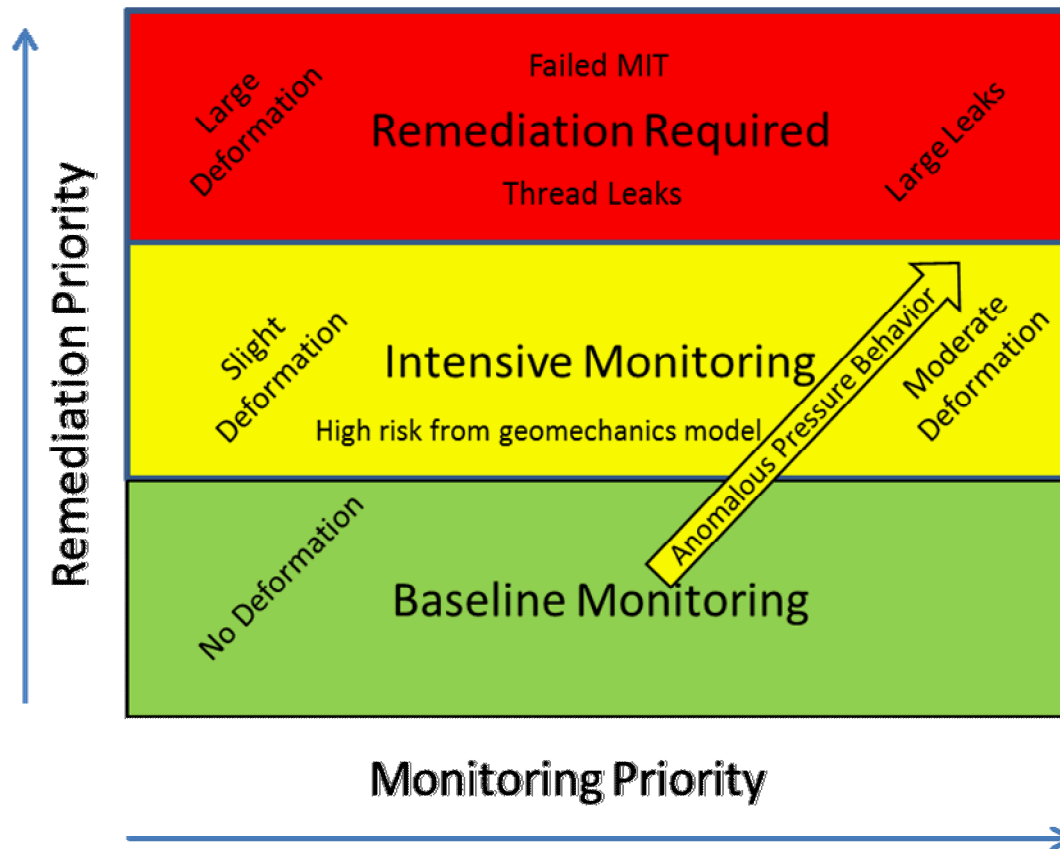
# Offsite Activities

- 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



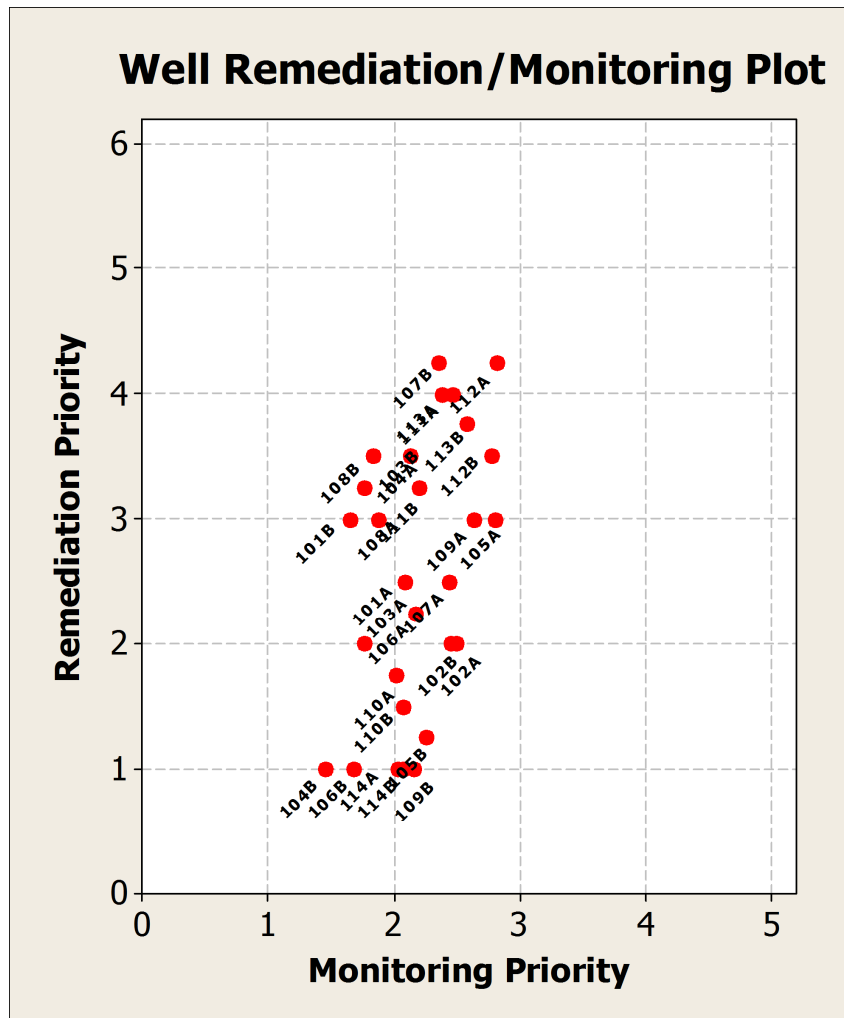
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19	BH108B	1	3.5	1	3.5	1	3.5	1	1.72	2.60	1.67	1	1.83
20	BH109A	1	3	1	3	1	3	5	2.44	2.60	1.67	1	2.64
21	BH109B	1	1	1	1	1	1	5	1.96	2.60	1.67	1	2.17
22	BH110A	1	1.75	1	1.75	1	2.5	3	1.86	2.60	1.33	1	2.02
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24	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
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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

MAC	Well	Pressure	Geomech	Geology	Cavern Geometry	Offsite Act.
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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. Eldred  
James Perry

Prepared by  
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Albuquerque, New Mexico 87185 and Livermore, California 94550

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National Nuclear Security Administration under contract DE-AC04-94-

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## SANDIA REPORT

SAND2015-3072  
Unlimited Release  
Printed April 2015

### 2015 Strategic Petroleum Reserve West Hackberry Well Integrity Grading Report

David L. Lord, Anna S.  
Eldredge, Karen Wynn

## SANDIA REPORT

SAND2015-3071  
Unlimited Release  
Printed April 2015

### 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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## SANDIA REPORT

SAND2015-9552  
Unlimited Release  
Printed October 2015

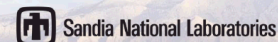
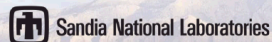
### 2015 Strategic Petroleum Reserve Bayou Choctaw Well Integrity Grading Report

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  
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# Summary

- SNL/OM/DOE team has 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](http://www.osti.gov)

## Thank You

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