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Literature Survey Concerning the Feasibility of Remedial Leach for Select Phase I Caverns

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Abstract

Bryan Mound 5 (BM5) and West Hackberry 9 (WH9) have the potential to create a significant amount of new storage space should the caverns be deemed “leach-ready”. This study discusses the original drilling history of the caverns, surrounding geology, current stability, and, based on this culmination of data, makes a preliminary assessment of the leach potential for the cavern. The risks associated with leaching BM5 present substantial problems for the SPR. The odd shape and large amount of insoluble material make it difficult to determine whether a targeted leach would have the desired effect and create useable ullage or further distort the shape with preferential leaching. The likelihood of salt falls and damaged or severed casing string is significant. In addition, a targeted leach would require the relocation of approximately 27 MMB of oil. Due to the abundance of unknown factors associated with this cavern, a targeted leach of BM5 is not recommended. A targeted leaching of the neck of WH9 could potentially eliminate or diminish the mid-cavern ledge resulting in a more stable cavern with a more favorable shape. A better understanding of the composition of the surrounding salt and a less complicated leaching history yields more confidence in the ability to successfully leach this region. A targeted leach of WH9 can be recommended upon the completion of a full leach plan with consideration of the impacts upon nearby caverns.

ACKNOWLEDGMENTS

The authors wish to thank Lisa Eldredge, Anna Lord, Barry Roberts, and Steve Sobolik for a technical review, Kathleen Thach for access to files related to the BM5 leach, David Rudeen for the preliminary leach analysis of WH9, and Barry Roberts and Anna Lord for visualizations of the caverns and site maps.

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Abbreviations and Nomenclature

BBL	–	Barrel (volume unit)
BC	–	Bayou Choctaw
BPD	–	Barrels per day
BM	–	Bryan Mound SPR site
MB	–	Thousand barrels
MBD	–	Thousand barrels per day
MMB	–	Million barrels
OBI	–	Oil-brine interface (depth)
P/D	-	Pillar-to-Diameter ratio
RW	–	Raw water (unsaturated brine)
WH	–	West Hackberry SPR site
SNL	–	Sandia National Laboratory
SPR	–	Strategic Petroleum Reserve

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1 Executive Summary

This report summarizes recent efforts to evaluate West Hackberry 9 (WH9), currently 9.1 million barrels (MMB), and Bryan Mound 5 (BM5) which is approximately 37.0 MMB at the U.S. Strategic Petroleum Reserve (SPR) for remedial leaching activities. Currently, these caverns are discounted from remedial leaching scenarios due to their odd shapes and narrow necks as well as the limited number of available drawdowns (namely 1 in both cases (Sobolik, Park et al. 2014)). BM5 and WH9 have the potential to create a significant amount of new storage space should the caverns be deemed “leach-ready”. This study discusses the original drilling history of the caverns, surrounding geology, current stability, and, based on this culmination of data, makes a preliminary assessment of the leach potential for each cavern.

The Phase I caverns in this study were not drilled nor were they developed by the SPR. Because of this, original data, logs, and well history information can be difficult to locate. Investigation of each cavern was done using available resources including the SPR Information Management System (SPRIMS), the SPR Library at Sandia National Laboratory (SNL), SNL’s PETRA geologic database, state records, Fluor Federal Petroleum Operations (FFPO) files on BM5, and verbal communication with several SPR project members. The focus of this report has been to couple historic data with current knowledge of the SPR sites and caverns, geology of the sites, and stability analyses.

Although leaching the narrow neck of BM5 could potentially create additional ullage, the risks associated with this leach present substantial problems for the SPR. The odd shape and large amount of insoluble material make it difficult to determine whether a targeted leach would have the desired effect and create useable ullage or further distort the shape with preferential leaching. Also, the likelihood of salt falls and damaged or severed casing string is significant. Additionally, in order to begin a targeted leach, approximately 27 MMB of oil would need to be moved out of the cavern and relocated. Because of these factors, no attempt has been made to investigate a potential leaching scenario for BM5 using SANSMIC simulations. Due to the abundance of unknown factors associated with this cavern, a targeted leach is not recommended.

A targeted leaching of the neck of WH9 could potentially eliminate or diminish the overlying and underlying ledges which would result in a more stable cavern with a more favorable shape. A better understanding of the composition of the surrounding salt and a less complicated leaching history yields more confidence in the ability to successfully leach this region. WH9 has not experienced frequent salt falls as has been the case with BM5. For these reasons, a preliminary leach plan with SANSMIC simulations has been generated. However, before moving forward with leaching plans and operations, it is imperative to investigate the affect this will have on nearby caverns, especially WH6.

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2 Problem Statement

The U.S. Strategic Petroleum Reserve comprises 63 crude oil storage caverns located in four salt domes across the U.S. Gulf Coast. The current number of active caverns is in flux following decisions to empty several of the oldest SPR caverns due to mechanical stability and well integrity concerns. All of these caverns were drilled and developed by other companies for a variety of purposes. Because of the variation in origin, many of these caverns have less than ideal shapes that can lead to long term cavern and well stability issues.

Several factors combine to reduce storage volume across SPR with time, and active steps must be taken in order to retain enough volume to not only contain the current oil inventory, but also allow extra working room called ullage, to permit routine maintenance and operations over the lifetime of the complex. This report investigates the potential and the risks of leaching two current storage caverns, namely Bryan Mound 5 (BM5) and West Hackberry 9 (WH9), which would increase overall SPR storage capacity and may also increase the stability of the caverns themselves.

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3 Background

The designation of Phase I, II, and III caverns is related to the time of acquisition or leach and the current storage space available at that time. Phase I caverns are the first caverns that were used by the SPR and were acquired, not leached. Many were brine production caverns and as such were not leached with the intention of storing crude oil. Phase II caverns were leached or acquired to bring the SPR capacity up to 500 MMB. Phase III caverns brought the SPR capacity up to 750 MMB and include BC101, WH117, BM113, BM114, BM115, BM116, and the Big Hill site (BH101-BH114) (Eldredge 2014). Phase II and Phase III caverns are specifically designed for crude oil storage and thus conform to a general pattern of tall, thin, cylindrical caverns. Two possible exceptions to the above are BC17 and BC102. BC17 would technically be a Phase II cavern because of the date of its acquisition, but it follows the non-standard geometry and early leach history common to the Phase I caverns and is often referred to as a Phase I cavern. BC17 was acquired because of the narrow web between it and BC15 requiring that they both be operated as a gallery. BC102 was originally leached by the SPR but was traded to Petrologistics in exchange for BC17. BC102 was recently reacquired by the SPR. For the purpose of this report, all non-SPR designed caverns will be referred to as Phase I caverns as their geometry is non-standard.

In February of 2013, a working group from DM Petroleum and Sandia Labs was tasked with determining the volume that could be gained by additional leach procedures given certain criteria. One criterion was requiring five or more available drawdowns or not reducing the number of available drawdowns after remedial leaching. This automatically eliminated all Phase I type caverns from consideration for leaching. Prior to this working group meeting, it was thought that withdrawal leach focused leaching near the OBI. This was found to not be true as withdrawal leach focuses leach near the injection depth and tapers up to the final OBI depth (is a function of time exposed to under saturated brine) (Lord, Roberts et al. 2012; Weber, Gutierrez et al. 2013; Weber, Rudeen et al. 2014). A plan was proposed where selected Phase II and III caverns could be leached with targeted sculpting in the middle depths of the caverns, and the resulting work was published in a Sandia/DM joint working group technical report (Eldredge, Checkai et al. 2013). It was also hypothesized that considerable new storage volume might be gained from leaching the neck regions of WH9 and BM5, though the specialized considerations of leaching Phase 1 caverns was beyond the scope of the 2013 report. Phase I caverns often represent the largest caverns owned by SPR; WH9 holds approximately 8.9 MMB of oil while BM5 is the largest SPR cavern with approximately 36.8 MMB of oil and represents more than 5% of the total capacity of the SPR. These two caverns have the potential to generate up to 6.8 MMB of additional storage capacity (as determined in section 5.5 and Appendix B). It is imperative to understand the history, structure, and surrounding geology of these caverns. With this understanding, the SPR could possibly realize the leach potential of these caverns.

The first half of this report deals with the detailed analysis and evaluation of BM5 while the second half investigates WH9. The same section headings will appear for each of the two caverns and include *Geology*, *History*, *Cavern Issues*, *Current Stability Assessment*, and *Leach Potential and Simulations*. As these are Phase I caverns and the SPR was not the original owner, the *History* section discusses information from the original cavern developers, if any, and additional information pertinent to the cavern shape and composition of the surrounding salt. The *Geology* section discusses trends in the salt dome and levels of impurities in the salt. *Cavern Issues* deals with known and reported instances of well damage and failure throughout the life of the cavern. *Current Stability Assessment* evaluates the current stability issues for the cavern and identifies areas of greatest stress and potential concern. Finally, an evaluation is made in section *Leach Potential and Simulations* of the cavern based on the suite of information as to whether or not the cavern should undergo targeted leach operations to generate a more favorable shape, therefore reducing stress, and create additional ullage. If the cavern is a good candidate for targeted leaching, a preliminary leach plan can be developed and utilized to generate a cavern shape that is more favorable and reduces the stresses identified in the *Current Stability Assessment* section.

The caverns of interest for this study were neither drilled nor developed by the SPR. Therefore, original data, logs, and well history information is scarce. A thorough investigation of each cavern utilizing available resources including the SPR Information Management System (SPRIMS), SNL's SPR Library, SNL's PETRA geologic database, state records, and several SPR project members. Effort is focused on coupling historic data with current knowledge of the SPR sites and caverns, geology of the sites, and stability analyses.

4 Bryan Mound 5

With a cavern volume of approximately 37.0 MMB, BM5 represents the largest cavern in the SPR. A map of the caverns and wells of the BM site is shown in Figure 4-1. The edge of the cavern is approximately 1200 ft from the edge of the salt dome boundary (Lord 2007) with BM4 as the nearest neighbor at a distance of 336 according to the updated pillar to diameter (P/D) code (Rudeen 2013). BM101 is also relatively close at 380 ft. by the P/D code.

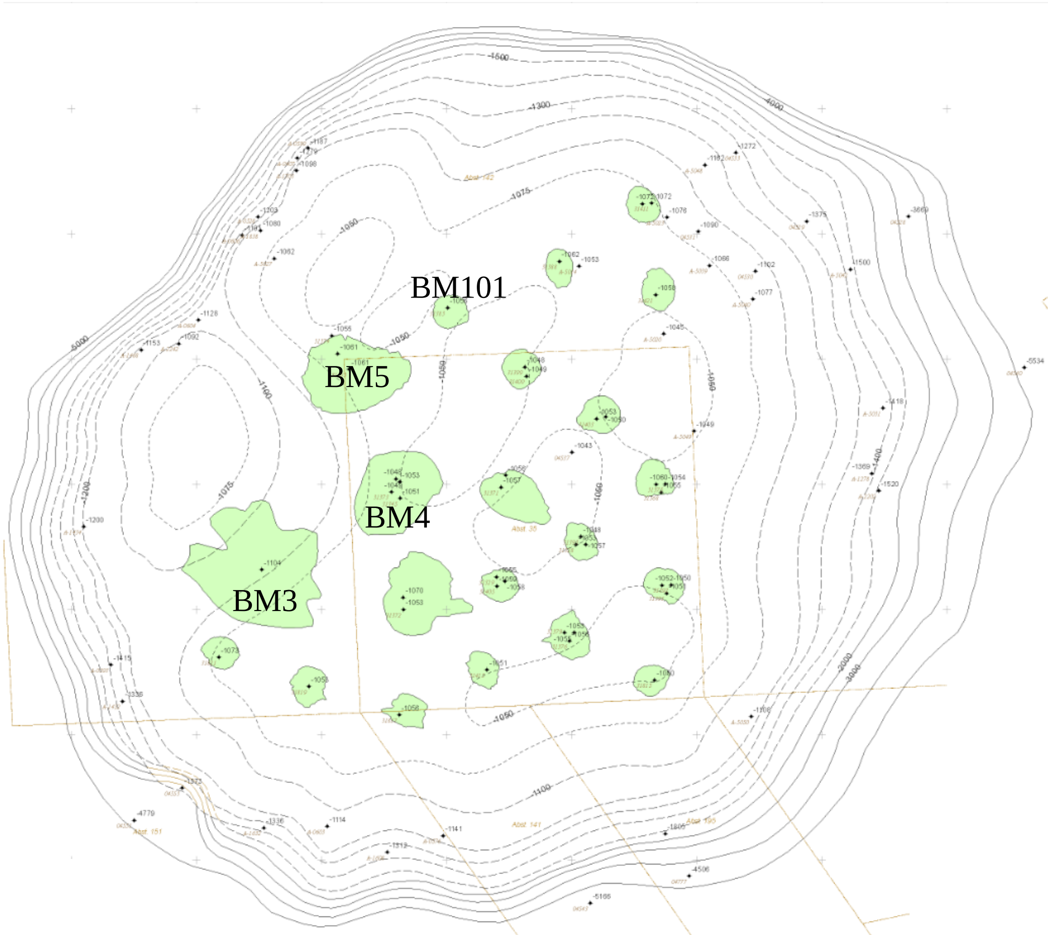
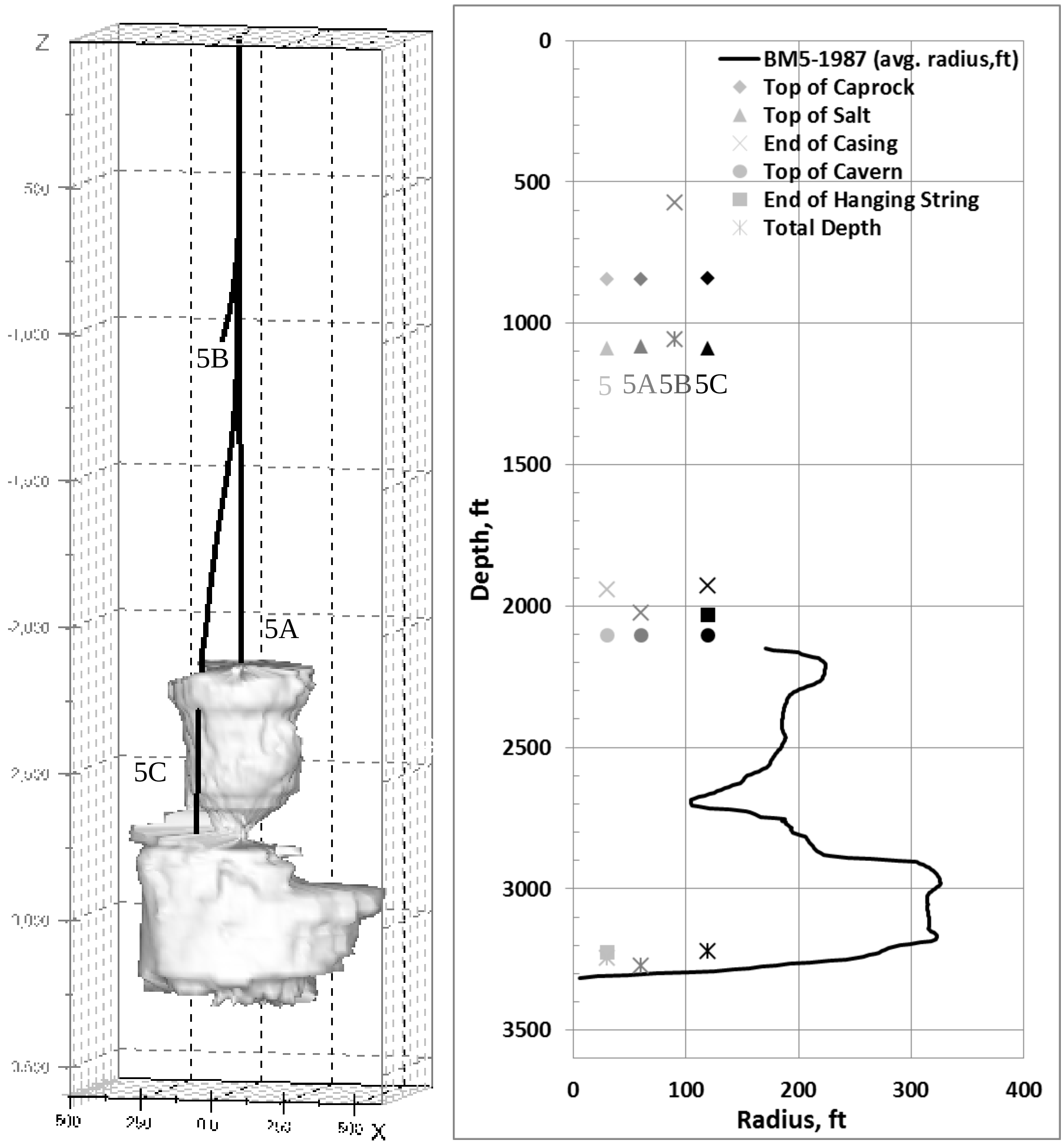


Figure 4-1. BM site map of cavern footprints and wells.

BM5 consists of two lobes separated by a very narrow neck at approximately 2700 ft and is used to store sour crude oil. BM5 has four wells, BM5, BM5A, BM5B, and BM5C. Figure 4-2(left) shows the complex system of three of these wells, their positions relative to one another, and where they enter the cavern. The figure on the right shows the relative heights of key well locations including total depth, end of hanging string, top of cavern, end of casing, top of salt, and top of caprock as determined by well schematics (see Appendix A) as well as the axisymmetric shape of the cavern. Note that the horizontal displacement of the wells is meaningless and is evenly spaced to avoid overlap.



a) Sonar image of BM5 with wells 5A, 5B, and 5C

b) Average radius with well depths noted - horizontal displacement is meaningless

Figure 4-2. Sonar image of Bryan Mound 5A (1987) with wells 5A, 5B, and 5C shown and key well depths.

BM5A enters the top of the cavern. BM5B was abandoned at 1057 ft. BM5C enters the lower lobe of the cavern. BM5C may or may not enter the upper lobe of the cavern as well – contacts at FFPO think it likely that it does enter the upper lobe as shown). A deviation survey could not be found for the original BM5 well and, therefore, is not shown.

4.1 Geology

The Bryan Mound salt dome is comparatively heterogeneous in composition. The dome contains more shale than typical for the region and contains bands of high anhydrite averaging to be 10-20% compared to the typical 3-5% (Roberts 2015). A map of irregular features in the Bryan Mound Dome indicates that anhydrite zones, salt falls, and other insoluble zones are abundant at Bryan Mound as seen in Figure 4-3. Additional anomalies include potash and gas in both the wells and the caverns themselves. Also noted, is a massive anhydrite region on the border of BM5. These anomalous zones make it difficult to understand the localized geology of the salt surrounding a cavern and, therefore, increase the uncertainty when investigating whether a targeted leach can be successful.

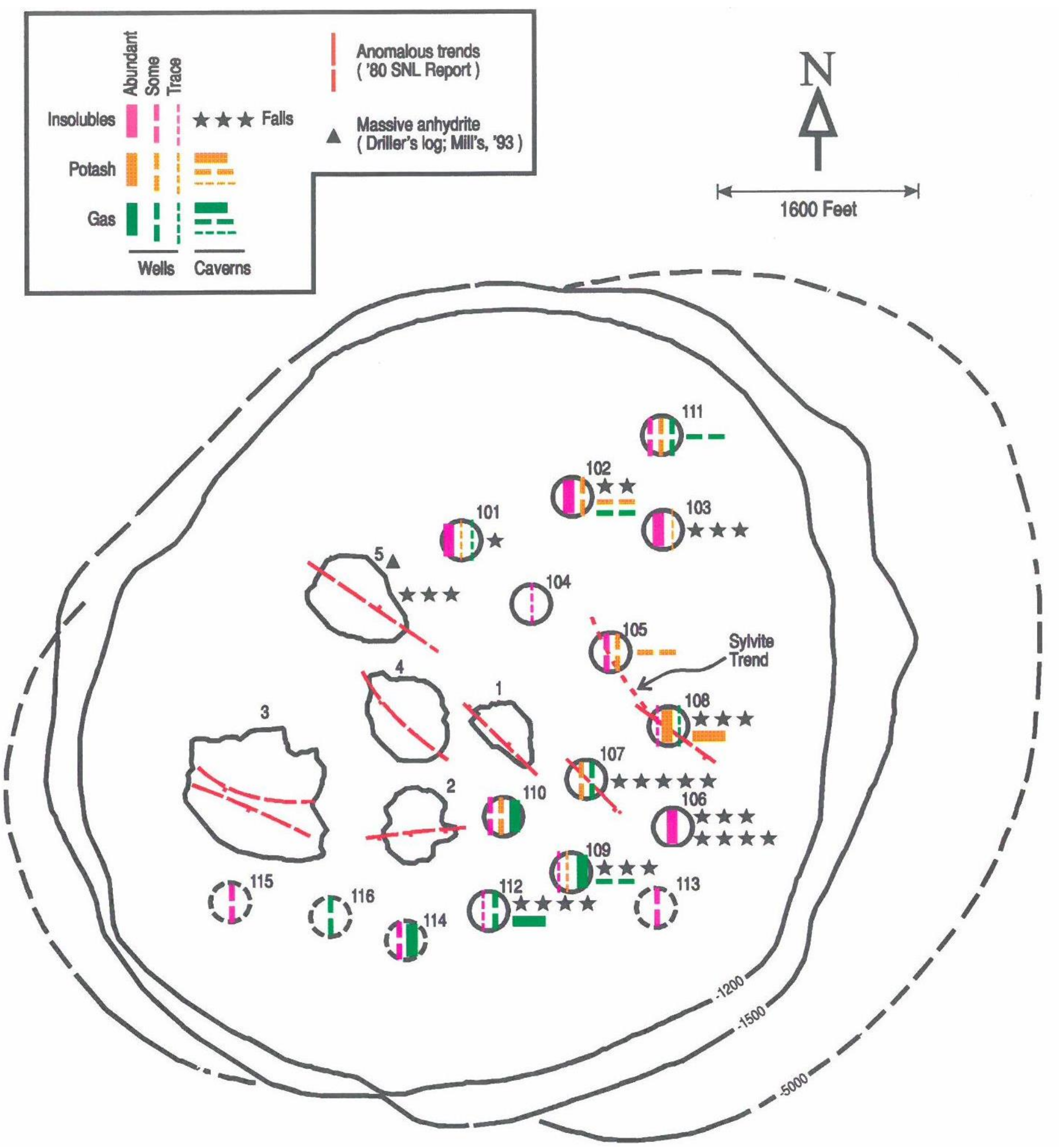


Figure 4-3. Anomalous features of the Bryan Mound Salt Dome from (Neal, Magorian et al. 1993).
Gas, potash, and insoluble data not available for the wells of BM1-BM5 as they are phase I caverns.

