A System for Salt Cavern Well Integrity Grading

Salt and the Environment

Keywords: Salt Cavern Storage, Well Integrity

Abstract

The U.S. Strategic Petroleum Reserve (SPR) holds a reserve of crude oil to help ease any interruptions in oil import to the United States. The oil inventory as of January 2017, stands at approximately 700 million barrels. The oil is stored in a set of 63 underground caverns distributed across four sites along the U.S. Gulf Coast. The caverns were solution mined into subsurface salt domes at each of the four sites. The plastic nature of the salt is beneficial for the storage of crude oil as it heals any fractures that may occur in the salt.

The SPR is responsible for operating and maintaining the nearly 120 wells used to access the storage caverns over operational lifetimes spanning decades. These wells provide the mechanism for the transport of fluids (oil and brine) into and out of the caverns. The wells are constructed in such a way as to provide critical isolation of cavern fluids from the surface environment and groundwater. Salt creep can induce deformation of the well casing which must be remediated to insure cavern and well integrity. This is particularly true at the interface between the plastic salt and the rigid caprock.

In order to prioritize well remediation resources, the Department of Energy (DOE), the SPR Management and Operations contractor, and Sandia National Laboratories has developed a multidimensional well-grading system for the salt cavern access wells. This system is designed to assign numeric grades to each well indicating its remediation priority. The system consists of several main components which themselves may consist of sub-components. The main components consider such things as salt cavern pressure history, results from geomechanical simulations modeling salt deformation, and well casing deformation due to salt creep. In addition, the general geology of the salt domes and their overlying caprock is also included in the grading.

The SPR well grading scheme provides a summation of the many factors that impact well integrity at a salt cavern storage facility. It has been designed to incorporate the unique conditions that occur when dealing with large storage caverns contained in salt. These well grading criteria are summarized into a remediation grade which can then be used to prioritize the application of remediation resources. The grading process is generic, and could be applied to other salt cavern storage facilities.

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Introduction

The U.S. Strategic Petroleum Reserve (SPR) holds a reserve of crude oil to help ease any interruptions in oil import to the United States. The oil inventory as of January 2017, stands at approximately 700 million barrels. The oil is stored in a set of 63 underground caverns distributed across four sites along the U.S. Gulf Coast (Figure 1). The caverns were solution mined into subsurface salt domes at each of the four sites. The plastic nature of the salt is beneficial for the storage of crude oil as it heals any fractures that may occur in the salt.

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Figure 1: Location of four SPR sites, Bryan Mound, Big Hill, West Hackberry, and Bayou Choctaw.

The SPR faces the challenge of operating and maintaining nearly 120 cased cavern wells across four sites in the storage complex over operational lifetimes spanning many decades. These cemented casing wells provide critical isolation of cavern fluids from the surface environment and groundwater. SPR well integrity monitoring shows that the wells require periodic remediation for a variety of issues which often are related to external geologic forces.

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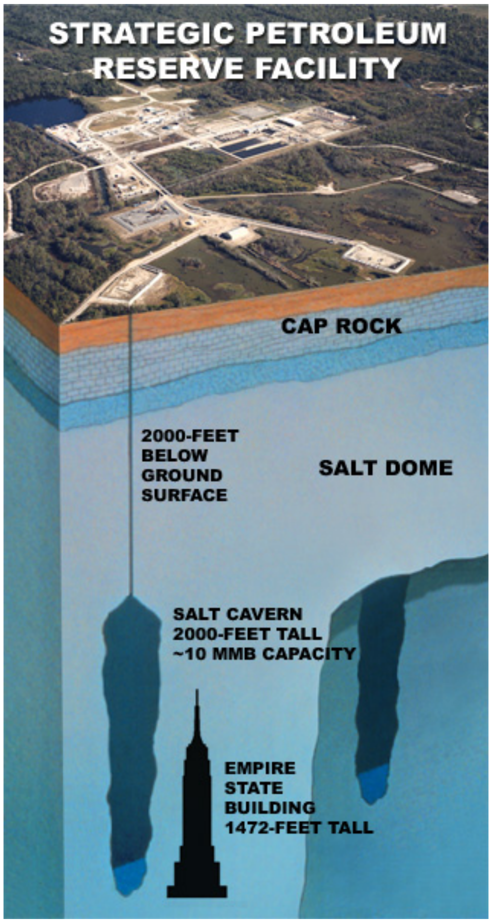

Figure 2. Schematic block diagram showing typical subsurface cavern configuration at SPR sites.

With increasing age, the SPR sites have also seen an increase in well integrity concerns. Because of the varied nature of the four SPR sites and their complex history and geology, a systematic process is needed to prioritize the application of remediation resources. The well integrity grading system presented here is the result of this need. Sandia National Laboratories (SNL), with input from Fluor Federal Petroleum Operations, maintenance and operations contractor for the SPR, and the U.S. Department of Energy (DOE), has developed a multi-dimensional well integrity evaluation system. This system provides evaluation of wells for remediation and monitoring using a numeric grading scheme. The components and framework for this system are described below.

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Grading Framework

Storage cavern well systems are complex and dynamic. Many factors must be considered when determining the drivers for monitoring and remediation. Abstraction of these many factors has resulted in the following seven components which are believed to represent the majority of the factors impacting salt cavern well integrity.

1. Well logging data
2. Cavern pressure history
3. Geomechanical simulation results
4. Geological considerations
5. Composite well information
6. Cavern geometry
7. Offsite activities

These seven components are combined to generate two final grades; one for remediation priority and one for monitoring priority. The remediation grade is the primary driver for the near-term application of remediation resources, while the monitoring grade provides an indication of the potential need for future remediation (risk). Grading values range from 1 to 5 with 5 representing the highest risk or priority. All seven components are used to determine the risk of future remediation (monitoring grade), while only components 1 & 2 (well logging data and cavern pressure history, respectively) are considered in determining the remediation priority. This is because these two components provide information indicating near term remediation needs. Details regarding the meaning and use of the seven grading components are provided below. Full documentation regarding the grading framework can be found in Lord et al. (2014).

Well Logging Data

Periodically, the SPR cavern access wells are surveyed using a series of down-hole logging tools. These tools provide information regarding the well and well environment as they are traversed along the well casing. Although there is a wide variety of logging tools used in this manner, the multi-arm caliper (MAC) provides information most useful in investigating integrity of the cavern access wells. The MAC tool records the inner diameter of the well in multiple directions, this information can then be used to determine if the well has been deformed from its original, circular, cross-section. Deformation of well casing is typically linked to geologic forces, especially at the salt-caprock interface, and can, eventually, lead to well integrity issues. Figure 3 shows an example of deformation identified by a MAC log. Because of the identified casing deformation, this well was remediated by installing a casing liner. Results from the MAC well surveys are examined and quantitatively incorporated into the well grading system, with wells showing greater deformation receiving a higher grade.

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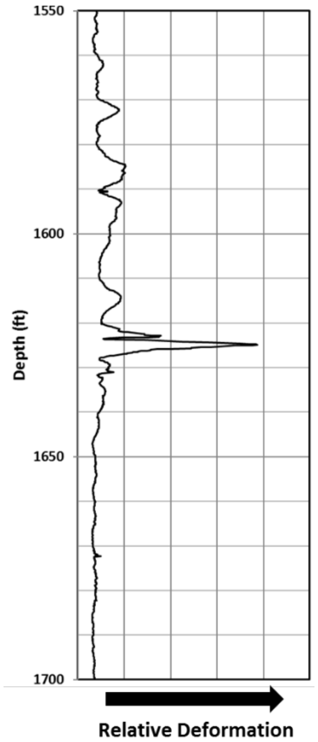

Figure 3. Relative deformation at salt-caprock interface in an SPR well as measured by MAC well logging tool.

Cavern Pressure History

The pressures in the storage caverns are monitored at the well head. This provides information on the status of the caverns and provides a direct indication of well integrity. Because of the plastic deformation of the salt, the storage caverns are continually shrinking in volume as the salt creeps to close the void space. As the cavern volume decreases, the pressure of the stored fluid increases. This requires the periodic bleed-off of some of the stored fluid to reduce the cavern pressure and assure it stays within the desired operating range. This repeated pressurization/depressurization results in a saw tooth pattern in the pressure history data. If the repeated pressurization cycles are overlaid on each other, they form a common pattern with a good degree of predictability. A re-pressurization rate lower than expected is an indication of a potential well integrity issue. This information is incorporated into the well grading system as a direct indicator of well integrity. An example of normal re-pressurization curves and a departure from expected re-pressurization is shown in Figure 4; this well was subsequently remediated by installing a casing liner.