Salt falls have been and continue to be an issue for caverns at Bryan Mound. Many of the caverns were initially leached in a tri-lobe formation as three wells were used for leaching. It is possible the tri-lobe shape results in more salt falls. BM107, for instance, has 8 reported salt falls. Although no anomalous trend is reported on this map for BM106, the cavern has 12 reported salt falls. BM108 has 4 reported salt falls but also has abundant potash in both the cavern and well. Nearby BM101 has a high abundance of insolubles but a relatively cylindrical cavern shape. The BM5 well has 10 reported casing issues with at least 3 due to salt falls. The copious reports of salt falls, anhydrites, and irregularities in the salt reinforce the characteristic heterogeneity of the Bryan Mound Dome.

Bryan Mound Cavern 4, in close proximity to BM5, is also a Phase I cavern and the map indicates that this cavern also displays anomalous trends. Salt spines are inferred by identifying regions of thick caprock. The spines inferred are identified in Figure 4-4 from (Lord 2007).

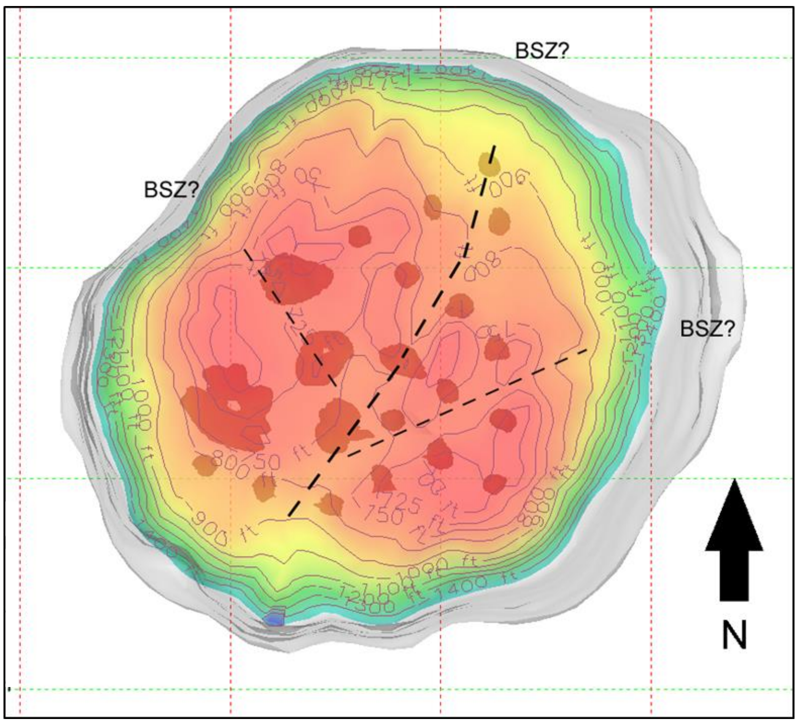


Figure 4-4. Bryan Mound top-of-caprock structure contour map with the inferred salt spines (Lord 2007).

4.2 History

Cavern 5 was drilled in 1957 by Dow Chemical Company and used as a brine production well. Analysis of cuttings from Dow's Laboratory Report shows a range in the percentage of $CaSO_4$ (anhydrite). Some samples report values of 80% or greater at five different depths (Menking 1957). The narrow neck of Cavern 5 falls within one of these regions of high anhydrite content ranging from 43.1% - 97.8% (see Figure 4-5). There are several large spikes in anhydrite levels (greater than 20% anhydrite) throughout the depths of the cavern including 3050 ft in the lower lobe of the cavern, 2720-2780 ft in the neck region, 2360-2420 ft, 2270 ft, and 2180-2210 ft in the upper lobe of the cavern. The increased anhydrite levels over a large depth range (approximately 60 ft) may explain the odd leach pattern and difficulty in uniformly leaching the neck region. Although there is a large spike in the lower lobe it is just over one depth reading and thus may not affect as large a volume of salt as an increased level over a greater linear distance. The upper lobe also shows increased anhydrite levels and over a greater depth range. The average CaSO4 percentage over the depth range 2180-2420 ft is 34% which is not very high when taken in isolation but could affect a large volume as it represents 240 linear feet of salt tested. This may explain odd features in the upper lobe as well.

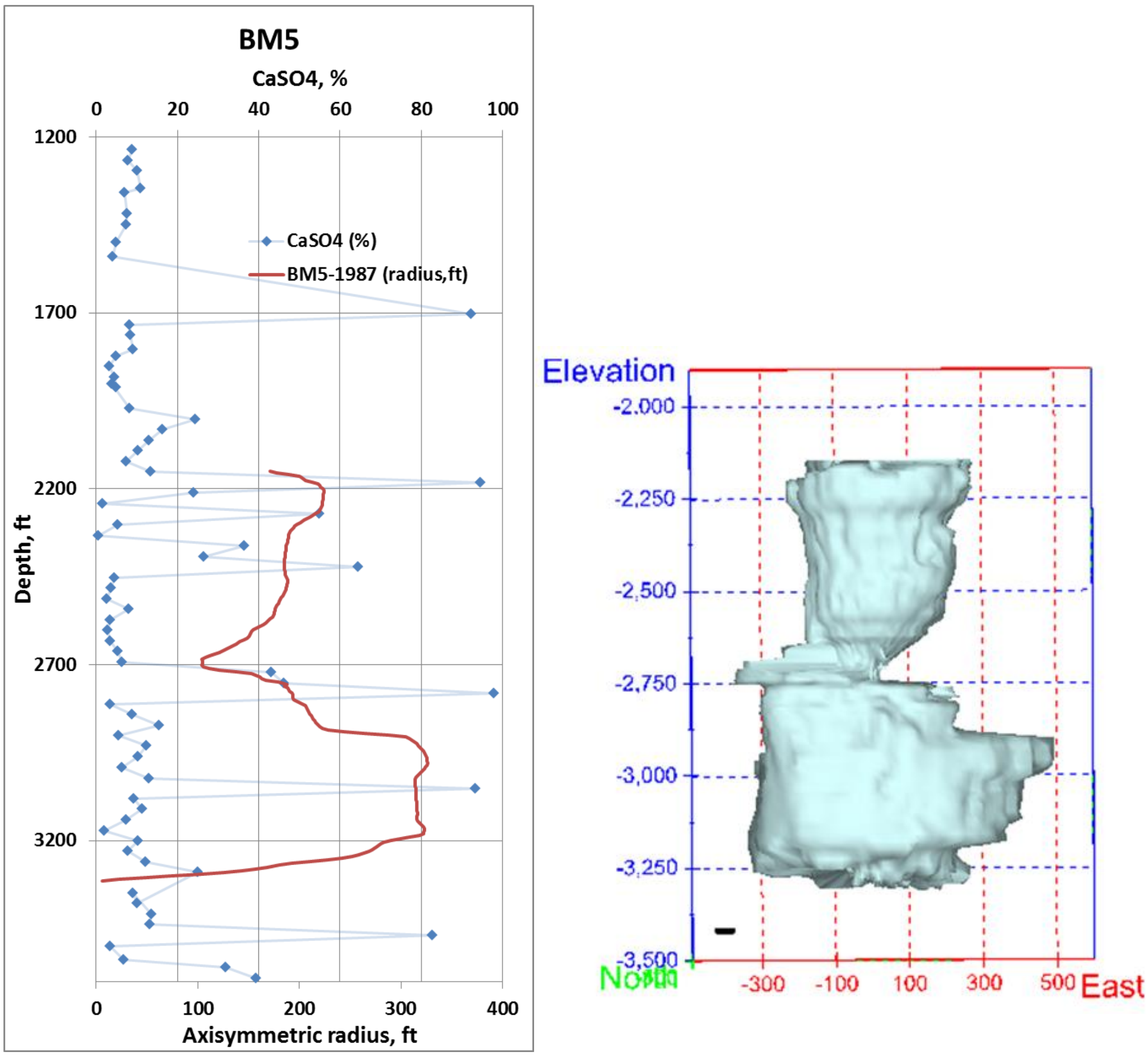


Figure 4-5. Percent anhydrite with depth compared to the BM5 cavern profile.
Anhydrite values are from core wall samples taken and analyzed when the cavern was spudded by Dow Chemical in 1957.

Table 4-1 describes the history of each of the four wells including the date they were spudded, completed, and additional completion information useful for unraveling the multifaceted history of BM5. The depths given from the older references are questionable as they are likely in reference to RKB instead of Bradenhead Flange (BHF) which is standard.

Table 4-1. BM5 Well History.

	5	5A	5B	5C
Date Spudded	2/22/1957[5]	6/24/1978[1]	3/16/1979[2]	9/16/1978[3]
Date Completed	5/24/1957[5]	7/26/1978[1]	3/25/1979	1/27/1979[3]
Top of Salt, ft	1074[5] (1090)	(1080)		1100 (1090)
Top of Cavern, ft	2130[4] (2102)	2155[1] (2102)		2757[3] (2102)
Total Depth,ft	3620[5] (3247)	(3273)	1057[2]	(3222)
Notes	Blocked at 2738 ft in 1978. Work over 9/25/1979[4]		abandoned - would not penetrate at intended location in the lower lobe	

Data from [1](LR&A 1978)b, [2](LR&A 1979)a, [3](Associates 1979)b, [4](Williams 1980), and [5](Menking 1957)
() hold values from current well drawings.

A timeline of the sonars available and the overall well and leaching history is given in Figure 4-6. The references that are used to establish the activity and date are given on the right of the figure. Events related to a particular well are generally grouped along the same vertical value where possible but the vertical displacement is primarily to avoid overlap of data.

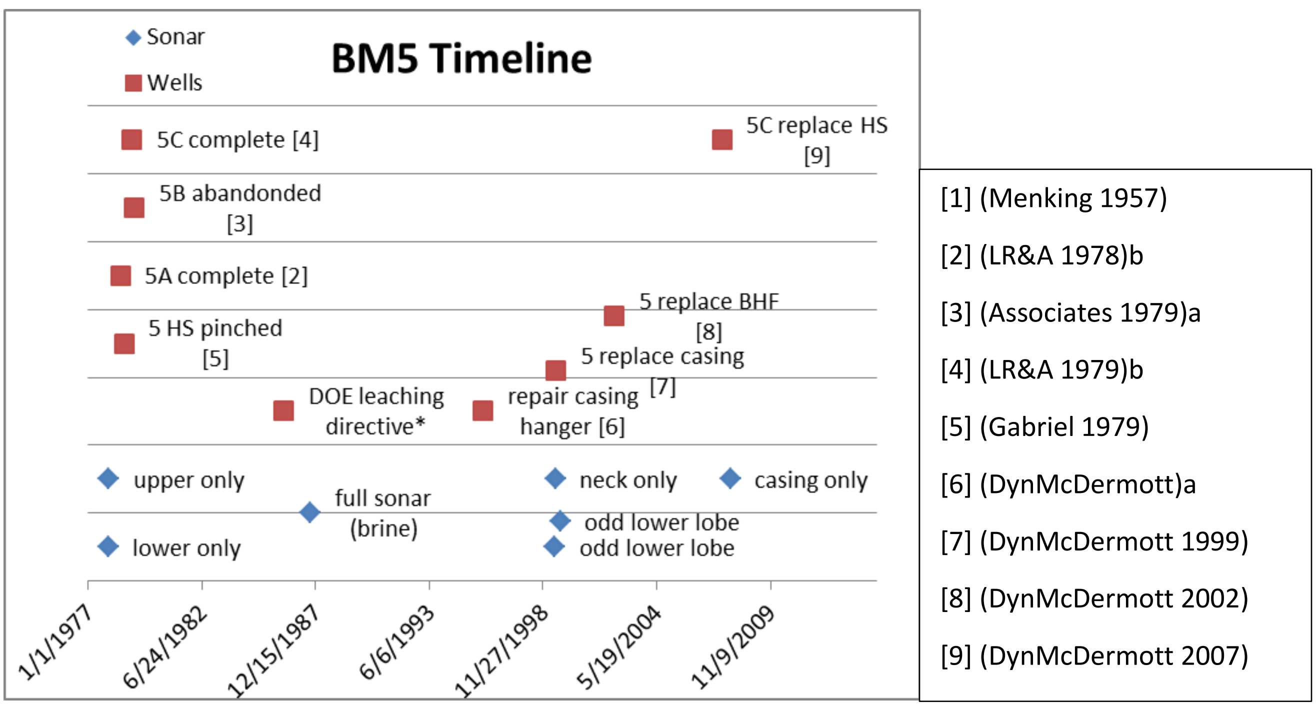
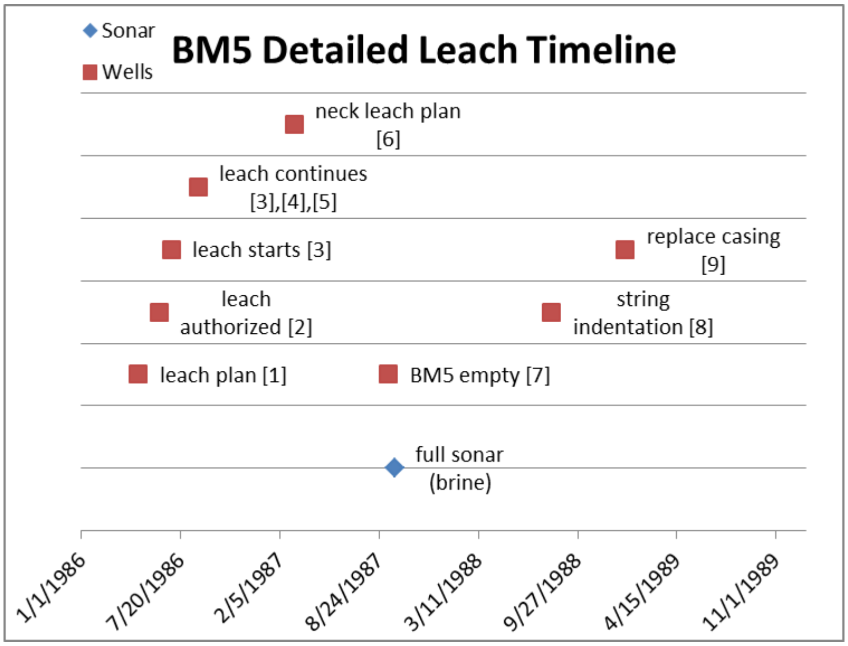


Figure 4-6. Timeline of BM5 events. Well 5 was completed in 1957 [1] but is not shown due to timescale. More detail on the leaching activities (*) of the mid 1980's is given in Figure 4-7.

In the mid-1980s there was a growing concern of being able to meet the 1.1 MMB/day delivery rates for the sweet and sour crudes at BM. As BM5 was the largest cavern holding the greatest amount of sweet oil, if a problem were to occur with the hanging string, the delivery status of the sweet oil would be in jeopardy. The decision was made to increase the delivery rate from 0.8 MMB/day to 1.1 MMB/day which also gave the opportunity to leach the neck region of BM5 in order to more fully connect the lower and upper lobes of the cavern (PB-KBB 1987). A more detailed timeline of this period and the associated references are presented in Figure 4-7. Vertical displacement is used solely to avoid overlapping data. Select references are available in Appendix C as noted.



[1] (Mills 1986)-b*

[2] (Milloway 1986)*

[3] (Mills 1986)-a*

[4] (Bartholomew 1986)*

[5] (Kenzie 1986)*

[6] (PB-KBB 1987)*

[7] (Boudreaux 1987)*

[8] (Girman 1988)*

[9] (DynMcDermott)a

Figure 4-7. Detailed timeline of the BM5 neck leach.

Not only is it important to understand the history of BM5, it is necessary to note the current operating status of the cavern. Table 4-2 lays out the current configuration for BM5 and the current properties of the cavern itself including the most recent interface depth and oil volume. Currently, BM5C is out of configuration with a suspended string at a depth of 2030 ft. A tilted wellhead has prevented the passage of piping passed the dog leg curve of the well.

Table 4-2. Bryan Mound 5 Current Configuration as of 1/15/15 from Bryan Mound Weekly Report.

Well	Cavern Top	IF & TD Date	IF Depth	TD Depth	Remarks
5	2102	2/17/2014	3210	3246	Pipe failed at 3045 ft. Lost 179 ft (12/27/12)
5A	2102	12/22/14	3222	3273	Static
5C	2709*	10/22/07	3226	3222	Pipe at 2030’. Oil in brine string

* Well 5C enters the cavern in the lower lobe (see Figure 4-2)

In October, 1978, the brine string in Well No. 5 was pinched and ruptured during oil fill. The string broke at approximately 2,738 ft, essentially the neck of the cavern, which is consistent with a sloughing off of wall material on the cavern floor of the upper lobe that likely struck and caused the damage to the brine string. Because of the inability to remove brine, the oil fill was stopped.

Well 5B was drilled with the intent of intersecting the roof of the lower lobe at its highest point. The decision was made, however, to plug and abandon the well after determining the drill would not enter the cavern in the region that was anticipated. Well 5C drilled into an oil-filled void at 2,718 ft and entered the cavern at 2,744 ft. Oil was added to the cavern while brine was displaced through the new 5C tubing (Gabriel 1979).

As late as 1980, the two lobes of BM5 were distinct and only connected by a narrow neck at 2700 ft. The volume determined by sonar survey indicated a 33.4 MMB cavern. An interface survey from February, 1980, however, indicates the volume at that time may have been underestimated by as much as 15% (Ortiz 1980). This difference is likely the result of additional brining that occurred after Cavern 5 was turned back over to Dow following the completion of sonars necessary for certification. Initial baseline sonars for BM5 likely misrepresented the cavern shape and volume.

Table 4-3 documents the history of sonar activities for BM5. Although many surveys have been attempted, the current picture of BM 5 is still unresolved. Sonars were completed in 1977 and 1978 of the lower and upper lobe, respectively. In 1987, a survey of the entire cavern was completed. This sonar was completed in brine due to the leaching activities at the time. As such it is more reliable than the other more recent sonars conducted in oil.

Table 4-3. History of BM5 Sonar Activities.

Well	Date	Depths Surveyed	Notes
BM 5	12/16/1977		Lower lobe only
BM 5	1/6/1978		Upper lobe only
BM 5A	9/24/1987	2145-3217	Full sonar survey
BM 5	6/28/1999	1945-3210	Peculiar result for lower portion of upper lobe and lower lobe; sections not read at certain depths
BM 5C	7/9/1999	1928-2760	Neck only
BM 5	9/28/1999	1945-3210	Peculiar result for lower lobe
BM 5C	12/12/2007	1928-2085	TD 2090 ft (above top of cavern); neck only

Several sonars in 1999 reflect only pieces of BM 5 with peculiar results reported especially in the lower lobe of the cavern where there appears to be missing data (i.e. full sweeps at a depth station were not completed). It is unclear whether these irregular results are due to inconsistencies in the sonar interpretation (such as the cavern radius being larger than sonar resolution capabilities) or a malfunction with the sonar tool. The sonar completed 7/9/1999 only surveyed a small region of the narrow neck of the cavern and does not show good agreement with 1987 sonar. The 1999 sonar shows much less volume even when looking at the same depths. The most recent sonar, completed in 2007, stops at a total depth of 2090 ft which is above the top of the cavern. Therefore, the best and most complete sonar available is the sonar completed in 1987 shown in Figure 4-8 as an interactive 3D representation of the cavern. The left mouse button is used to drag and rotate the image. The right mouse button is used to zoom in and out. When both buttons are held, the image can be panned.

Figure 4-8. Interactive 3D representation of the 1987 sonar survey of BM5 - right click to zoom, left click to drag, both to pan.

The accuracy of the sonars are dependent upon several factors including the type of fluid it is in and whether or not the sonar is taken through casing. The measurement through casing is limited because the most accurate means of sonar measurement require the salt saturation (if in brine) and the temperature in order to determine the speed of sound in the fluid (McDonald, Davis et al. 2004). If casing is present, the measurement is done at the end of the hanging string and used as the approximation for the entire cavern. This is appropriate only if cavern operations have been static for an extended period of time. The maximum radius that can be read in brine and hydrocarbons as stated in (Reitze and Tryller 1996) is found in Table 4-4 below (measurement improvements may have been made, but no new documentation is available through SMRI). The maximum extent that can be read in oil is much smaller than that of brine, and the single casing in oil value is considered high. It is possible that the accuracy of measurements in oil may be less than those in brine as well.

Table 4-4. Maximum radius in brine and oil from (Reitze and Tryller 1996).

		Brine	Oil
Maximum Range, ft	No casing	800	130 - 250
	Single casing	220	70 - <160

4.3 Cavern Issues

BM5 has a long history of casing damage with many of the issues attributed to salt falls. The tiered bi-lobe structure of the cavern separated by a narrow neck lends itself to stability issues. Table 4-5 presents an overview of reported casing damage or loss.

Table 4-5. History of Lost or Damaged Casing for BM5.

Well No.	Cavern Volume	Date Discovered	Activity*	Probable Cause[+]	Casing Lost, ft	Casing Diameter
5[+]	37.5	10/78	Oil Fill	Anhydrite slough	456	9 5/8”
5[+]*	38.65	8/88 (or 89*)	Static	Salt Fall	204	10 3/4”
5[+]*	38.65	06/90	Static	Salt Fall	458	10 ¾”
5C[+]*	34.05	07/92	Static	Salt Fall	530	9 5/8”
5*		10/97	Oil Fill		456	9 1/2” *
5*		6/99	Static		Damaged	10 3/4”
5*		7/99	Workover		553	10 3/4”
5C*		7/99	Workover		381	9 5/8”
5C*		7/06	Static		Damaged at 2704	10 3/4”
5**		12/27/12			179	

[+] (Bakhtiari 1993), *BM Weekly Report, 5/21/13 and **BM Daily Report, 5/21/13

4.4 Current Stability Assessment

BM5 has a high diameter-to-height ratio and a pronounced neck between lobes, features which make it more likely than typical caverns to experience tensile and dilatant stress conditions. Areas of greatest worry include the narrow neck region, the large-diameter flat ceiling at the top of the cavern, the bottom portion of the upper lobe, and the top portion of the lower lobe. These features, in particular the narrow neck in the region of high variability in anhydrite content, are considered to play a prominent role in the large number of string failures due to salt falls. The Bryan Mound stability report, (Sobolik and Ehgartner 2009) suggests additional special monitoring of BM5 during workovers because of the potential for high tensile stress during these operations especially in the neck region as seen in Figure 4-9 (shown below) from the report. These issues greatly increase the likelihood of damage to the hanging string. On the other hand, BM5 is a shallower cavern and, as such, has a smaller closure rate. BM5 would be more stable with less potential for hanging string damage if the neck region was enlarged.

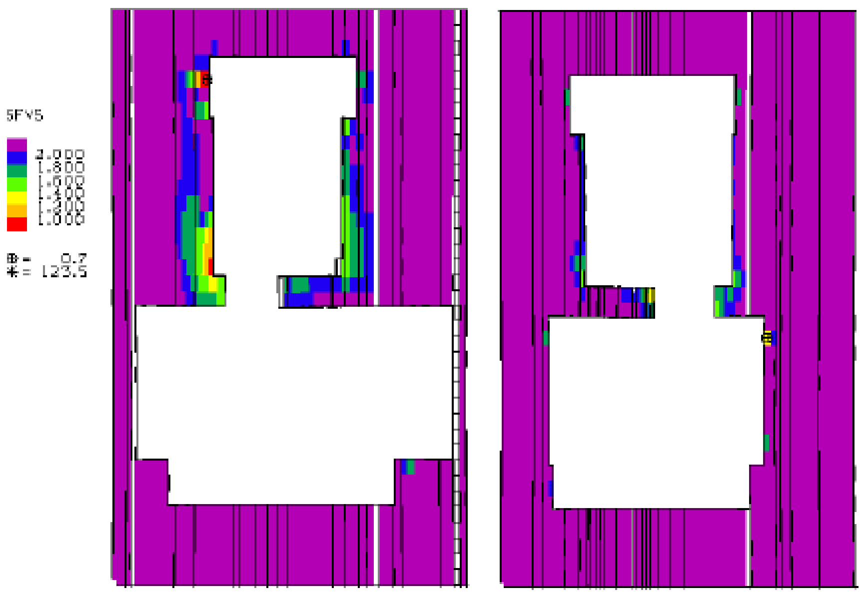


Figure 4-9. Contour plot of damage factor in the salt around BM5 (two cross-sections, looking north and west) from (Sobolik and Ehgartner 2009)a.

In the determination of the baseline for the remaining drawdowns effort recently exerted by Sandia, BM5 is stated to have 1 remaining drawdown (Sobolik, Park et al. 2014). It is also at risk for salt fall and string breaks that could limit access to the oil in the lower lobe or create a stable emulsion. As such, the use of saturated brine is recommended.

4.5 Leach Potential and Simulations

BM5 is an extremely odd-shaped cavern with a history of salt falls and string failure. Additionally, the chemical composition of the surrounding salt is relatively unknown and heterogeneous at best with varying levels of impurities and insolubles. These unknowns contribute to the conclusion that an attempted leach may not yield the desired shape, but may in fact result in preferential leach. Although the potential for a large increase in ullage volume exists if this cavern were to be leached to the current maximal radial extent, however, the risks associated with leaching present several significant issues for the SPR and the success of such a leach is difficult to determine. Because of the odd shape and high level of insoluble material, it is likely that any effort to leach out the neck of the cavern and move to a more cylindrical, more stable shape would result in falls and damaged casing string. Also because of the unknown shape and extent of the insoluble surrounding BM5, it is possible that an attempt to leach the cavern would result in an even more irregular shape with only 5.6 MMB of ullage created when leaching to a reasonably conservative radius. Finally, in order to reach the neck of the cavern for a targeted leach, approximately 27 MMB of oil would first need to be moved out of the cavern. For these reasons, there has not been an attempt to investigate a leaching scenario with SANSMIC simulations.

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5 West Hackberry 9

West Hackberry 9 is one of the oldest caverns owned by the SPR and is located in the state of Louisiana. WH9 has a cavern volume of approximately 9.1 MMB and, similar to BM5, is bi-lobal with a narrow neck. Nearby neighbor, WH8, is more than 100 ft away (147 ft by the P/D code (Rudeen 2013)) from WH9 but (Whiting 1980) suggest keeping the same oil in WH8 and WH9 as the two caverns will coalesce after three full drawdowns. WH6 was originally reported to be as close as 100 ft away from WH9 at their closest point. Additional sonars show the closest point between WH6 and WH9 is approximately 360 ft according to the P/D code. WH109 is closer to WH9 than WH6 at 360 ft by the P/D code. Above the top of the cavern lies a 1,000 ft thick salt roof and WH6 lies between the edge of the salt dome and WH9. WH9 is currently used to store sour crude oil. A map of the WH site with cavern outlines and wells is shown in Figure 5-1.

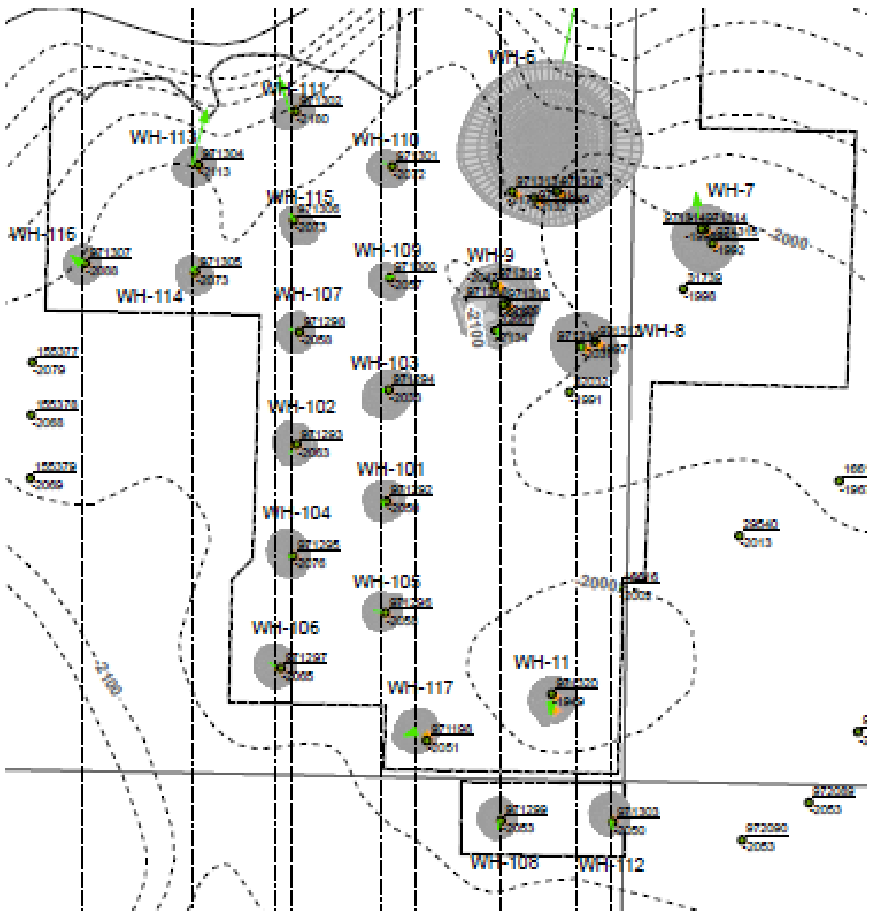
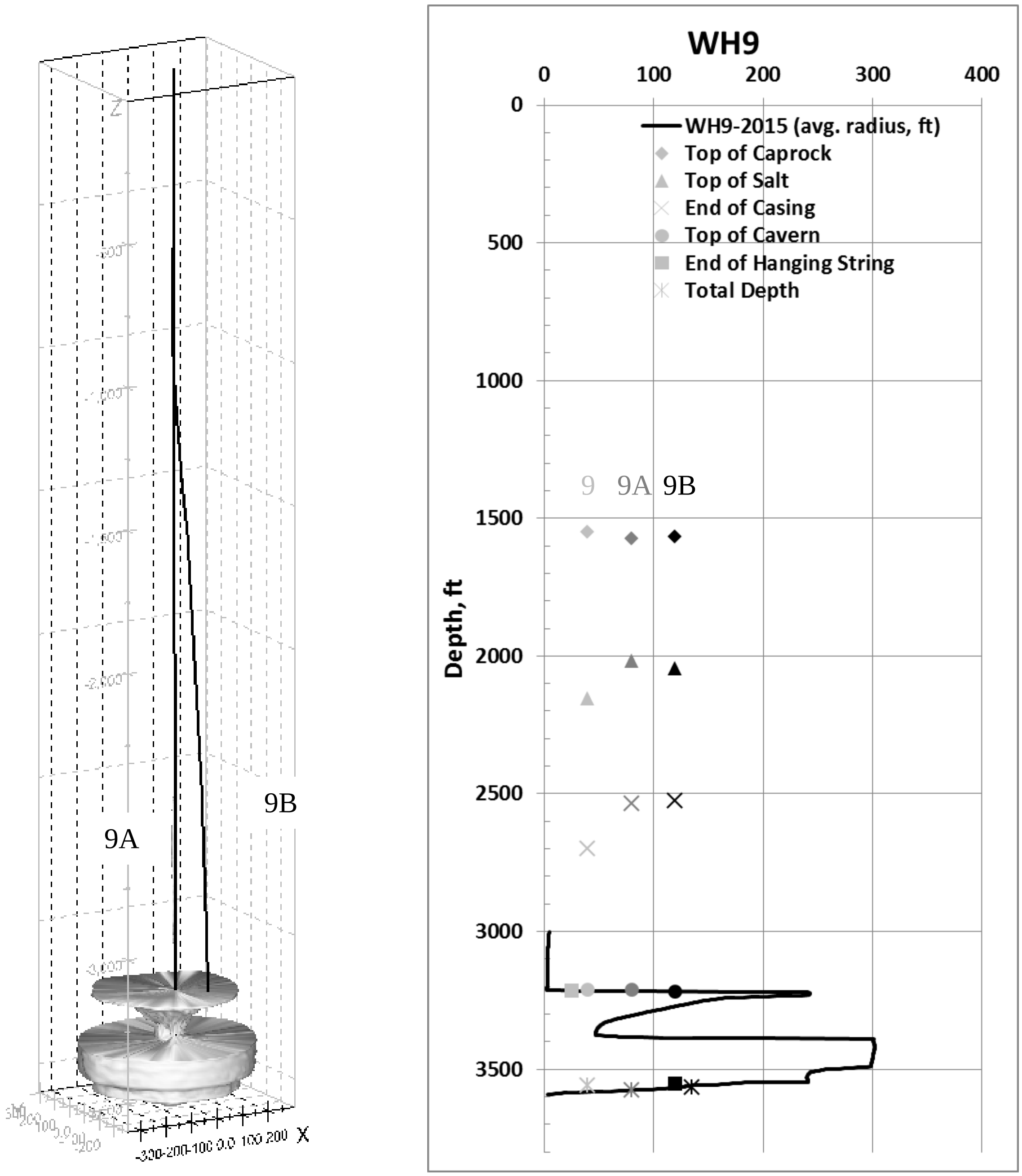


Figure 5-1. West Hackberry site map of cavern and well locations.

Figure 5-2 (left) shows the relative positions of two of the three wells servicing WH9 and where they enter the cavern. No deviation survey could be found for well 9 and, therefore, is not pictured. The figure on the right shows the axisymmetric geometry and important well depths derived from well schematics (see Appendix A). Note that the horizontal displacement of the well data is meaningless and used to avoid overlap. Sonar data is from 2015 for both images.



a) Sonar image of WH9 with wells 9A and 9B

b) Average radius with well depths noted - horizontal displacement is meaningless

Figure 5-2. Sonar image of West Hackberry 9 with wells 9A and 9B shown as well as key well depths.

5.1 Geology

The West Hackberry Salt Dome is known for its purity and lack of interbedded sediments. Salt cores from 4 West Hackberry cavern wells revealed approximately 3 percent of anhydrite (Whiting 1980) in the total composition of the salt. This differs greatly from the 43-97% reported for BM5. The SPR developed caverns were only partially logged so it is not possible to map the anhydrite bands or internal structure of the salt inclusion (Magorian, Neal et al. 1990).

5.2 History

At the time of purchase, WH9 had a reported volume of 8.9 MMB. However, after certification, the cavern was returned to the Olin Company for continued brining (Whiting 1980). WH9 was completed in 1947 and is one of the oldest operating caverns at SPR. Unfortunately, little else is known regarding the early history of WH9 prior to being purchased by the SPR. It is widely recognized, however, that the shape of the cavern is due to persistent brining operations and the unique bi-lobal shape and narrow neck are the result of a broken string during early operations. Initially, leaching was occurring in the bottom lobe. After a string break high in the developing cavern, leaching began at a much higher elevation creating the upper lobe of the cavern. The overall radial symmetry of the cavern is consistent with a string break as irregularities in cavern shape would be more diagnostic of impurities within the salt. A timeline of sonar and well events is presented in Figure 5-3. The references for the events can be found on the right of the figure.

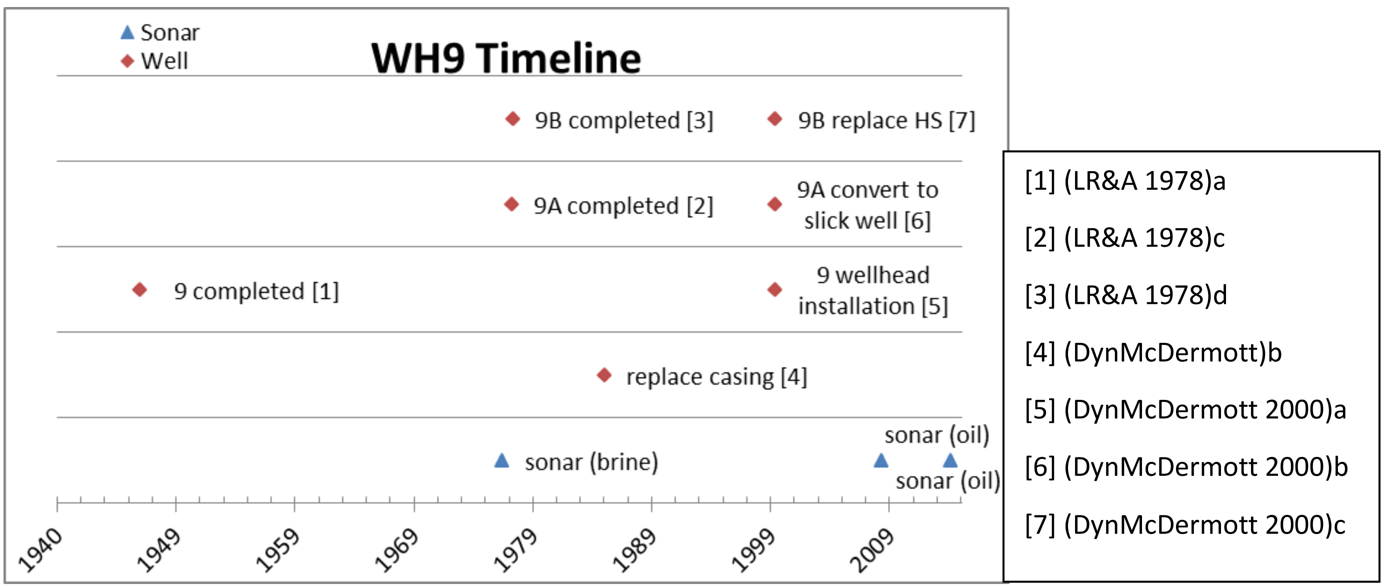


Figure 5-3. Timeline of sonars and well events for WH9.

Table 5-1 provides pertinent historical information for the three wells (WH9, WH9A, and WH9B) including casing and completion information useful for gaining a full understanding of the WH9 system. Additionally, Table 5-2 provides data for the current operations of WH9 including cavern and oil volume and interface depth. This is critical information for investigating the plausibility and benefit of remedial leaching activity. The recent work characterizing the WH salt dome (Lord and Roberts 2013) gives the top of cavern for WH9 (well non-specific) to be a depth of 3213 ft and the top of salt for cavern WH9 (well non-specific) to be a depth of 2100 ft.

Table 5-1. WH 9 Well History.

	9	9A[2]	9B
Date Spudded		2/1/1978[2]	3/21/1978[3]
Date Completed	1947[1]	3/19/1978[2]	4/28/1978[3]
Top of Salt, ft	2000[1] (2153)	2109[2] (2000)	2046[3] (2016)
Completion Depth[4], ft	2700	2537	2525
Top of Cavern[4], ft	3210	3212	3217
Suspended String[4], ft	Slick Hole	Slick Hole	3554
Total Depth[4], ft	3560	3575	3567

() indicates conflicting data given in more recent Murry and Foley 2011
[1] (LR&A 1978)a; [2] (LR&A 1978)c; [3] (LR&A 1978)d; [4] (Murry and Foley 2011).

Table 5-2. West Hackberry 9 Current Configuration as of 1/15/15.

Well	Depth Casing	IF & TD Date	IF depth	Total Depth
9S	2700	5/4/05	3531	3560
9A	2537	6/24/09	3545	3574
9B	2525	4/15/14	3544	3567

West Hackberry Weekly Report, 1/7/15.

Figure 5-4 shows sonar results from 2009. The 1977 sonar was completed while the cavern was being used for brining operations while the 2010 sonar was completed while the cavern was being used for oil storage and was done by Socon. Because the 1977 survey was completed in brine, the survey has a much greater resolution. Recall that the maximum extent that can be accurately measured in oil is less than that in brine and the sonar in 2010 was less accurate than the 1977 sonar (see Section 4.2). Although sonar technology has improved since the 1970's, the expansive diameter of WH9 and the survey through oil makes the results of the 2010 sonar questionable and the normal data files were not made available for this sonar run. In February of 2015, a sonar was conducted by Sonarwire through oil with reasonable radial readings and typical data files were provided. The furthest extent of WH9 remains indeterminate.