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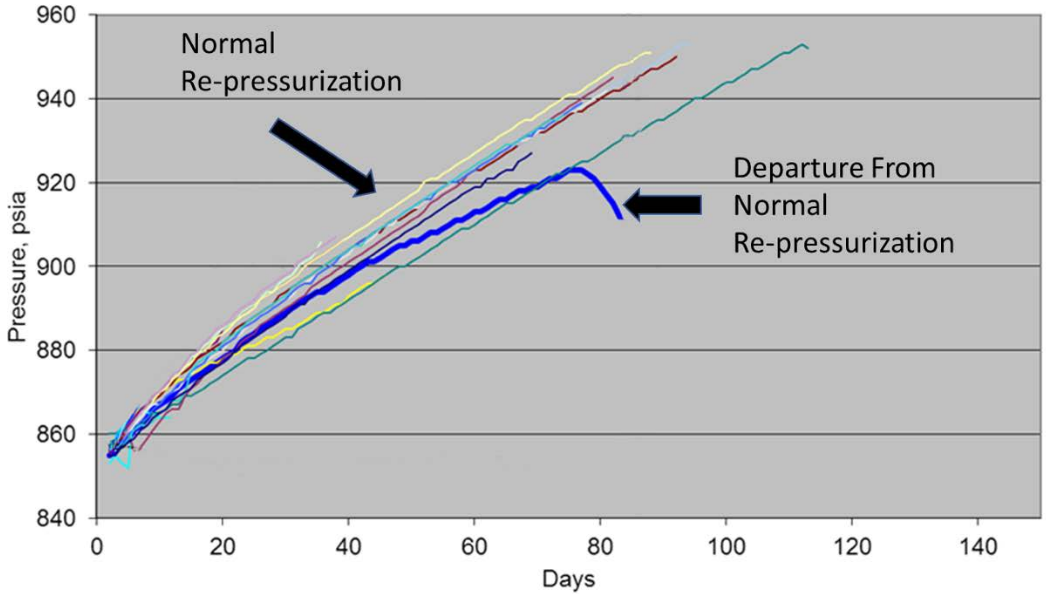

Figure 4. Overlay of multiple cavern pressurization curves; blue curve shows departure from expected pressurization.

Geomechanical simulation results

Each of the four SPR storage sites has its own dedicated geomechanical model. These models simulate the salt dome, surrounding geologic strata, and the caverns themselves. The models provide important estimates of the stress/strain environment around the caverns and along the cavern access wells. These stress/strain patterns are evaluated to assess the likelihood that they may lead to damage which would compromise the well system. This assessment is then numerically coded for incorporation into the well grading system.

Geological considerations

The geology of each of the four SPR sites is unique. Although the caverns are all located in salt domes, the details of each dome are different. These differentiating details include the shape of the dome (whether the salt margin has over hangs, etc.), the distribution of shear zones within the salt, the relative rate of subsidence at the site, and the characteristics of the caprock above the salt dome. These, plus any other pertinent geologic information, are evaluated by SPR geologists who then assign a qualitative value which is incorporated into the well grading system.

Composite well information

The composite well information grading component incorporates information related to the well itself and its history. This includes the age of the well, how recently was the well surveyed using a down hole logging tool, the well bore's deviation from vertical, and if there is any history of integrity issues for this well or nearby neighboring wells. These factors, plus others, are evaluated using a mixture of qualitative and quantitative techniques which then provide a single number which is integrated into the well grading system.

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Cavern geometry

Each cavern in the SPR system has a unique shape. This is due to a combination of salt characteristics and the level of control applied during leaching of the cavern. During creation (leaching) of a salt cavern, the final shape can be controlled by carefully adjusting the freshwater injection and brine withdrawal depths. This, along with repeated sonar measurements of the developing cavern, provides the mechanism to create a desired cavern shape. For the SPR, this desired shape is a cavern about 200 feet in diameter and 2,000 feet tall, with a slightly tapered (decreasing diameter with depth) profile. All the caverns created by the SPR follow this desired shape. In addition to the SPR-created caverns, 3 of the 4 SPR sites have preexisting caverns that were acquired with the site. Most of these caverns were created as a source of brine, and not as storage caverns. The result is that some SPR storage caverns have odd shapes not matching the nominal SPR-created cavern shape. The cavern geometry component takes these differences in cavern shape into consideration. These differences are believed to have a general impact on the long-term cavern stability, which will, in-turn, have an impact on well integrity. Typical factors for this component include the shape of the cavern, the thickness of salt to the next nearest cavern, and the thickness of salt above the cavern.