Figure 5-4. Interactive 3D representation of the 2015 sonar survey of WH9 - right click to zoom, left click to drag, both to pan.

5.3 Cavern Issues

Far fewer operational issues have been reported for WH9 compared to BM5. WH9 has a high potential for increased stress and potential for salt falls during workovers. However, even though WH9 has experienced several workovers, no hanging string failure events have been reported (Sobolik and Ehgartner 2009)b. It should also be noted that WH9 near WH6 and low-pressure conditions in one cavern may cause adequate pressure changes in the other resulting in unstable conditions. Potential consequences are reported in (Sobolik 2012) and active pressure management for these caverns is delineated in (Sobolik 2013). At this time, WH6 is nearly empty of oil and its ongoing use as a storage cavern is in question (Sobolik, Roberts et al. 2014).

5.4 Current Stability Assessment

Similar to BM5, the areas of greatest instability for WH9 are the large-diameter roof, the narrow neck region between the upper and lower lobe, the floor of the upper lobe, and the roof of the lower lobe. The angled ledge of the upper lobe leading into the narrow neck has significant potential for dilatant damage during workover operations. Due to the close proximity of WH6, caution during workovers of WH6, WH8, or WH9 must be taken. (Sobolik and Ehgartner 2009; Sobolik 2014) describe the scenario of a propagating crack traveling from WH6 to WH9 during a workover period that could result in pressure changes that could drive oil to the surface if a wellhead was not in place or blowout prevention methods failed.

WH9 currently has a 2D P/D less than 1 on the first drawdown and as such is investigated more fully in the recent work to baseline the remaining drawdowns. It is currently stable and would remain so after one withdrawal, but presents potential risk at the following depressurization of the cavern (Sobolik, Park et al. 2014).

5.5 Leach Potential and Simulations

Overall, the West Hackberry Salt Dome is relatively “clean” and more homogenous than the salt at the other three SPR sites. The current configuration of WH9 is most likely due to a broken string during brining operations before the cavern was purchased by SPR. It is highly unlikely that the narrow neck of WH9 is due to insoluble material in this region although Sandia National Laboratories cannot confirm this due to lack of reported logging activity and core samples from the initial well completion from 1947.

It is understood that a successful targeted enlargement of the neck of WH9 that would eliminate or diminish mid-cavern ledge resulting in a more stable cavern with a more favorable shape. Additionally, a better understanding of the composition of the salt of the dome in general yields more confidence in the ability to successfully leach this region. The absence of numerous reports of casing damage due to salt falls in spite of workovers and additional stress in certain areas of WH9 also lend to an overall assurance that WH9 will tolerate leaching operations. However, it is imperative to investigate the affect that leaching will have on nearby caverns, especially WH6.

In order to target the desired neck region, approximately 7.5 MMB of oil would need to be displaced. A preliminary SANSMIC simulation was completed in January 2012 simulating a 3 stage reverse leach with oil fill for the purpose of leaching the neck of the cavern. This operation would require workovers to properly position the strings. The results of these runs are shown in Figure 5-5 with the initial and final OBI depth, the injection depth, and the production depth.

SANSMIC is a solution mining software package that was developed at Sandia in the early 1980s by A. J. Russo specifically for developing tall-thin cylindrical caverns such as the Phase II and III SPR caverns. The type of controlled leach necessary for the leaching of WH9 requires a controlled OBI, injection string depth, and production string depth. A reverse or top leach is recommended in which the production string is set deeper within the cavern than the injection string. Oil fill is required so as to limit the total leaching that occurs in the upper depths of the cavern. SANSMIC has been validated for multiple scales of withdrawal and reverse leaching and a limited range of direct leach (Weber, Rudeen et al. 2014). However, it has not been validated for Phase I type cavern geometry. WH9's geometry is short and wide; the opposite geometry type for which SANSMIC is designed. Validity of SANSMIC results in this case are therefore unknown.

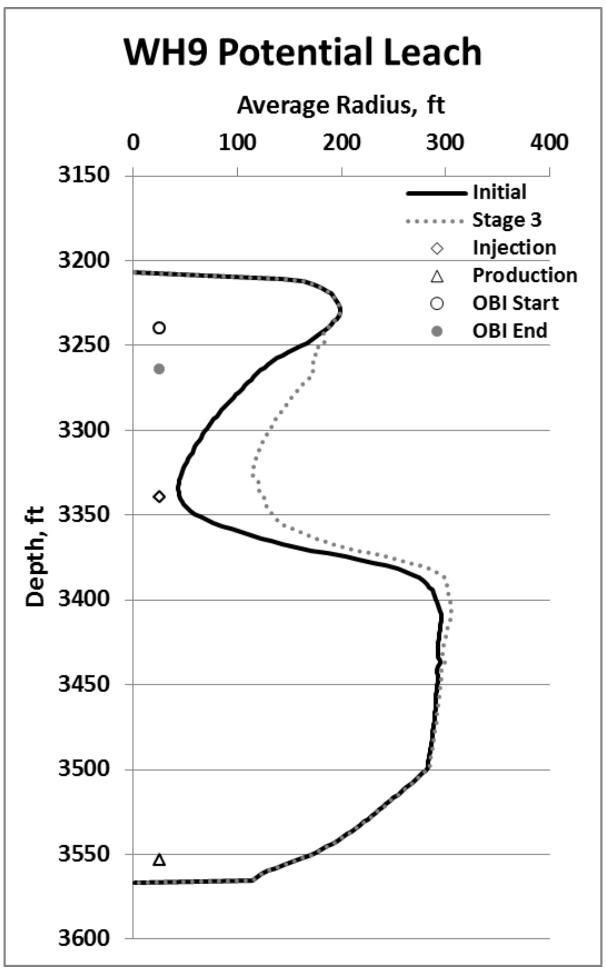


Figure 5-5. Preliminary SANSMIC simulation results targeting the narrow neck of WH9.

Table 5-3 illustrates the type of leach, duration of the leach, and additional parameters used for the SANSMIC simulation results for the targeted leaching of WH9. This simulation represents a quick effort and more analysis is necessary before devising a specific leach plan.

Table 5-3. SANSMIC leach proposal for WH9.

Description	Stage 1	Stage 2	Stage 3
Type	Top - Leach/ Fill	Top - Leach/ Fill	Top - Leach/ Fill
Duration, days	60	60	60
OBI final depth, ft	3246	3254	3264
Injection Rate (oil), MBD	50	50	50
Injection Rate (raw water), MBD	2.0	2.4	2.8
Final Cavern Volume, MMB	9.242	9.662	10.086
Δ in Cavern Volume, MMB	0.370	.789	1.213

6 Conclusions and Recommendations

BM5 and WH9 are atypically-shaped, Phase I, acquired caverns for SPR, each with two lobes separated by a narrow neck. BM5 is the largest cavern owned by the SPR with a cavern volume of 37.0 MMB. WH9 is one of the oldest caverns owned by the SPR with initial well completion in 1947. Leaching these caverns to obtain a more beneficial shape could result in approximately 6.8 MMB of additional ullage and/or oil storage capacity at SPR. However, there are significant risks and issues associated with leaching each of these caverns. In order to leach the narrow neck of BM5, approximately 27 MMB of oil would need to be relocated. Additionally, the composition of the salt surrounding BM5 is heterogeneous and occupied by sequences of anhydrite. The uncharacterized blocks of insoluble material at the narrow neck of BM5 may be too large to be leached out with a targeted leaching effort. The high rate of string failure due to salt falls also raises concern. An attempt to leach BM5 could result in a large amount of space created but the risks are very high. Remedial leaching for BM5 is not recommended at this time.

The shape of WH9 is not due to anomalies in the composition of the salt but rather due to a broken string early in cavern development. WH9 does not have a significant history of well failure due to salt falls even though it suffers from similar stress factors as BM5. To perform a targeted leaching operation of WH9, 7.5 MMB of oil would need to be relocated and the potential ullage gain would be 1.2 MMB. Preliminary SANSMIC simulations illustrate potential cavern geometry and the parameters that are needed to achieve this shape. The SANSMIC simulations are done as a preliminary analysis only and should not be used as a leach plan. Based on the SANSMIC predicted shape, the narrow neck of WH9 could be expanded giving the cavern a more cylindrical form and increased stability. However, SANSMIC has not been validated for caverns with the opposite aspect ratio for which it is designed (it is designed for tall-thin cylinders). Also, a thorough geomechanical investigation must be completed to understand the effects of this operation on nearby WH6 and neighboring caverns.

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Appendix A: Well Schematics

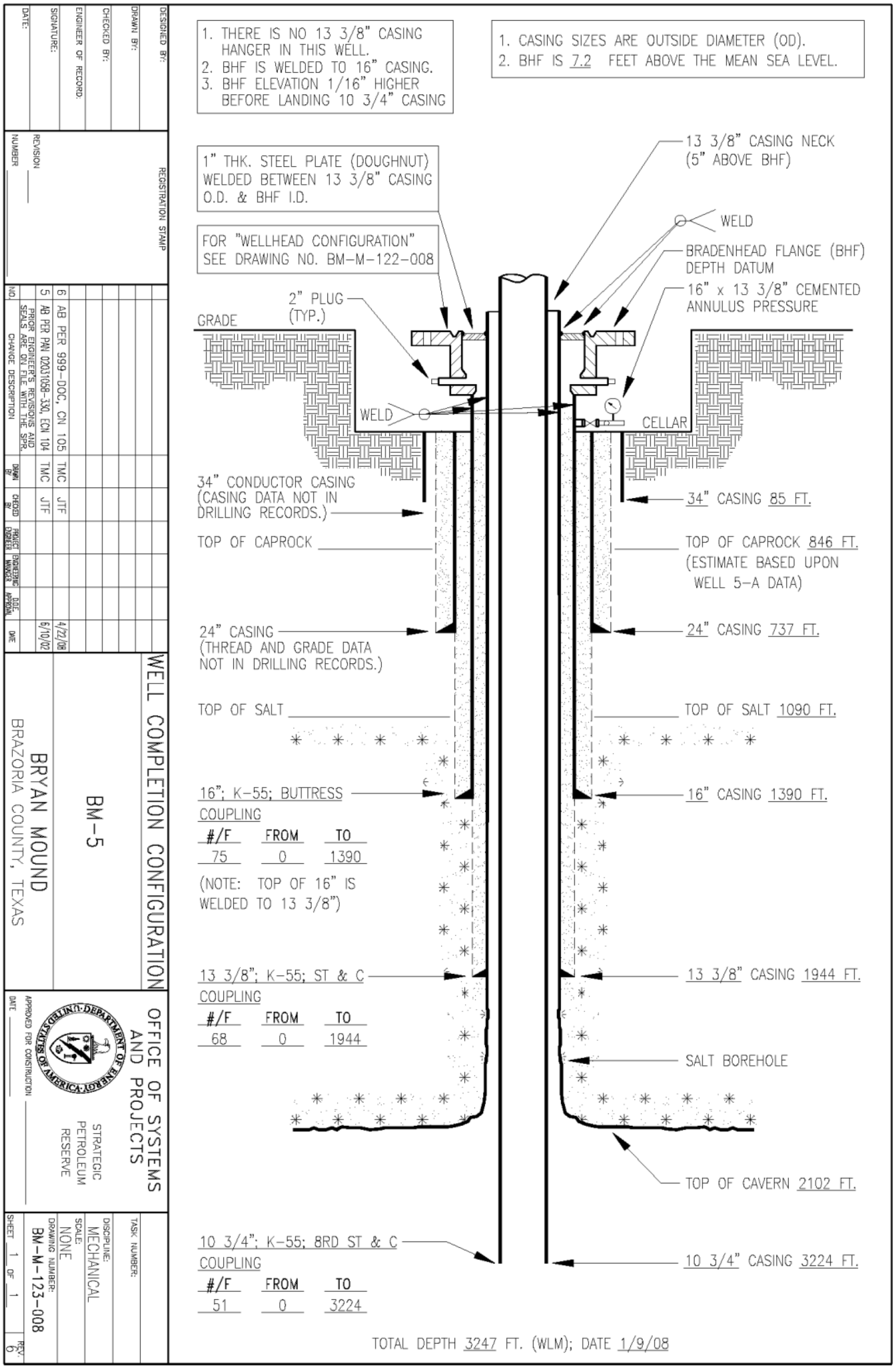


Figure A-1. Well schematic for BM 5.

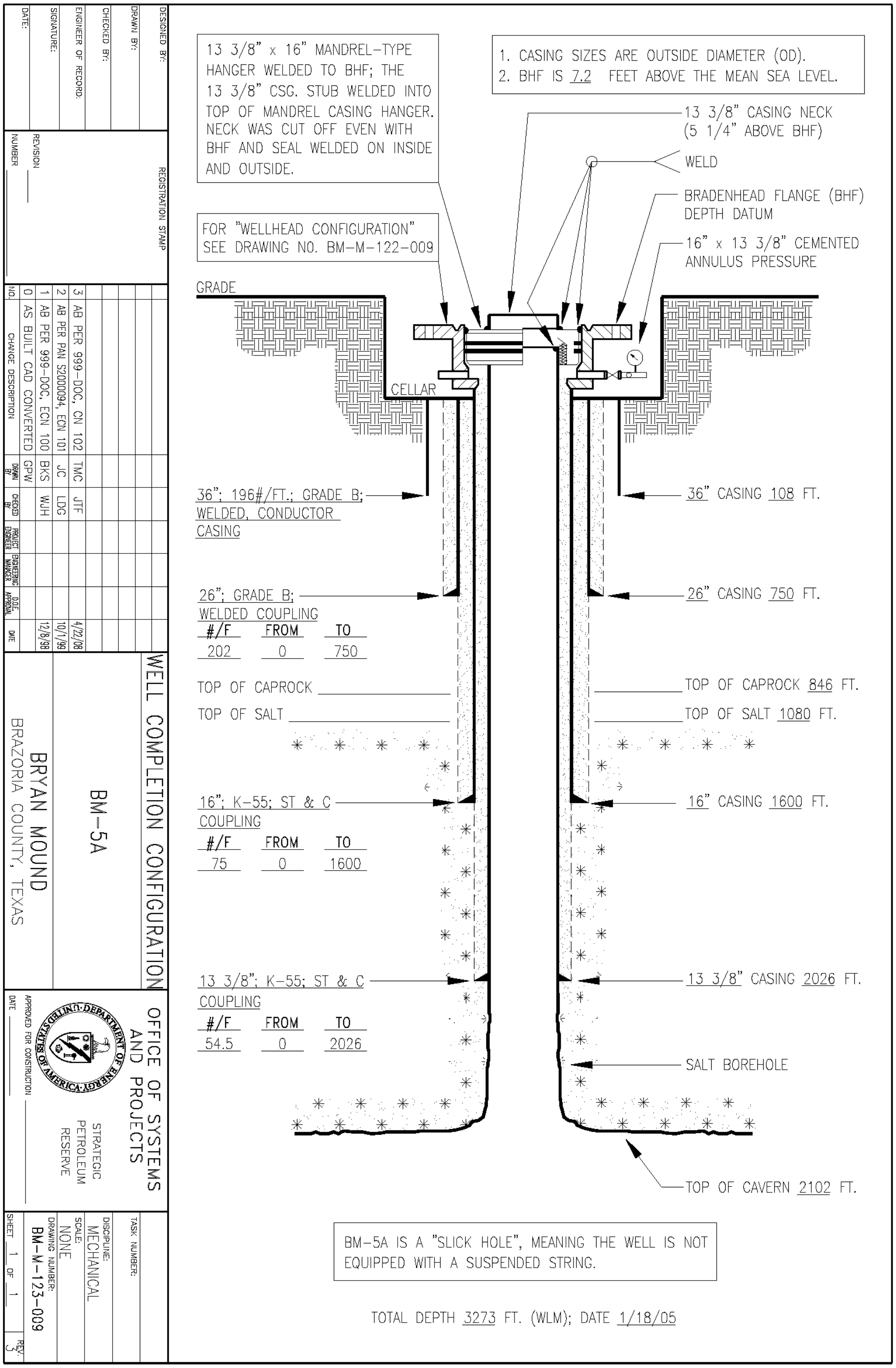


Figure A-2. Well schematic for BM 5A.

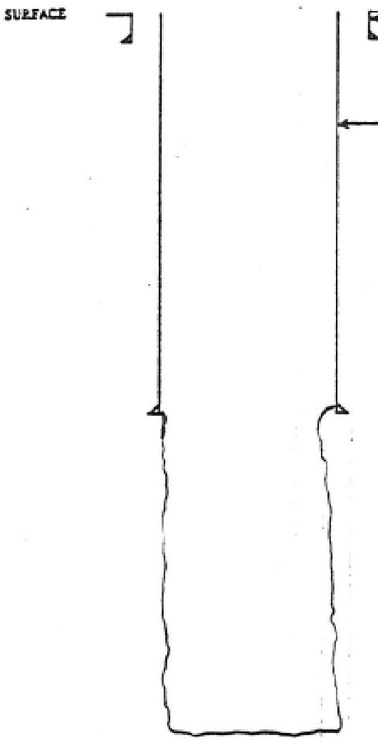
RE-ENTRY WELL NO. 5B FIGURE 1

WELL NAME Re-Entry #5B CAVERN #5 FIELD Bryan Mound

SERIAL NUMBER ______ C. Areola A-142 Survey

PARISH (COUNTY) Brazoria STATE TX SPUD DATE 2-2-79 COMPLETION DATE N/A

SURFACE



CONDUCTOR PIPE:

SIZE 36 " DEPTH 117 ' GRADE B
WT. ____ #/ft., COUPLING TYPE Welded
REMARKS .625" wall, 102' penetration

SURFACE CASING:

SIZE 26 " DEPTH 575 ' GRADE B
WT. ____ #/ft., COUPLING TYPE Welded
OPEN HOLE SIZE 32"
CALIPERED HOLE VOLUME FACTOR N/A
BARRELS OF CEMENT PRE-FLUSH 50 BBLS
TOTAL SACKS CEMENT USED 1360
485 SACKS OF CLASS TLW - SLURRY DENSITY 12 P.P.G.
875 SACKS OF CLASS H - SLURRY DENSITY 16.1 P.P.G.
REMARKS 45 BBLS returns
3/4" and 1/2" wall pipe

Depth 1057

OH Size 24"

FORMATION DATA

TOP OF CAPROCK ______'
TOP OF SALT ______'
TOP OF CAVERN ______'
BOTTOM OF CAVERN ______'

LOG DATA

SERVICE	DATE	LOGGED DEPTH (FEET)
DA Induction Electrolog	2-10-79	597'

CORE DATA

DEPTH CORED From - To (ft)	DIAMETER OF CORE (Inches)	FORMATION TYPE
' to '		
' to '		
' to '		
' to '		

REMARKS

Well operations were suspended due to transfer of supervision to Williams-Fenix and Scission

LOUIS RECORDS AND ASSOCIATES, INC.
LAFAYETTE, LA

RE-ENTRY WELL NO. 5B
SCHEMATIC
DATE 4-10-79 BY ADB

Figure A-3. Well schematic for BM 5B (Well History Re-Entry, 1979).

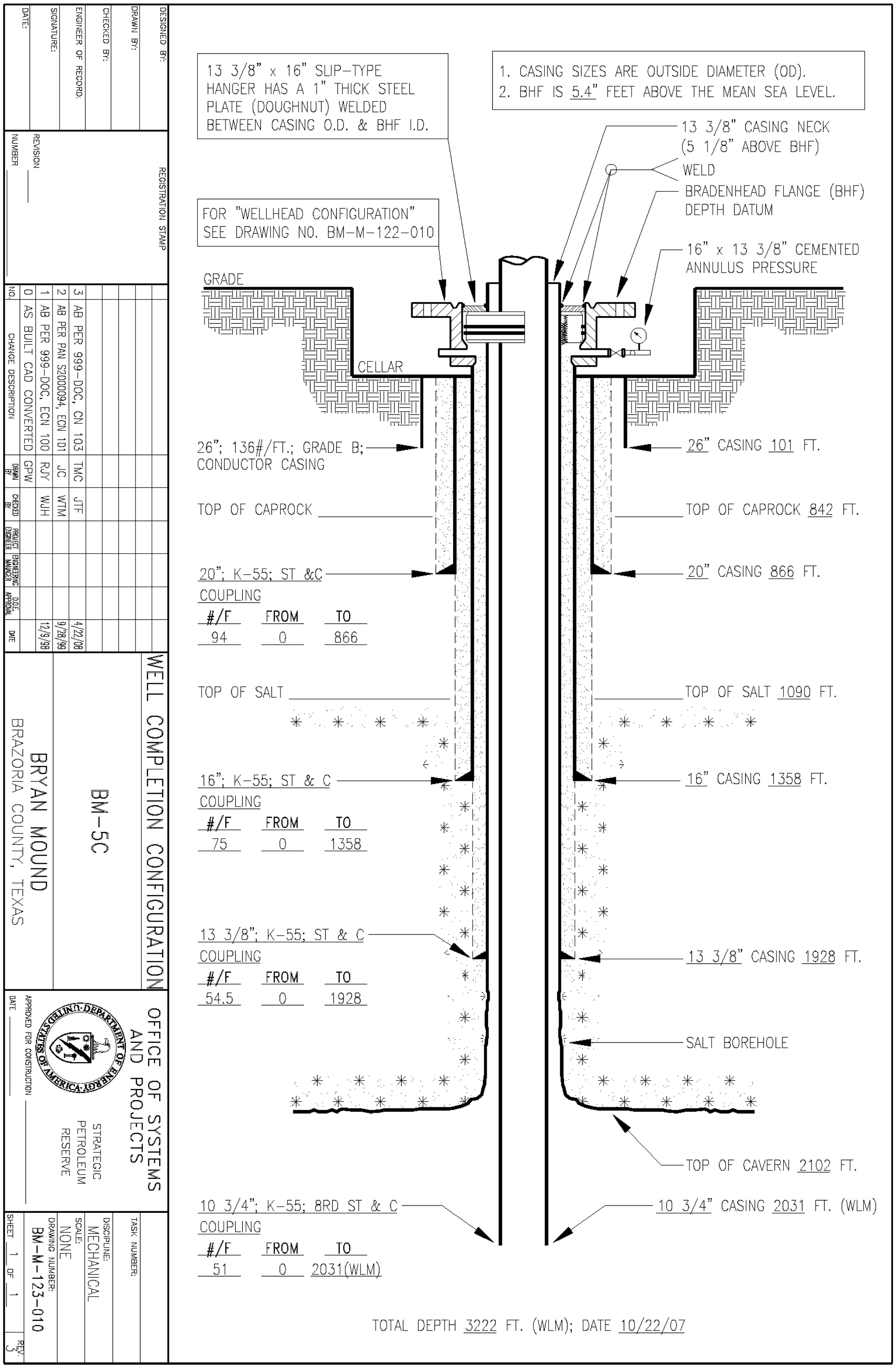


Figure A-4. Well completion diagrams for BM 5C.

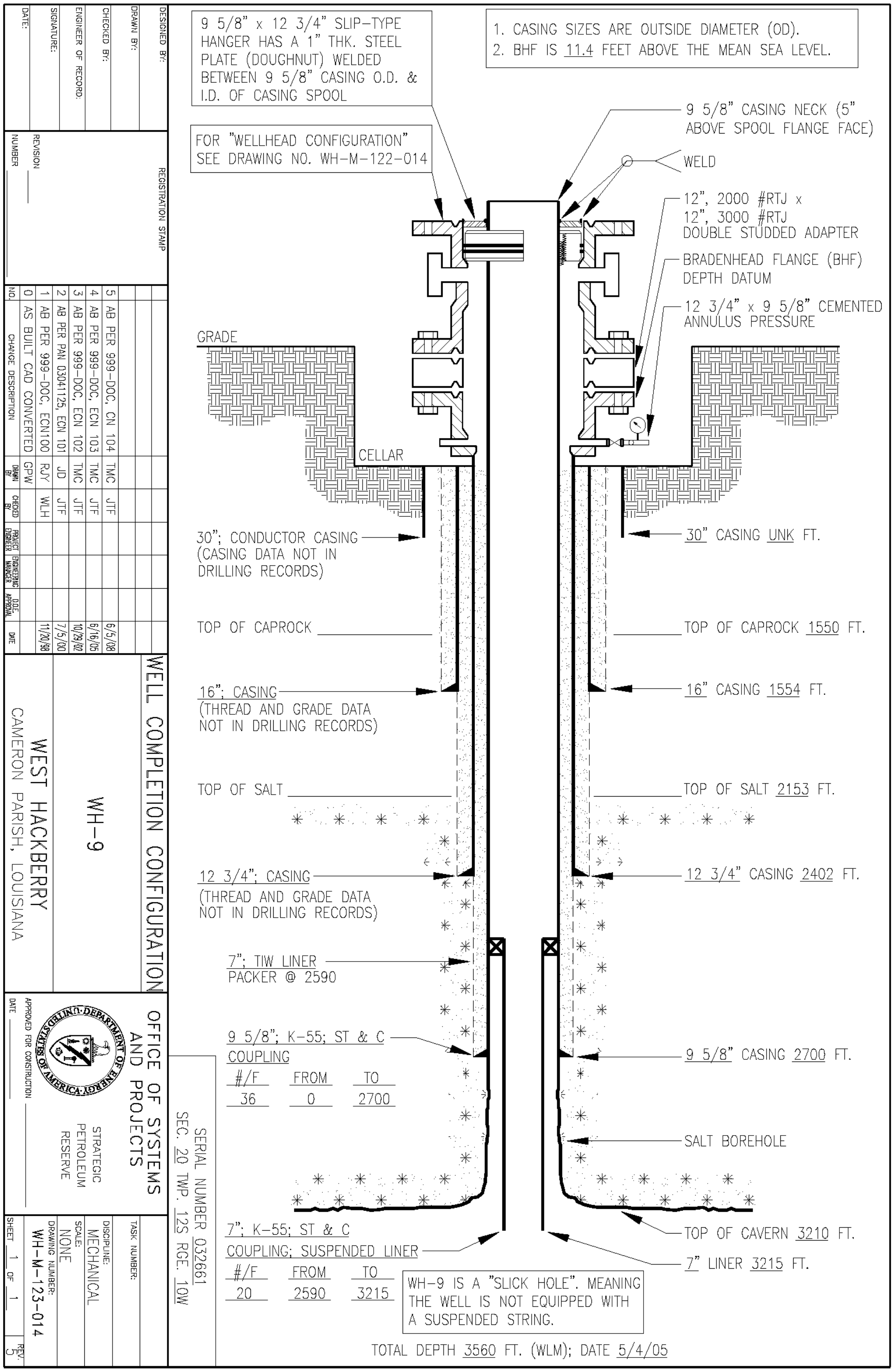


Figure A-5. Well schematic for WH 9.

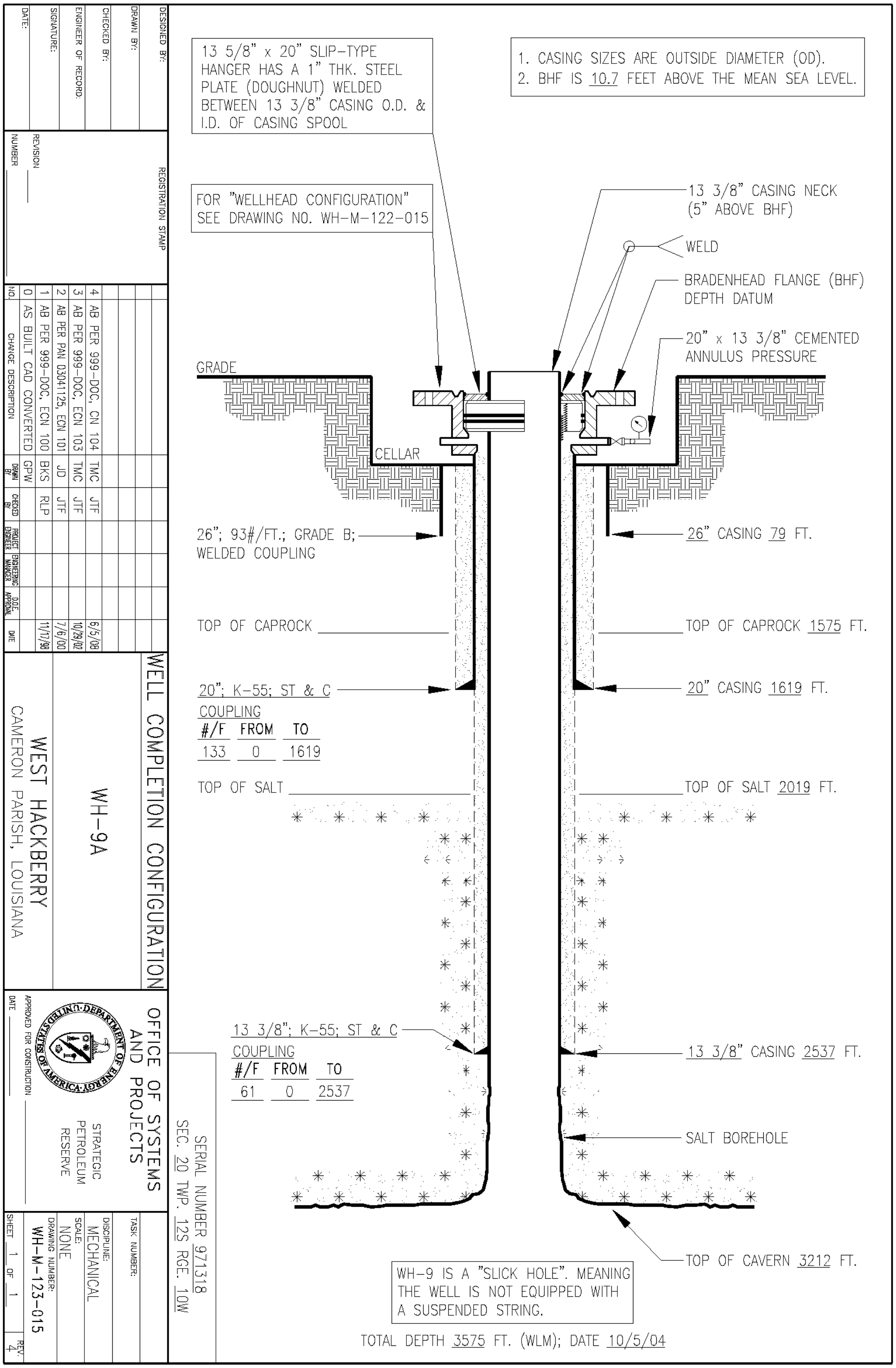


Figure A-6. Well schematic for WH 9A.

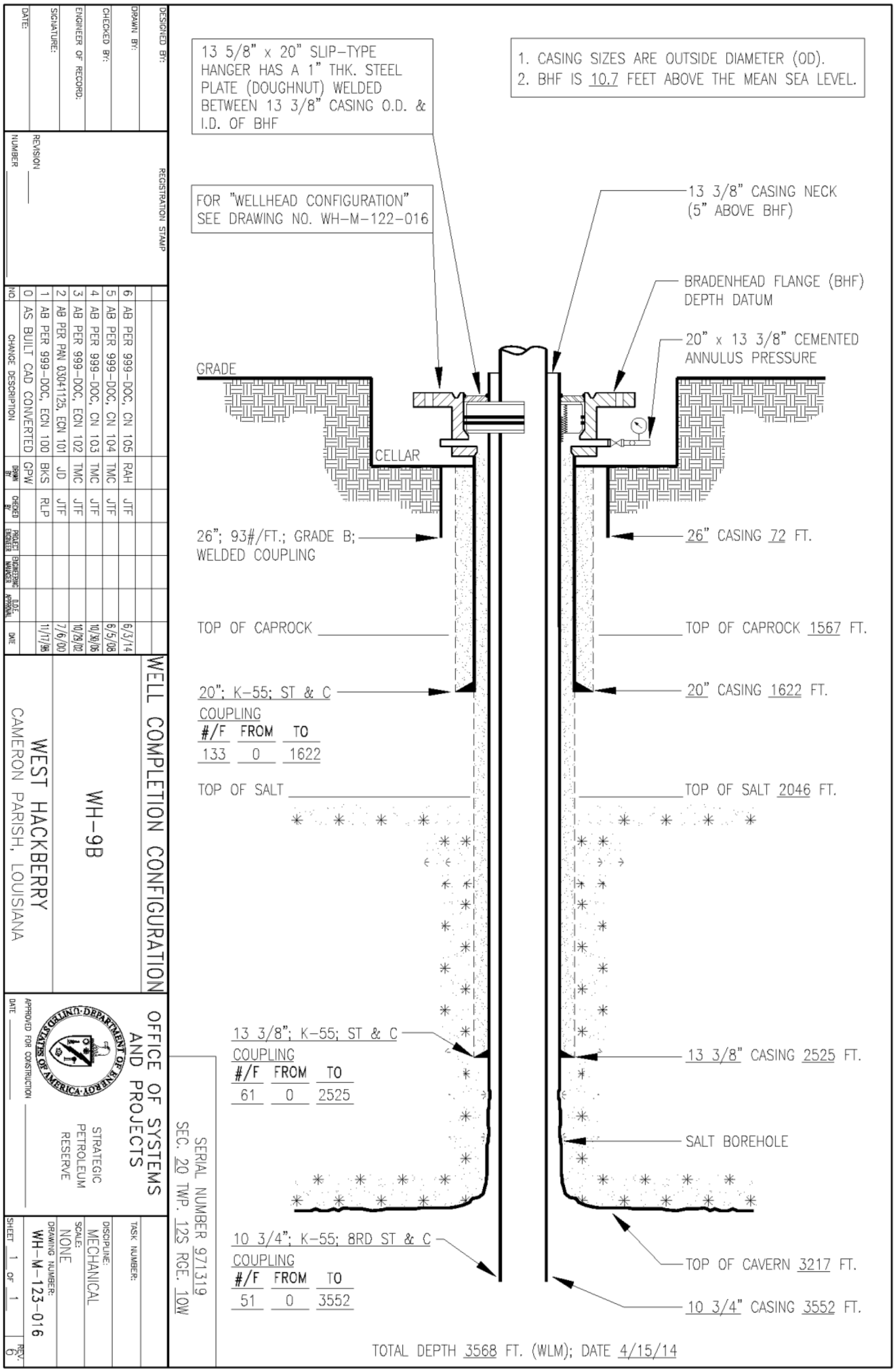


Figure A-7. Well schematic for WH 9B.

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Appendix B: Volume Calculations and Sources

The current source and associated volumes for BM5 are shown in Table B-1.

Table B-1. BM5 Total and Oil Volumes.

Total Volume	Oil Volume	Source	Date associated
34,479,441	32,671,154	1987 sonar	OBI=3222 on 12/22/14
37,072,000	36,857,000	Cap10312014.xls	10/31/14
37,811,486		Weekly excel (well 5)	12/27/12
	36,855,976	Weekly excel (well 5)	2/17/14
36,779,819		Weekly excel (well 5A)	12/22/14
37,768,368	36,378,019	Weekly excel (well 5C)	10/22/07
	36,861,506	Ullage workbook	6/30/14

The range that can be used for the total volume of BM 5 utilizing the table above is [36.780-37.072] MMB and so a reasonable approximation is to use 37.0 MMB. The similar range for oil volume is [36.766-36.862] MMB and the associated approximation is 36.8 MMB.

The source, date and available measured depths for BM5 are given in Table B-2.

Table B-2. HS, IF, and TD depth for BM5.

Well/source	HS Depth-Date	IF Depth-Date	TD Depth-Date
5/weekly excel	3226 -	3210 - 2/17/14	3246 -
5A/weekly excel		3222 - 12/22/14	3273 -
5C/weekly excel	2031 -	3226 - 10/22/07	3222 -
Ullage workbook	3226 -	3210 -	3246 -

Oil to be removed is calculated by using the volume in the 1987 sonar as 32,671,154 bbls at a depth of 3222, subtracting the volume of 9,545,259 bbls at a depth of 2600 to be 23,125,895 bbls. However the volume of the 1987 sonar is underestimated by approximately 4MMB which is likely located in the lower lobe and so the volume to be removed is 23 MMB + 4 MMB = 27MMB. It is of note that an MIT was initialized on BM5 on 12/22/14.

A look at the potential leach volume is shown in Figure B-1. Various leach radius extents are shown and the associated volume that could be gained by leaching to each of the radii is described below.

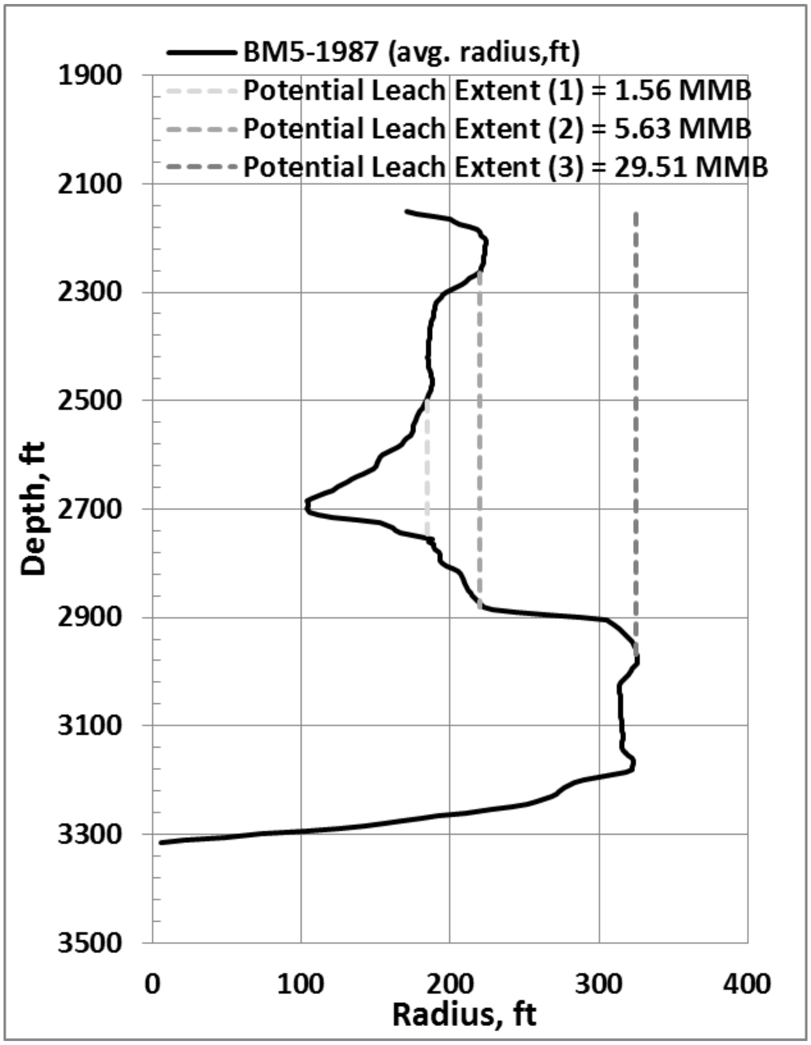

Figure B-1. Potential Leach for BM5.

Potential Leach Extent (1): Leach from 2500-2750 assume a maximum extent of 185 ft (radius) and a cylinder =4,787,577 bbls total. The current volume already leached in that region = 3,231,313 bbls leaving an additional volume of 1,556,264 bbls.

Potential Leach Extent (2): Leach from 2265-2880 assume a maximum extent of 220 ft (radius) and a cylinder = 16,655,313 bbls total. The current volume already leached in that region=11,027,943 bbls leaving an additional volume of 5,627,370 bbls.

Potential Leach Extent (3): Leach from 2155-2975 assume a maximum extent of 325 ft (radius) and a cylinder = 48,463,291 bbls total. The current volume already leached in that region =18,952,085 bbls leaving an additional volume of 29,511,206 bbls.

The current source and associated volumes for WH9 are shown in Table B-3.

Table B-3. WH9 Total and Oil Volumes.

Total Volume	Oil Volume	Source	Date associated
9,144,946	8,799,430	2009 sonar	OBI=3544 on 4/15/14
9,055,000	8,866,000	Cap10312014.xls	10/31/2014
8,885,572	8,935,003	Weekly excel (well B)	4/15/14
9,683,154		Weekly excel (well B)	10/9/12
9,682,459	8,913,898	Weekly excel (well A)	6/24/09
9,657,000	8,885,012	Weekly excel (well C)	5/4/05
	8,930,059	Ullage workbook	9/30/14

The range that can be used for the total volume of WH9 utilizing the table above is [8.886-9.145] MMB and so a reasonable approximation is to use 9.1 MMB. The similar range for oil volume is [8.800-8.935] MMB and the associated approximation is 8.9 MMB.

The source, date and available measured depths for WH9 are given in Table B-4.

Table B-4. HS, IF, and TD depth for WH9.

Well/source	HS Depth-Date	IF Depth-Date	TD Depth-Date
9B/weekly excel	3552 -	3544 - 4/15/14	3567 -
9A/weekly excel		3545 - 6/24/09	3574 -
9S/weekly excel		3531 - 5/4/05	
/ullage workbook	3552 -	3544 - 4/15/14	3568 -

Oil to be removed is calculated by the volume in the 2009 sonar as 8,799,430 at a depth of 3544, subtracting the volume of 1,350,157 at a depth of 3260, to be 7,449,273.

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Appendix C: Archived BM5 Leach Documents

The following sources were obtained from FFPO. The files were taken from a folder marked "BM5" and were electronically scanned and sent to Sandia. They are included here to give reference to the leach period of 1984-1989 from which electronic records are scarce. The title used in this report is highlighted on the first page of the associated file, however, some files had multiple attachments associated with it and all are included as the relevant information may have been included in an attachment rather than the main text of the file. More files were transferred from FFPO, but the attached documents held the relevant information referenced in this report.