Offsite activities

At some SPR locations, there are other storage operations occupying the salt dome or adjacent areas. In some cases, these operations may have an impact on stresses in the subsurface system which may be a concern for well integrity at the SPR. Examples of this include injection into the caprock or cavern pressurization cycling. This grading component captures the potential for activities beyond SPR control to impact well integrity.

Application of Grading System

The seven components described above are combined into two separate grades; one indicating remediation priority, and the other indicating the need for monitoring. The numeric value for each of the seven components can be composed from up to seven sub-components. These sub-components are combined using a weighted average to get the final component value.

The well grading system is currently implemented at the SPR using a system of spreadsheets. Each of the four SPR sites has its own grading spreadsheet, but all of them are based off a common framework. The spreadsheets automate the integration and combination of the different data which feeds into the grading, and provides a flexible and familiar environment for entering and reviewing the data.

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WELL ID	WELL LOG DATA	PRESSURE HISTORY	REMED GRADE	GEOMECH MODEL	GEOLOGY	WELL INFO	CAVERN GEOMETRY	OFFSITE ACTIVTIES	MONITOR GRADE
1	2.5	2.0	**2.5**	1.0	2.4	2.1	1.3	1.00	**2.1**
2	1.5	2.0	**2.0**	1.0	2.4	2.1	1.3	1.00	**1.7**
3	2.0	2.0	**2.0**	4.0	2.4	2.1	1.3	1.00	**2.5**
4	1.3	2.0	**2.0**	4.0	2.4	2.1	1.3	1.00	**2.5**
5	1.3	2.0	**2.0**	1.0	3.2	1.9	1.7	1.00	**1.7**
6	1.3	2.0	**2.0**	1.0	3.2	2.2	1.7	1.00	**1.8**
7	3.0	1.0	**3.0**	2.0	2.4	2.3	1.3	1.00	**2.2**
8	1.0	1.0	**1.0**	2.0	2.4	1.2	1.3	1.00	**1.4**
9	3.5	1.0	**3.5**	5.0	2.4	2.6	1.3	1.00	**2.8**
10	1.3	1.0	**1.3**	5.0	2.4	2.6	1.3	1.00	**2.3**
11	2.8	1.0	**2.8**	3.0	2.4	2.1	1.7	1.00	**2.2**
12	1.0	1.0	**1.0**	3.0	2.4	1.3	1.7	1.00	**1.7**
13	3.5	1.0	**3.5**	4.0	2.0	2.6	1.3	1.00	**2.5**
14	2.3	4.0	**4.0**	4.0	2.0	1.6	1.3	1.00	**2.9**
15	3.0	1.0	**3.0**	1.0	2.6	2.0	1.7	1.00	**1.9**
16	2.5	1.0	**2.5**	1.0	2.6	2.0	1.7	1.00	**1.9**
17	2.0	1.0	**2.0**	5.0	2.6	2.7	1.7	1.00	**2.7**
18	3.0	1.0	**3.0**	5.0	2.6	2.4	1.7	1.00	**2.2**
19	1.8	1.0	**1.8**	3.0	2.6	2.1	1.3	1.00	**2.1**
20	2.8	1.0	**2.8**	3.0	2.6	1.7	1.3	1.00	**2.1**

Figure 5. Typical SPR well integrity grading spreadsheet. Read column headers feed into remediation grade, green headers represent additional factors included in monitoring grade.

The spreadsheets are periodically reviewed and updated as new information becomes available. These updates are commonly driven by changes in the cavern pressure regime, recent well logging activities, or remediation of the well casing. The resulting well integrity grades are provided as tables and plots which can be used in assigning remediation resources. Figure 6 shows an example of a typical SPR well integrity/remediation plot. This plot would be accompanied by a table listing the well ID and associated grades.