TECOLOTE CORPORATION
531 WAGONTRAIN DRIVE, S.E.
ALBUQUERQUE, NEW MEXICO 87123
TELEPHONE (505) 293-8970

GEORGE B. GRISWOLD, PH.D.
PRESIDENT

January 27, 1981

Mr. James F. Ney
Division 4543
Sandia National Laboratories
Albuquerque, N.M. 87185

Re: Cavern No.5 - Bryan Mound

Dear Jim:

Clyde Walker and I met with personnel from Diamond Shamrock and Welsh Drilling in Houston on January 20, 1981. The purpose of the meeting was to learn of methods to monitor long term conditions in SPR caverns.

Incidental to the objective of our meeting we found out that Mr. Robert E. Young, VP for Engineering with Welsh, was former manager for Dow Chemical brining operations. I asked him for details concerning the odd geometry of Cavern No. 5. He told me that it was entirely an operational problem, and not, as I suspected from the logs, due to an insoluable block of anhydrite.

He says that the brining string severed up hole and they inadvertently started washing an upper cavern. Once this was discovered they attempted to lower a new string back into the lower cavern but were unsuccessful. Therefore, they raised back up and continued to leach the upper cavern. He feels that overall conditions are stable, and the cavern is suitable for crude oil storage.

All of the above is quite in contrast with my earlier thoughts. I could be partially right if insoluable material caused a restriction in an otherwise uniform growth of the cavern. Such a restriction may have been a fatigue point for the brine string which I would expect to be swaying back and forth during active brining operations.

In any event, Bob Young is an important source of information concerning past operations at Bryan Mound.

Sincerely yours,

GEORGE B. GRISWOLD

GBG:tcj

cc: H. Clyde Walker-Division 4543

April 24, 1986
5-0285-HWL-479

FILE COPY

To: R. Girman, EF-32

cc: D. Guier, PR-622.2
H. Lombard, EF-91
L. Rousseau, PR-63

Subject: Conversion of Bryan Mound Cavern 5 from Sweet to Sour Service

Attached as Enclosure 1 is a schedule of activities showing how the conversion of Bryan Mound Cavern 5 from sweet crude to sour crude service can be accomplished, if DOE should direct such an action.

Attached as Enclosure 2 is a table showing over time the actions occurring in each cavern together with the times required at each point to recover the sour ullage involved.

Enclosures 1 and 2 have been compiled at DOE request to serve as indications of capability and related impacts on overall oil fill capability over time in order to assist DOE in its deliberations over the desireability of converting Bryan Mound Cavern 5 from sweet to sour crude service and thus to enhance sweet crude drawdown capability, as recommended in a recent DOE project office study.

It has continually been emphasized that the enclosed data represents capability only and does not represent an indication on the part of BPS as MOM contractor that such an action would either be operationally desireable or cost-effective.

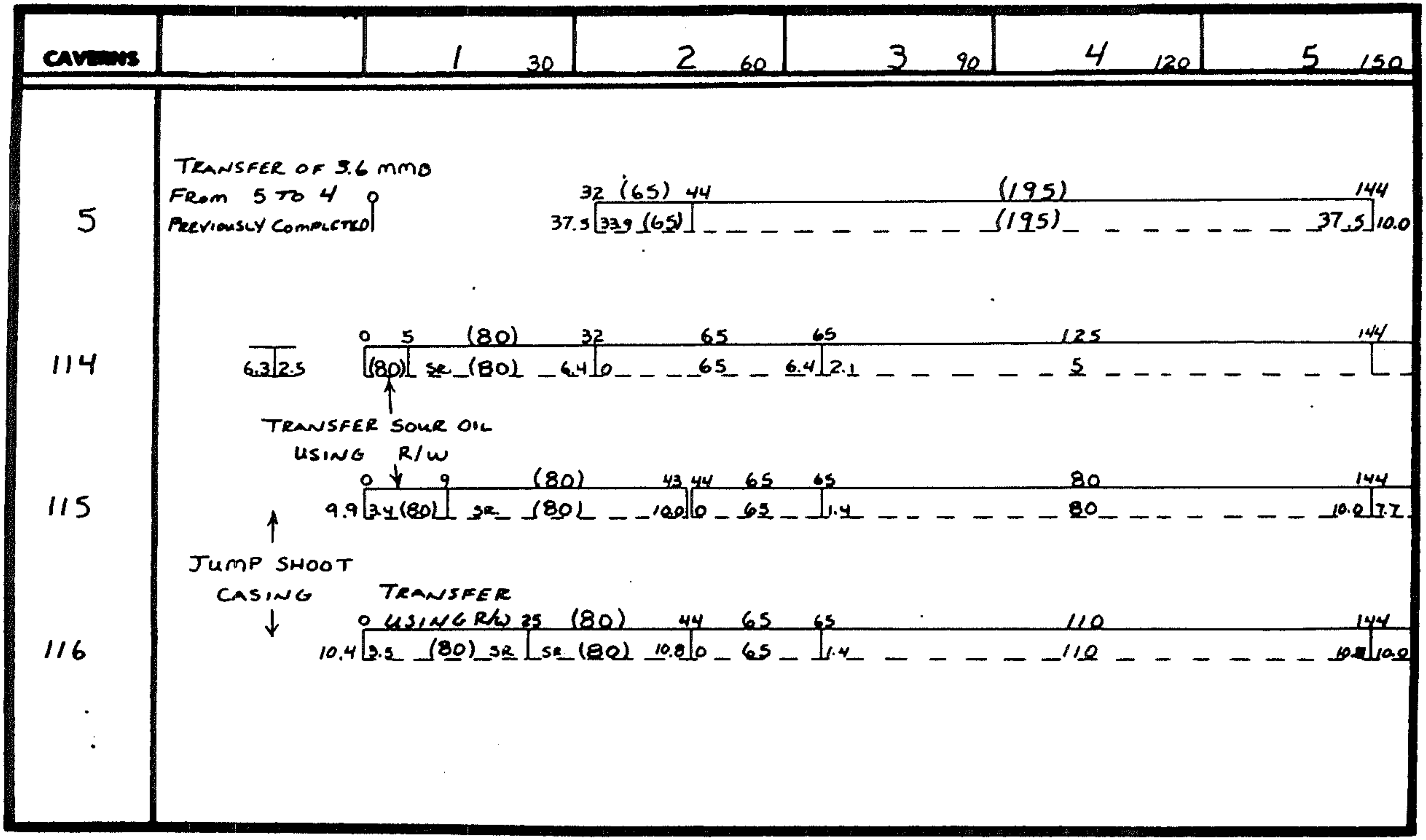
Enclosure 3 is a memo dated 4/15/86 from J. Henderson to R. Sipe discussing implications of the conversion of Bryan Mound 5 to sour service.

KEMill

K. E. Mills

Attachments

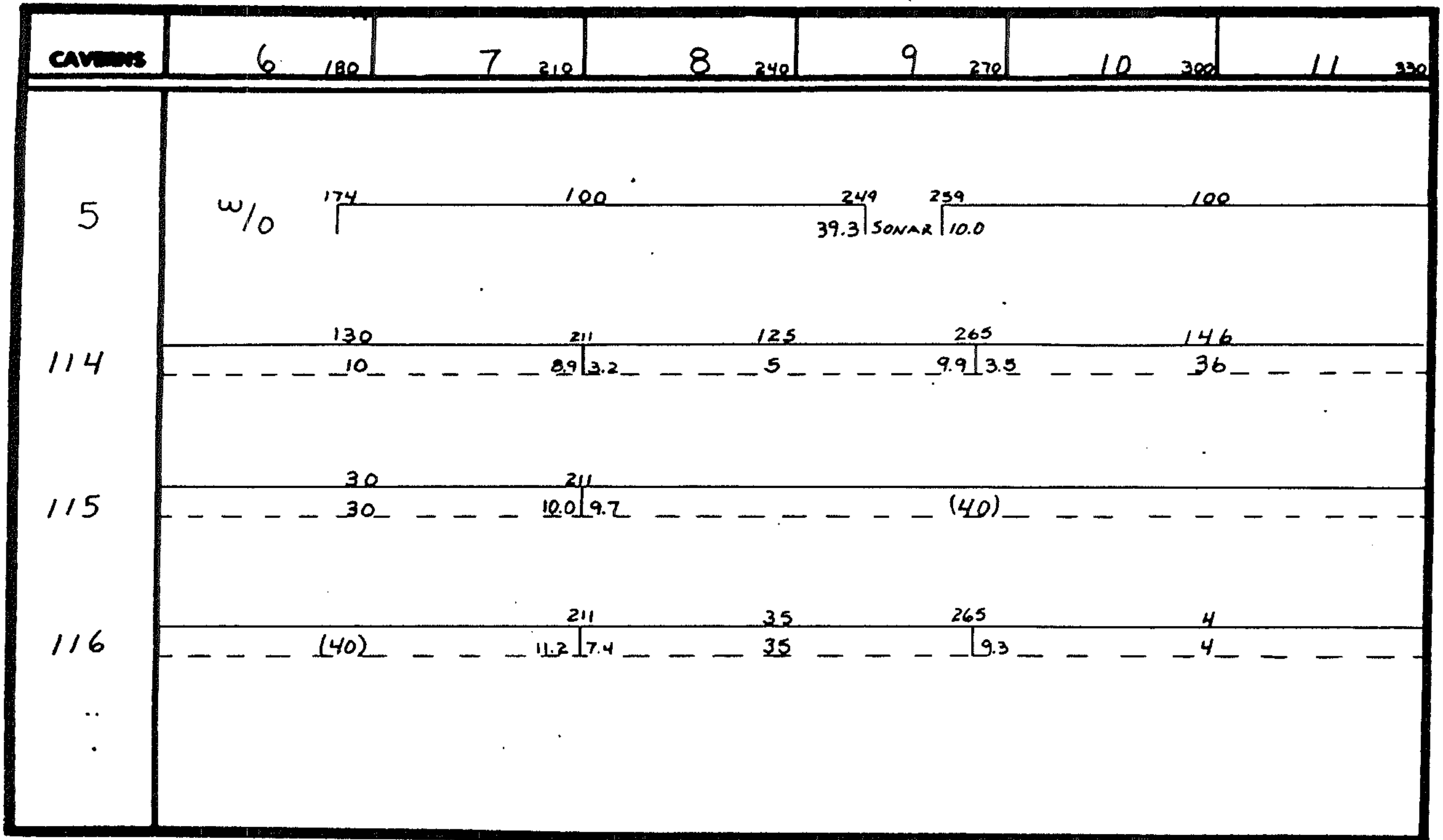
BRYAN MOUND LEACH SCHEDULE



- NUMBERS ABOVE SOLID LINES EQUAL AVERAGE BRINE-OUTFLOW PER CAVERN (MBD). ( ) = INFLOW (BRINE)
- NUMBERS ABOVE DASHED LINES EQUAL AVERAGE OIL-INFLOW PER CAVERN (MBD). ( ) = OUTFLOW (OIL)
- NUMBERS AT RATE CHANGES AND WORKOVERS INDICATE CUMULATIVE CAVERN AND OIL VOLUMES, RESPECTIVELY, IN MMB. FOR EXAMPLE: (CAV.) 6.3 | 1.6 (OIL)

- OIL IS SWEET UNLESS OTHERWISE NOTED

BRYAN MOUND LEACH SCHEDULE



- NUMBERS ABOVE SOLID LINES EQUAL AVERAGE BRINE-OUTFLOW PER CAVERN (MBD). ( ) = INFLOW (BRINE)
- NUMBERS ABOVE DASHED LINES EQUAL AVERAGE OIL-INFLOW PER CAVERN (MBD). ( ) = OUTFLOW (OIL)
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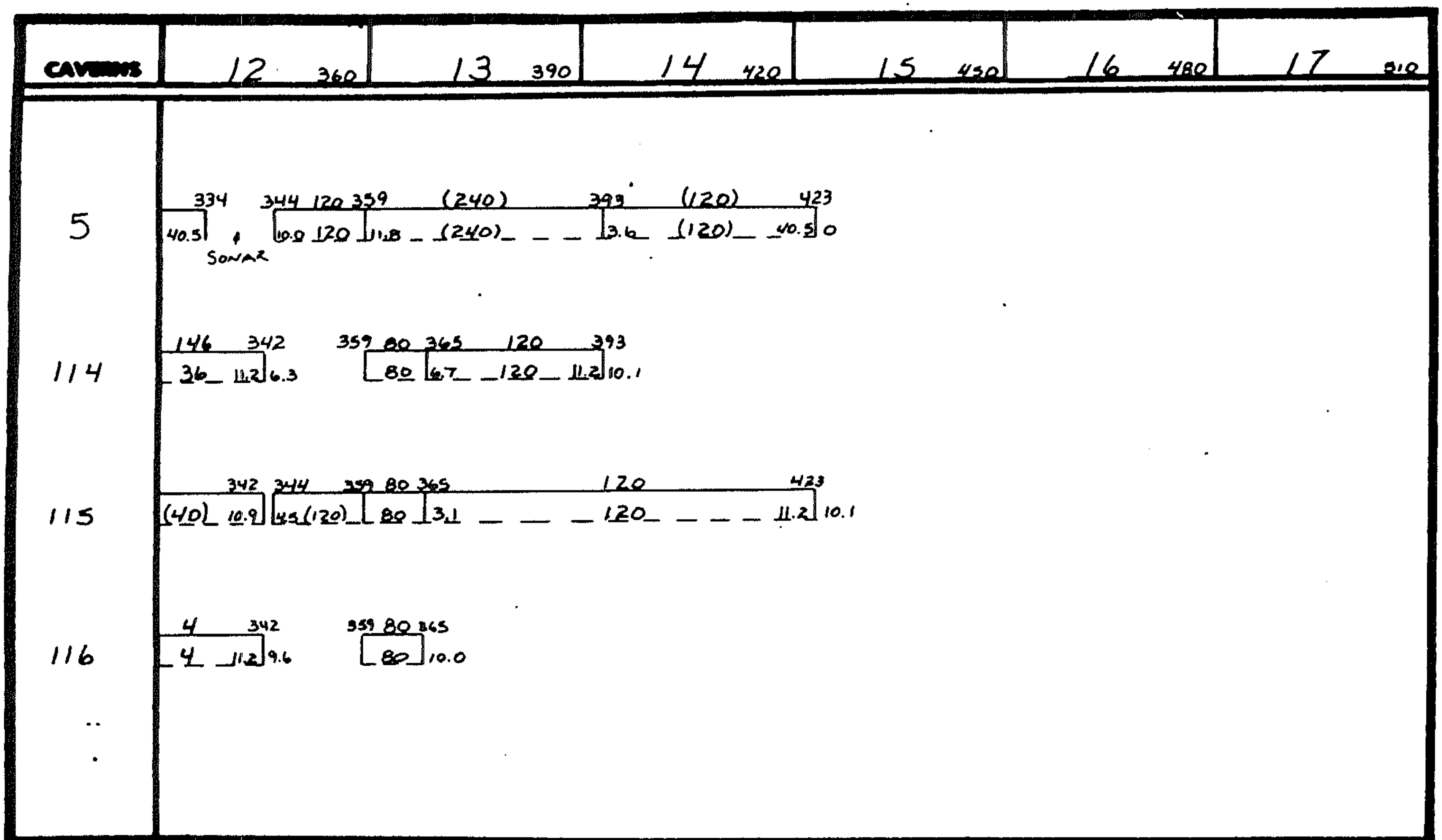
- OIL IS SWEET UNLESS OTHERWISE NOTED

BRYAN MOUND LEACH SCHEDULE



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- NUMBERS ABOVE DASHED LINES EQUAL AVERAGE OIL-INFLOW PER CAVERN (MBD). ( ) = OUTFLOW (OIL)
- NUMBERS AT RATE CHANGES AND WORKOVERS INDICATE CUMULATIVE CAVERN AND OIL VOLUMES, RESPECTIVELY, IN MMB. FOR EXAMPLE: (CAV.) 6.3 | 1.6 (OIL)

- OIL IS SWEET UNLESS OTHERWISE NOTED

CAVERN ACTIVITY

Month	Days to Recover Sour Ullage (1)	5	114	115	116
1	0	Inactive	Transfer sour to Phase II caverns. Use raw water for a part of the transfer as indicated on schedule		
2	16	Transfer sweet oil to Phase III with RW	Receive sweet	Finish sour removal Receive sweet	Finish sour removal Receive sweet
3	41	Transfer sweet	Start Leach/Fill with sweet	Receive sweet Cavern Volume 10.0 MM	Receive sweet Cavern Volume 10.8 MM
4	65	Transfer sweet	Continue Leach/Fill	Receive sweet	Receive sweet
5	(2) 95	Finish sweet transfer, Part 1	Leach/Fill	Receive sweet	Finish sweet fill, begin transfering 114, 115 w/RW
6	85	Workover for leaching	Leach/Fill	Receive sweet from 116	Transfer sweet with RW
7	85	Begin Leach with oil in upper lobe	Leach/Fill	Receive sweet	Transfer sweet, complete cavern
8	85	Leach	Leach/Fill	Transfer sweet w/RW to 114, 116	Receive sweet from 115
9	85	Leach, run sonar Cavern Volume 39.3 MM	Leach/Fill Cavern Volume 9.9 MM	Transfer sweet	Receive sweet
10	85	Leach	Leach/Fill	Transfer sweet	Receive sweet
11	85	Leach	Leach/Fill	Transfer sweet	Receive sweet
12	(3) 62	Finish leach, vol. 40.5 MM sonar receive sweet	Finish leach Configure for final fill	Transfer sweet Complete cavern	Receive sweet
13	32	Transfer sweet with brine	Receive sweet	Receive sweet	Finish sweet fill
14	2	Transfer sweet	Finish Final Fill	Receive sweet	Filled
15	0	Empty cavern	Filled	Finish final fill	Filled

(1) Time from end of month. Does not include time to workover 115 and 116 to reconfigure wells for leaching.
(2) Time extended for workover to return casing to original configuration.
(3) Less time required to complete program than to revert to original configuration. Time shown to complete program.

CC Lombard

sent 4/24/86

ENCLOSURE # 3

Tom - 9/4/ Please Copy Ken

April 15, 1986
5-0220-JHH-480

PB-KBB

CAVERN ENGINEERING

APR 24 1986

RETURN TO KEN ROUTE
FILE COPY

To: R. Sipe

cc: R. Girman
W. O'Connell
J. McEntire

Subject: Conversion of Cavern 5 to Sour Crude Storage

Reference: Letter, DOE PP-63: Rousseau, 86-007, dated February 10, 1986, subject: Bryan Mound Storage Configuration (ACTRAK No. 518)

The above cited reference proposed the subject conversion; it also described how the conversion could be accomplished and the benefits of the change in configuration. Comments were not solicited from the site, however this correspondence forwards some considerations that were not included in the reference.

A major consideration is whether or not there will be a sufficient demand for sweet crude to justify the costs associated with supplying 1.1 MMB/D. If the demand is not there, the only thing accomplished is an ability to say that we can drawdown and distribute that amount.

If the proposal is accepted, a major piping change would be required to make effective use of the conversion. The oil piping from the Phase III caverns is on the same mainline header as the Phase II, Group I, caverns. This common header will restrict movements from those groups and will create numerous interfacial mixtures for blending. Caverns 114, 115 and 116 are on a common line that enters the mainline header at the northwest corner of Cavern 110, where the "split tee" is located. If these three caverns are converted to sweet crude, then they could be tied into the Cavern 2 oil line, or another line could be constructed. The new line would parallel the recently commissioned, above ground thirty inch brine return line.

The ullage figures have changed since the reference was prepared. The sour crude could not be relocated from the Phase III caverns without the maximum use of the sumps in the Phase II caverns. This can be done, however the chances of "U Tubing" is ever present. When the sumps are reestablished and the crude is moved to Cavern 5, additional space will be created in the Phase II caverns unless brine is used for displacement. The use of brine has limitations such as volume restrictions and pressure limitations.

Subsequent to the release of the reference, oil was transferred from Cavern 5 to Cavern 4, using raw water. Preliminary surveys indicate that this transfer action may have removed some of the ledge that separates the lobes of Cavern 5. Since then, we have put over 500 thousand additional barrels of raw water into the cavern; we have not yet checked the results of this action. A sonar survey is tentatively scheduled on/or about April 22, 1986; it could provide the data needed for future determinations.

Another factor of consideration would be the elimination of oil receipts during the period of conversion. While current planning does not reflect crude oil deliveries at Bryan Mound in the near future; the site is a backup capability should conditions at West Hackberry affect that site's capability to receive the product.

The above is not meant to discredit the proposal; however, it seems that not all of the factors were considered when it was being formulated. It is recommended that it be studied in detail prior to the publishing of any decisions and schedules.

If additional information is required, contact the undersigned.

John H. Henderson

06/06/86 13:18 FCRSTL NO.017 001

DOE F 1325.7
(8-80)

Exception to SF 14, Approved by NARS, June 1978

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Office of Strategic Petroleum Reserve
Wash DC 20585

7. [signature]
(Signature of authorizing official)

8. DATE June 6, 1986

9. TO
John Milloway
Assistant Manager for SPR Project
Oak Ridge Operations Office
Oak Ridge, TN

John Wagoner
Project Manager
Strategic Petroleum Reserve
New Orleans, LA

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57

Department of Energy
Washington, DC 20585

JUN 6 1986

SPR PROJECT MANAGEMENT DIRECTIVE

TO: Assistant Manager for the SPR Project
Oak Ridge Operations Office

FROM: Director
Office of Strategic Petroleum Reserve

SUBJECT: BRYAN MOUND CAVERN STORAGE CONFIGURATION ENHANCEMENT

BACKGROUND

The Bryan Mound storage site is designed to have a storage capacity of 226 million barrels and a drawdown capability of 1,100,000 B/D. The storage site is currently configured to store 66 million barrels of sweet crude in four (4) industry-developed Phase I caverns and 160 million barrels of sour crude in sixteen (16) SPR-developed Phases II/III caverns.

Currently, the maximum combined drawdown rate capability for sweet crude oil is 840,000 B/D, less than the site's designed drawdown rate capability and less than the distribution rate capability (1,000,000 B/D) of the planned Bryan Mound-to-Texas City, Texas pipeline.

In addition, one of the sweet caverns, Cavern 5, contains 33 million barrels or 53 percent of the site's sweet crude, which presents a risk to the site's sweet crude drawdown capability should that cavern become unavailable for any reason during drawdown. Cavern 5 also contains a salt ledge which essentially divides the cavern into two chambers, creating an oil trap containing an estimated 1 million barrels of crude which would require nitrogen displacement for recovery.

A change in Bryan Mound's cavern storage configuration has been approved which would:

- o Increase the site's sweet crude oil drawdown rate capability from 840,000 B/D to the maximum design rate of 1,100,000 B/D;
- o Increase site reliability by increasing the number of sweet crude oil caverns from four (4) to six (6) for drawdown operations, i.e., reduce the site's vulnerability and risk associated with a single cavern failure;

- o Provide greater operational flexibility for distribution of sweet and sour crude oil to the Houston/Texas City area, i.e., the distribution rate of sweet crude by pipeline to that area would increase to 1,000,000 B/D, equal to the present sour crude rate; and

- o Make available for drawdown and distribution, 1 MMB of currently trapped oil in Cavern 5.

DIRECTION

ORO is directed to proceed with all necessary actions to enhance Bryan Mound's cavern storage configuration, by interchanging Cavern 5 and Caverns 114, 115 and 116 crude types, and to free the trapped oil in Cavern 5 by eliminating the salt ledge between the two Cavern 5 storage chambers.

To the extent possible, brine, rather than raw water, should be used as a medium to transfer the oil from Cavern 5 to Caverns 114, 115, and 116 to minimize further Cavern 5 growth and reduce development of a Cavern 5 oil/water emulsion.

SCHEDULE

The attached schedule provides for fifteen (15) months to complete the reconfiguration at Bryan Mound, with the commencement no later than July 1, 1986 and completion by September 30, 1987, not including oil fill of Cavern 5.

During the reconfiguration of Bryan Mound, the site shall maintain an operational readiness capability to return to a maximum oil fill mode within ninety (90) days should mandated SPR fill rates require such action.

FUNDING

The Bryan Mound storage configuration enhancement project, estimated to cost $10,000,000, shall be funded from existing contingency funds.

John W. Bartholomew

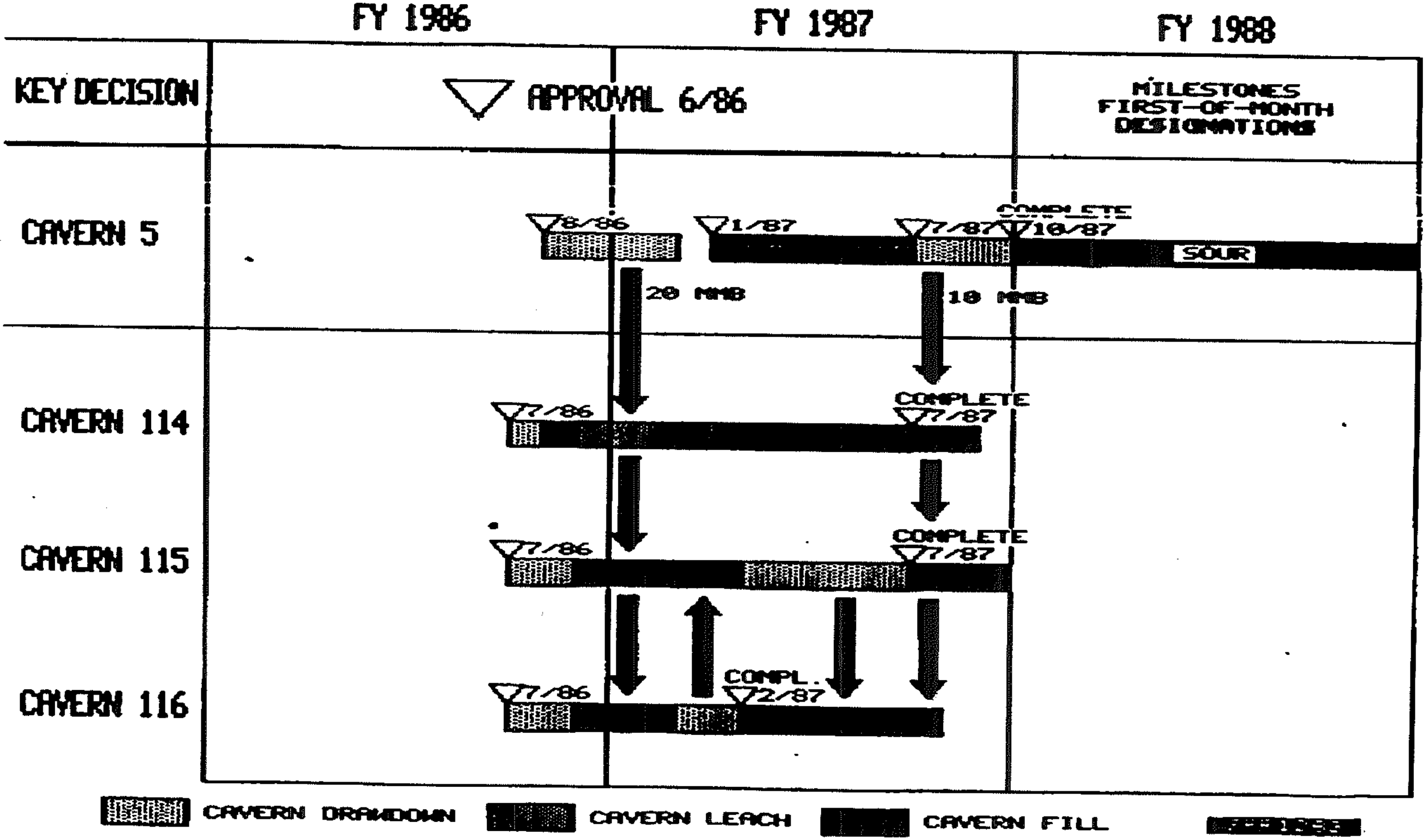
John W. Bartholomew

Attachment
Bryan Mound Cavern 5 Conversion Schedule

APPROVED: [signature] JUN 06 1986
Deputy Assistant Secretary for Petroleum Reserves

57

BRYAN MOUND CAVERN 5 CONVERSION SCHEDULE



Q001-P02

United States Government

Department of Energy

memorandum

Bartholomew, J. W. (1986). "Bryan Mound Configuration".

DATE: AUG 25 1986

REPLY TO ATTN OF: FE-421

SUBJECT: Bryan Mound Configuration

TO: Assistant Manager for SPR Project
Oak Ridge Operations Office

THRU: Deputy Assistant Secretary for Petroleum Reserves

A recent analysis of storage capacity development at Bryan Mound indicates that with completion of the Cavern 5 configuration enhancement, the site will possess sufficient storage capcity to achieve the planned 226 million barrels of fill. This means that no additional leaching of the other caverns at Bryan Mound is necessary to achieve this Level I requirement. While additional leaching of Caverns 113 and/or 114 would provide some advantages, as indicated by the attached issue paper such action is not considered to be of sufficient benefit to warrant the additional cost.

You are therefore directed to confine future capacity development at Bryan Mound to the minimum amount necessary to complete the Cavern 5 configuration enhancement/conversion project, i.e., Alternative C of the attached issue paper.

John W. Bartholomew
Director
Office of Strategic Petroleum Reserve

Attachment

cc: H. Borgstrom, FE-43
J. Wagoner, PR-61

Originator

0001-P03

August 25, 1986

STRATEGIC PETROLEUM RESERVE
ISSUE PAPER

ISSUE:

Should the Strategic Petroleum Reserve (SPR) continue the development of Cavern 113 and/or Cavern 114 at Bryan Mound beyond their current storage capacity?

BACKGROUND:

The Bryan Mound storage site is to be developed to a minimum ultimate storage capacity of 226 million barrels as specified in the Level I Criteria. Currently, the Bryan Mound site has completed the development of approximately 218 million barrels. SPR Project Management Directive PMD 86-2, dated June 6, 1986, authorized the Project Management Office to proceed with a cavern storage enhancement project, interchanging Cavern 5 and Caverns 114, 115 and 116 crude types. Under this project, the SPR would complete the development of Caverns 114, 115, and 116 and leach an additional capacity in Cavern 5 to dissolve the salt ledge and free the trapped oil.

On July 2, 1986, the President signed the Urgent Supplemental Appropriations Act which released $41.2 million that had been previously proposed for deferral for continued capacity development. On July 3, 1986, the SPR resumed storage cavern development at Bryan Mound and West Hackberry, including Bryan Mound Cavern 113. However, recent analysis indicates that the ultimate storage capacity requirement of 226 million barrels can be achieved without further development of Cavern 113.

ALTERNATIVES:

Alternative A: Complete leaching of Caverns 113 and 114 to planned capacity of 10 MMB each.

Alternative B: Terminate leaching of Cavern 113.

Alternative C: Terminate leaching on both Caverns 113 and 114; convert Cavern 113 to sweet storage.

DISCUSSION:

Alternative A: Under Alternative A, the SPR would complete leaching of Caverns 113 and 114 as planned. The final site configuration would be:

	Storage Capacity	Planned Fill	Remain Ullage
Sweet Caverns	64.4	64.4	0
Sour Caverns	173.4	161.6	11.8
Total	237.8	226.0	11.8

Advantages

- Provides a 5 percent site surge ullage (11.4 MMB) in case of a catastrophic cavern failure or interim storage requirements.
- Reduces crude oil storage requirement in Cavern 5.
- Reduces drawdown time for Cavern 5.

Disadvantages

- Expands site storage capability beyond Level I requirements, incurring additional cost.

Alternative B: Under Alternative B, the SPR would complete the cavern storage reconfiguration as planned, but terminate further leaching of Cavern 113. The final site configuration would be:

	Storage Capacity	Planned Fill	Remain Ullage
Sweet Caverns	64.4	64.4	0
Sour Caverns	169.4	161.6	7.8
Total	233.8	226.0	7.8

Advantages:

- Provides a 3.5 percent site surge ullage (7.8 MMB) in case of a catastrophic cavern failure or interim storage requirements.
- Reduces site development cost by $400,000 over Alternative A.
- Immediate availability of 3.5 MMB of additional sour crude storage.

Disadvantages:

- Expands site storage capability beyond Level I requirements, incurring additional cost.
- Cost would be greater than Alternative C.

Alternative C: Under Alternative C, the SPR would terminate further leaching of Cavern 113 and 114 and convert Cavern 113 to sweet storage. The final site configuration would be:

	Storage Capacity	Planned Fill	Remain Ullage
Sweet Caverns	67.4	66.0	1.4
Sour Caverns	163.4	160.0	3.4
Total	230.8	226.0	4.8

Advantages

o The site could meet Level I requirement of 66 MMB of sweet capacity and 160 MMB of sour capacity.

o Provides 2 percent site surge ullage in both sweet and sour capacity (4.8 MMB).

o No further leaching other than Cavern 5 would be required, saving an estimated $675,000 over Alternative A.

Disadvantages

o Cavern 5 inventory would be increased to approximately 36 MMB, making it the largest SPR cavern.

o Cavern 5 drawdown time would be increased, but would remain within criteria.

RECOMMENDATION:

Implement Alternative C which achieves the Level I requirements for storage capacity development at Bryan Mound at minimum cost and provides a 2 percent site surge ullage of 4.8 MMB.

CAVERN	Capacity
1	8,136
2	5,921
4	20,324
5	38,000
	72,381
101	10000
102	10000
103	10000
104	10000
105	10,000
106	11200
107	10,000
108	10,000
109	10,000
110	10000
111	10000
112	10000
	121,200
113	6529
114	7372
115	9384
116	10000
	33,285

TOTAL	226,866	
SWEET	67,666	(Phase III sweet)
SOUR	159,200	(Cav 5 sour)

√√ BC

Mills, K. E. (1986). "Conversion of Bryan Mound Cavern 5 from Sweet to Sour Service - summary". R. Girman, D. Guier, H. Lombard and L. Rousseau.

SUMMARY OF EVENTS

CONVERSION OF BRYAN MOUND CAVERN 5 FROM SWEET TO SOUR SERVICE

February 10, 1986:

Letter, DOE PP-63: Rousseau, 86-007, Subject: Bryan Mound Storage Configuration (ACTRAK No. 518) proposes conversion of Cavern BM-5 to sour service

April 15, 1985:

BPS Memo, J. Henderson to R. Sipe, identifies site piping changes needed if DOE proposal is accepted and implemented.

April 24, 1986:

BPS Memo, K. Mills to R. Girman, transmits 423-day schedule for conversion of Cavern 5 if directed by DOE, plus tabulation of activity durations and sour ullage recovery times in generic format; i.e., Month 1 through Month 15. Implicit assumption is that operational conditions will permit immediate implementation to begin, if and when DOE directive to do so is received by BPS.

June 6, 1986:

SPR Project Directive issued to implement program to convert Cavern BM-5 from sweet to sour service. Schedule of activities and milestone completion dates set for 15 month performance period commencing July 1, 1986.

June 15, 1986:

Revised Cavern BM-5 conversion scheduled developed for implementation; this schedule did not account for new oil receipts which would interfere with schedule performance.

June 6-30	: Leached 1.38 MMB volume, Phase III caverns : Internal site oil transfers to prepare for scheduled oil receipts
July 28	: Cavern 116 completed
July 1-31	: Oil receipts 1.23 MMB (sour) : Leached 2.15 MMB volume Phase III caverns

August 10	: Cavern 115 completed
August 26	: Bryan Mound site development completed; Cavern 113 designated to receive sweet oil
August 1-31	: Oil receipts 1.57 MMB (sour) : Leach 0.68 MMB volume, Phase III caverns
September 10	: Casings cut, Caverns 115 and 116
September 1-12	: Oil receipts 0.45 MMB (sour)
September 16	: Major drawdown of Caverns 115 and 116 initiated - initial oil volume 6.5 MMB
October 10,14	: Casings cut, Caverns 113 and 114; oil withdrawals from 115 and 116 stopped (6.0 MMB withdrawn)
October 16	: Major drawdown of Caverns 113 and 114 initiated - initial oil volume 5.4 MMB

SUMMARY:

Between June 6, 1986 when DOE directed implementation of the Cavern BM-5 conversion to sour service, and September 12, 1986 when oil deliveries of new oil to Bryan Mound were completed, 98 calendar days elapsed. During that 98 day period, it is estimated that 58 days of progress were achieved toward completion of the 423-day originally scheduled conversion of Cavern BM-5. That original schedule did not envision oil drawdown from Cavern 113 but did envision leach-to-completion of Cavern 114. That original generic schedule also did not allow specific time for scheduled site maintenance shutdowns or drawdown exercises, but did allow five months to leach out the trap in the bottom lobe of Cavern 5.

With scheduled site shutdowns for maintenance (2 weeks) and drawdown exercise (1 week), the scheduled completion of the Bryan Mound Cavern 5 conversion should be amended by 60 days to about October 12, 1987 which still provides five months for leaching out the trap in the bottom lobe. Since this provides for no contingency (i.e., unexpected events), it is recommended that the Milestone Date of September 30, 1987 be changed to November 15, 1987.

April 24, 1986
5-0285-HWL-479

To: R. Girman, EF-32

cc: D. Guier, PR-622.2
H. Lombard, EF-91
L. Rousseau, PR-63

Subject: Conversion of Bryan Mound Cavern 5 from Sweet to Sour Service

Attached as Enclosure 1 is a schedule of activities showing how the conversion of Bryan Mound Cavern 5 from sweet crude to sour crude service can be accomplished, if DOE should direct such an action.

Attached as Enclosure 2 is a table showing over time the actions occurring in each cavern together with the times required at each point to recover the sour ullage involved.

Enclosures 1 and 2 have been compiled at DOE request to serve as indications of capability and related impacts on overall oil fill capability over time in order to assist DOE in its deliberations over the desireability of converting Bryan Mound Cavern 5 from sweet to sour crude service and thus to enhance sweet crude drawdown capability, as recommended in a recent DOE project office study.

It has continually been emphasized that the enclosed data represents capability only and does not represent an indication on the part of BPS as MOM contractor that such an action would either be operationally desireable or cost-effective.

Enclosure 3 is a memo dated 4/15/86 from J. Henderson to R. Sipe discussing implications of the conversion of Bryan Mound 5 to sour service.