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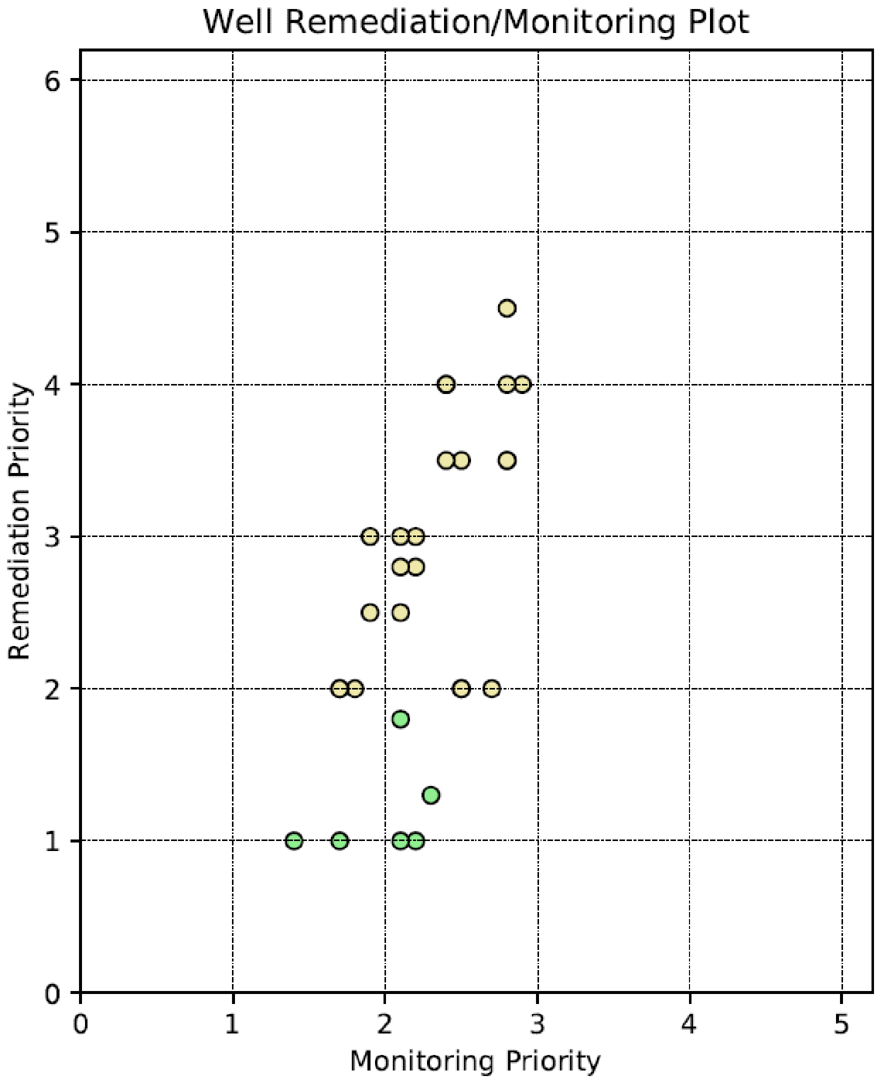

Figure 6. Example SPR well integrity remediation/monitoring plot. Each dot represents the remediation/monitoring grades for a single well at a given SPR site.

Conclusions

This paper has presented a well integrity grading system developed and used at the U.S. Strategic Petroleum Reserve. This system was developed as a means of prioritizing remediation resources and assuring the integrity of the SPR cavern access wells. The framework used in the grading scheme was developed with input from multiple subject matter experts and includes a wide-spectrum of information. Information ranging from direct measurement of any well casing deformation, to the results from geomechanical simulations are incorporated into the grading system. Each well in the SPR system has been reviewed and a grade assigned to it. Because some elements of salt dome geology can be dynamic and have an impact on casing integrity, information for the well casings are periodically reviewed and the

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grades updated as needed. The final grading results are presented using a numeric grading scheme with higher values indicating a greater need for monitoring and/or remediation.

Although this grading framework was developed specifically for the SPR, its factors are common to virtually all salt cavern storage installations. With its modular framework, additional, site-dependent factors, could be easily incorporated into the grading process. Implementation and adaptation of the grading scheme to other sites should be relatively straight-forward.

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