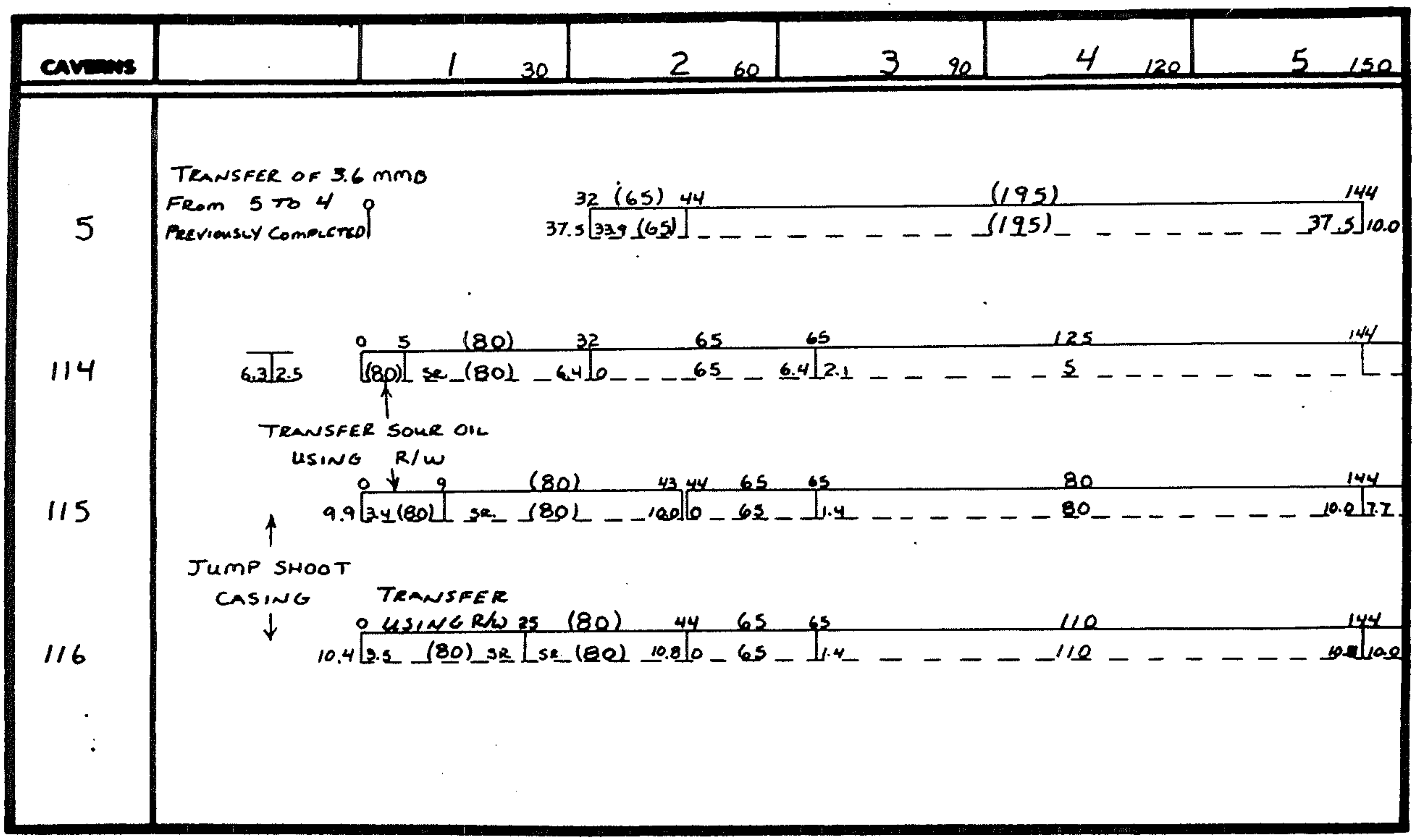
KEMills

K. E. Mills

Attachments

ENCLOSURE # 1

BRYAN MOUND LEACH SCHEDULE

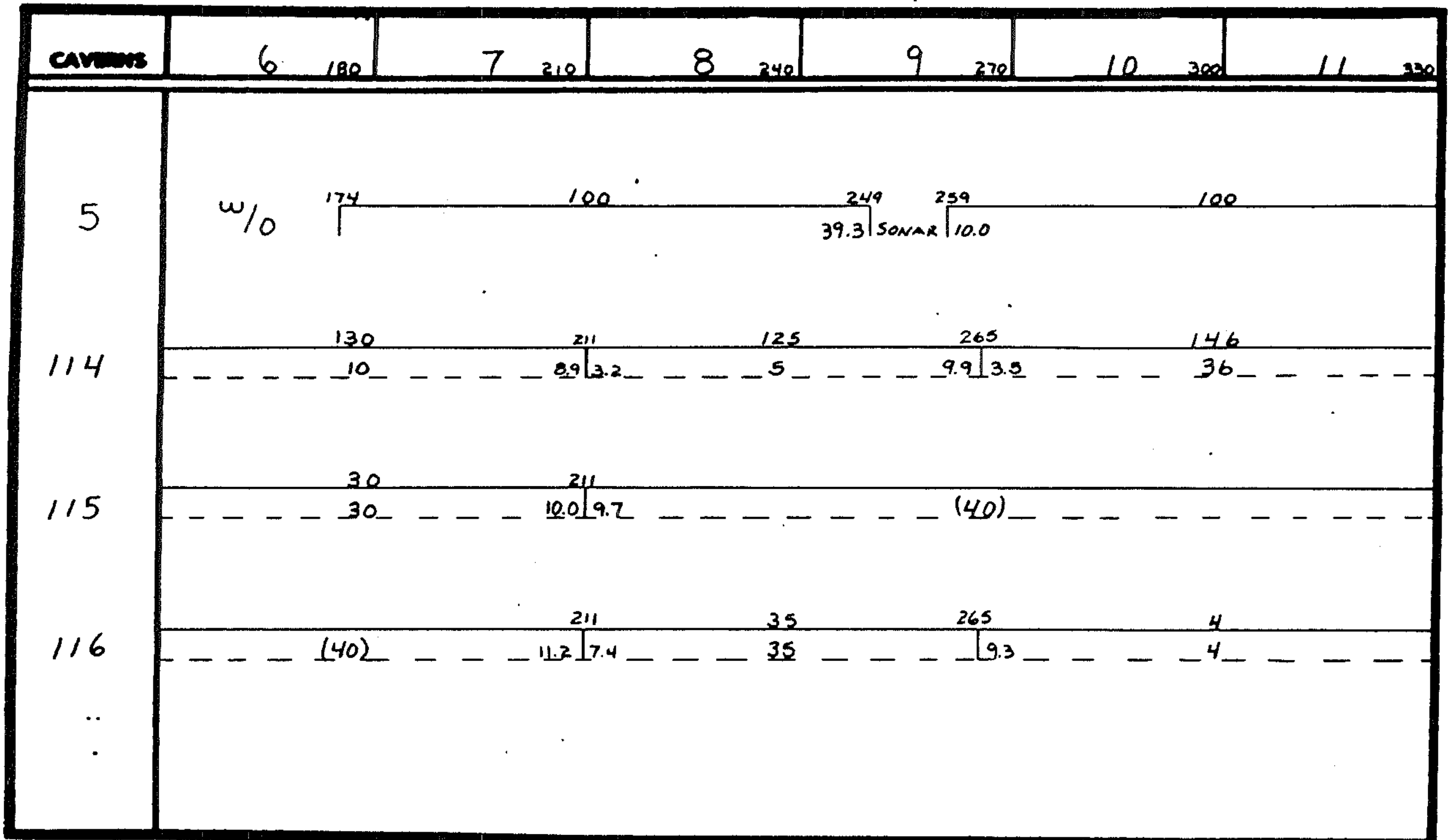


- **NUMBERS ABOVE SOLID LINES EQUAL AVERAGE BRINE-OUTFLOW PER CAVERN (MBD).** ( ) · INFLOW (BRINE)
- **NUMBERS ABOVE DASHED LINES EQUAL AVERAGE OIL-INFLOW PER CAVERN (MBD).** ( ) · OUTFLOW (OIL)
- **NUMBERS AT RATE CHANGES AND WORKOVERS INDICATE CUMULATIVE CAVERN AND OIL VOLUMES, RESPECTIVELY, IN MMB. FOR EXAMPLE:** **(CAV.) 6.3 | 1.6 (OIL)**

- OIL IS SWEET UNLESS OTHERWISE NOTED

4/24/86

BRYAN MOUND LEACH SCHEDULE



- NUMBERS ABOVE SOLID LINES EQUAL AVERAGE BRINE-OUTFLOW PER CAVERN (MBD). ( ) : INFLOW (BRINE)
- NUMBERS ABOVE DASHED LINES EQUAL AVERAGE OIL-INFLOW PER CAVERN (MBD). ( ) : OUTFLOW (OIL)
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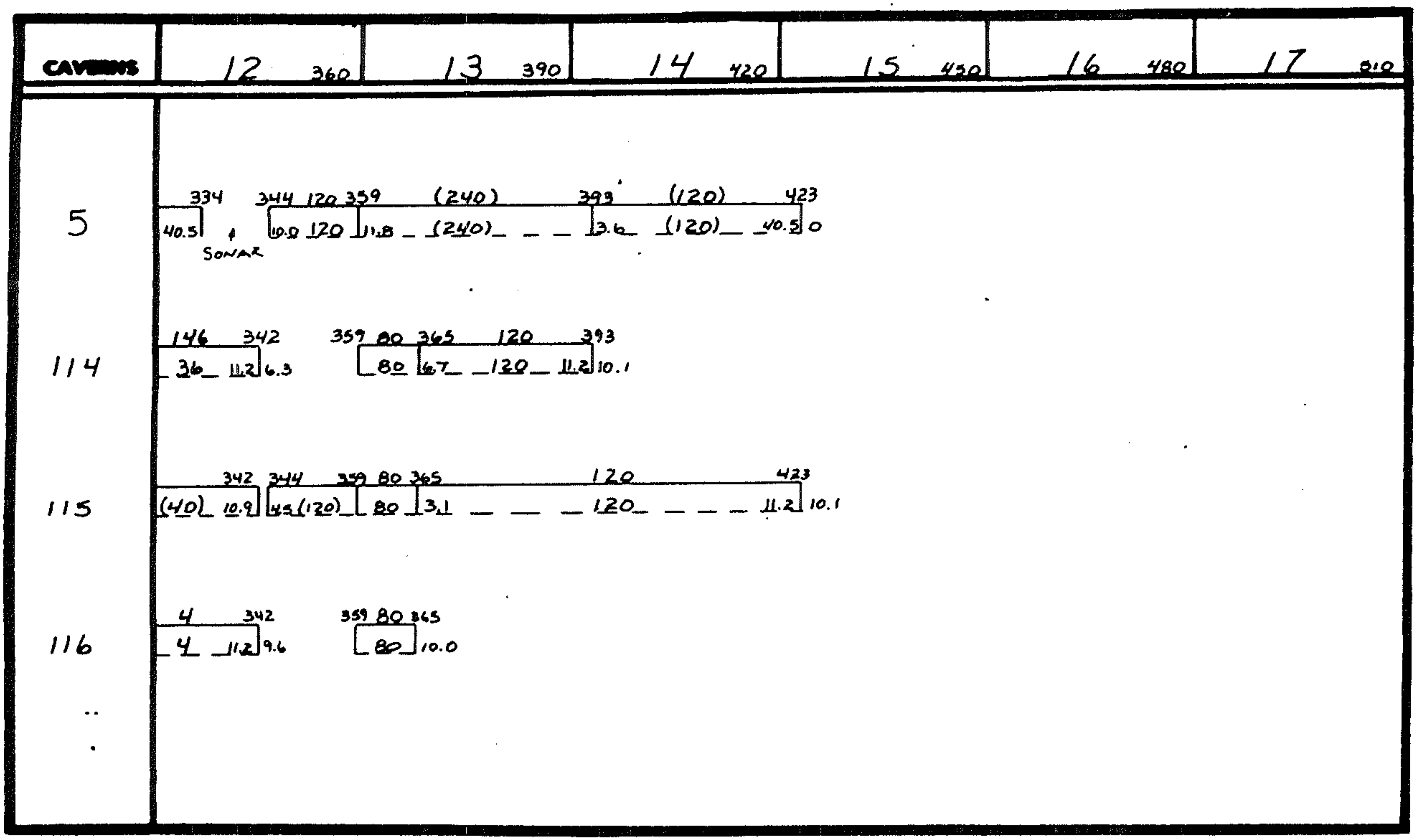
- OIL IS SWEET UNLESS OTHERWISE NOTED

4/24/86

BRYAN MOUND LEACH SCHEDULE



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- OIL IS SWEET UNLESS OTHERWISE NOTED

4/24/86

ENCLOSURE # 2

CAVERN ACTIVITY

Month	Days to Recover Sour Ullage (1)	5	114	115	116
1	0	Inactive	Transfer sour to Phase II caverns. Use raw water for a part of the transfer as indicated on schedule		
2	16	Transfer sweet oil to Phase III with RW	Receive sweet	Finish sour removal Receive sweet	Finish sour removal Receive sweet
3	41	Transfer sweet	Start Leach/Fill with sweet	Receive sweet Cavern Volume 10.0 MM	Receive sweet Cavern Volume 10.8 MM
4	65	Transfer sweet	Continue Leach/Fill	Receive sweet	Receive sweet
5	(2) 95	Finish sweet transfer, Part 1	Leach/Fill	Receive sweet	Finish sweet fill, begin transfering to 114, 115 w/RW
6	85	Workover for leaching	Leach/Fill	Receive sweet from 116	Transfer sweet with RW
7	85	Begin Leach with oil in upper lobe	Leach/Fill	Receive sweet	Transfer sweet, complete cavern
8	85	Leach	Leach/Fill	Transfer sweet w/RW to 114, 116	Receive sweet from 115
9	85	Leach, run sonar Cavern Volume 39.3 MM	Leach/Fill Cavern Volume 9.9 MM	Transfer sweet	Receive sweet
10	85	Leach	Leach/Fill	Transfer sweet	Receive sweet
11	85	Leach	Leach/Fill	Transfer sweet	Receive sweet
12	(3) 62	Finish leach, vol. 40.5 MM sonar receive sweet	Finish leach Configure for final fill	Transfer sweet Complete cavern	Receive sweet
13	32	Transfer sweet with brine	Receive sweet	Receive sweet	Finish sweet fill
14	2	Transfer sweet	Finish Final Fill	Receive sweet	Filled
15	0	Empty cavern	Filled	Finish final fill	Filled

(1) Time from end of month. Does not include time to workover 115 and 116 to reconfigure wells for leaching.
(2) Time extended for workover to return casing to original configuration.
(3) Less time required to complete program than to revert to original configuration. Time shown to complete program.

4/24/86

Kenzie, J.M. (1986). "Bryan Mound Sweet Crude Drawdown Enhancement Progress".

xc: W. O'Connell

PB-KBB Inc.
Subsurface Systems & Technology

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Houston, Texas 77079
P.O. Box 19672
Houston, Texas 77224
(713) 496-5590 - Telex #792539
Telecopy (713) 496-5658

October 20, 1986

TO: Tom Eyermann

FROM: Jeanne Mac Kenzie JM

SUBJECT: Bryan Mound Sweet Crude Drawdown Enhancement Progress

A schedule of leaching, sour drawdown and sweet transfer operations for the Bryan Mound Cavern 5 Conversion dated 6/15/86 was published as the guide for the necessary operations. (See Attachment 1)

The milestones* of that schedule are listed below:

(1) Leaching resumed 6/6/86 on Caverns 114, 115, and 116.

(2) Stop leaching 7/22/86 when Cavern 116 reaches the design volume of 11.2 MMB.

(3) Cut casing in "A" wells of Caverns 115 and 116 when Cavern 116 is complete. (7/22 - 7/25)

(4) Begin sour drawdown in Caverns 114, 115, and 116 on 7/25/86.

(5) Complete sour drawdown 9/25/86.

(6) Begin transfer of sweet 9/25/86 until 10 MBB remains in Cavern 5.

(7) Leach Cavern 114 to design volume.

(8) Leach 2.4 MMB of space in Cavern 5.

(9) Resume sweet transfer out of Cavern 5 to Caverns 114, 115, 116; complete by 8/8/86.

Since that 6/15/86 schedule, several significant events have occurred. On August 26, leaching was suspended which forced the addition of Cavern 113 to Caverns 114, 115, and 116 for sweet conversion. Also, throughout July, August and early September approximately 3.3 MMB of oil were received into the site forcing the Cavern 5 conversion to be delayed while the incoming oil was stored. Other conflicts caused deviations from the schedule:

(1) Extending the leaching of Cavern 115 to its design volume** through 8/11/86.

(2) Disagreement over the inclusion of Cavern 113 in the conversion.

(3) Operational constraints at site which included two of the four site oil storage tanks out of service for maintenance.

In response to the previously mentioned milestones, the following actual dates are given:

(1) Cavern 116 reached design volume 7/28/86.

(2) Casing cut in Caverns 115 and 116 on 9/10/86 in Cavern 113 on 10/10/86 and in Cavern 114 on 10/14/86.

(3) Initial oil removal from Caverns 115 and 116 began on 8/27 and 8/28/86. Oil removal, in earnest, began 9/16/86, averaging 105,000 bpd and continued through 10/15/86. Oil removal from Caverns 113 and 114 began on 10/15/86.

At this time, the conversion project is approximately 46 days behind the 6/15/86 schedule.

* Dates and volumes are approximate.
** Subsequent sonar survey showed cavern to be undersized.

JMK/llm

March 5, 1987
5-0200-JMM-930

To: J. Davis, EF-BM

cc: H. Andrews, EF-83
W. Bozzo, EF-83
E. Chapple, PR-63
T. Eyermann, EF-90
D. Guier, PR-622.2
G. Herzog, PR-83
J. Mac Kenzie, EF-90
W. O'Connell, EF-BM
N. Packard, DOE/BM
W. Pryor, EF-83
D. Williams, PR-641

Subject: Bryan Mound SPR Cavern 5 Leaching Operations Guide

Attached is the Bryan Mound SPR Cavern 5 Leaching Operations Guide.

R. A. Dyer

Attachment

U S DEPARTMENT OF ENERGY
STRATEGIC PETROLEUM RESERVE PROGRAM

BRYAN MOUND SPR CAVERN 5
LEACHING OPERATIONS GUIDE

Prepared for:

BOEING PETROLEUM SERVICES, INC.

Presented by:

PB-KBB Inc.
880 West Commerce
New Orleans, LA 70123
(504) 734-2600

February 1987

BRYAN MOUND CAVERN 5 LEACHING OPERATIONS GUIDE

1.0 INTRODUCTION AND BACKGROUND INFORMATION

On June 6, 1986 DOE approved a plan which would increase the sweet crude drawdown rate from 0.84 MMBD to 1.1 MMBD by transferring sweet crude from Cavern 5 into the Phase III caverns and converting Cavern 5 to sour crude storage. Two additional benefits of this program are that the trap in the roof of the lower lobe would be eliminated to release trapped sweet oil and that the neck connecting the upper and lower cavern lobes would be opened to allow a brine string to be run into the lower lobe through Well 5, with reduced risk of damage from salt falls. The plan would be accomplished by transferring the sweet crude from Cavern 5 to Caverns 4, 114, 115, and 116 (later amended to include Cavern 113). The process would be in five stages: 1) Transfer sweet oil from Cavern 5 to Cavern 4; 2) Transfer sour oil from the Phase III Caverns 113, 114, 115, and 116 to Phase II caverns; 3) Transfer remaining sweet oil in lower lobe of Cavern 5 to Caverns 114, 115, and 116; 4) Leach the region separating the upper and lower lobes of Cavern 5; and 5) Empty the sweet oil remaining in Cavern 5 into Caverns 113, 114, 115, and 116.

This guide outlines the steps necessary to perform step 4 of the plan. The leaching will consist of both oil removal with fresh water and, the more familiar method, fresh water injection with brine removal. Several sonar surveys of Cavern 5 will be run to monitor and assess the leaching progress.

2.0 Oil Removal with Fresh Water

When the oil/brine interface in Well 5 is approximately 2630', the sweet oil transfer will be interrupted. Then, the entire cavern from the oil/brine interface to T.D. will be examined by sonar surveys through each of the three wells. The first sonar survey will be through Well 5. Prior to running the sonar survey through Well 5C, the 9 5/8" casing should be cut at 2850'. The sonars should concentrate on the web between the lobes, provide angle shots from multiple stations, and a composite report of the cavern. A projection of leaching time required and possible changes in leaching strategy may result from the sonar information.

Oil will be transferred with raw water from Cavern 116 to Cavern 5 until the oil/brine interface in Well 5C is at 2840'. The transfer rate should be as high as possible to minimize the time involved. It is estimated from previous sonar surveys that the volume of oil to be transferred is 3.5 MMB.

When the transfer from Cavern 116 to Cavern 5 is completed, the oil movement will be reversed and the oil will be removed from Cavern 5 and transferred into Caverns 115 and 116. Fresh water will be injected into Wells 5 and 5C and the oil will be removed from Wells 5 and 5A. Again the transfer rate should be as high as possible to maximize leaching in the area of interest and will continue until the oil/brine interface in Well 5A is at 2633'.

After the interface in Well 5A has been established at 2633', locate the interface in Well 5C and then remove oil through Well 5C until the interface in Well 5C is between 2600' and 2300'. To maintain protection of the casing seat, it may be necessary to add oil to Well 5C and recheck the interface after one week of leaching. Before leaching starts, the 9 5/8" casing in Well 5C will be cut at approximately 2700'. If the brine piping modifications are not in place yet, fresh water will be injected thru Well 5C using the flush water line at a rate of about 60,000 BPD and the brine removed from Well 5. When the temporary brine piping is in place, fresh water will be injected at a rate of about 140,000 BPD through Well 5 and brine removed from Well 5C. Interface surveys will be run weekly through Well 5A to watch for the release of any trapped oil which will appear as a downward interface movement.

After 1.0 MMB of cavern space are created, sonar surveys will be run through Wells 5 and 5C and will concentrate on the floor of the upper lobe and the neck between the lobes. If the trapped oil has been released, leaching will be complete; however, if the web remains, additional leaching will be necessary.

3.0 Conclusion

The leaching of Cavern 5 is expected to be accomplished in approximately 130 days, including down time for interface and sonar surveys and additional casing cuts, if necessary. The leaching will be done in two stages, as outlined previously, with sonar surveys following each stage to assess the effects of the leaching. The leaching will enlarge the neck and release trapped oil from the roof of the lower lobe to avoid commingling when the cavern is filled with sour crude. Conversion of the Phase III caverns to sweet service will increase the sweet drawdown rate from 0.84 MMBD to 1.1 MMBD.

September 28, 1987
5-0282-BAB-87-1321

To: M. Berrigan EF-33

cc: S. Pavel EF-33
B. Girman EF-32
R. Smith EF-33
J. Smith EF-BM

Subject: Bryan Mound Cavern 5

As of September 11, 1987 the book inventory for Bryan Mound cavern 5 is 793,292 barrels. Since the cavern is physically empty, an adjustment to zero out cavern 5 is in order.

After thorough analysis of the cavern 5 fill and withdrawal history, we have concluded that the accuracy of measurement during the fill was reduced by the use of sonic meters as opposed to turbine meters used during the withdrawal.

During the withdrawal of cavern 5, the turbine meters were used to calculate the amount of oil transferred to the phase III caverns, therefore the quantity being measured is for that of cavern 5 only and is representative of what was in cavern 5.

During the fill, tank gauges were used and the oil was split streamed with other caverns, using the sonic meters to prorate the quantity shipped by tank gauges. With the accuracy of these sonic readings in question, it would be difficult to prorate the caverns with any degree of accuracy.

It is our conclusion that an adjustment should be made to add the remaining barrels in cavern 5 to caverns 1 and 4, which were split streamed with cavern 5 during the fill.

An example of the inventory adjustment DD250 has been sent to the accountability clerk at Bryan Mound for completion in FY87. The quantity used for the adjustment is in net barrels and the API gravity is the average of the gravities obtained during the withdrawal of cavern 5.

If you have any questions, please contact me at ext. 4284.

B. Boudreaux

B. Boudreaux

Attachments

Girman, R. (1988). "Cavern/Well5 Concerns".

August 12, 1988
5-0280-RCS-88-162

To:	J. Davis	5-0220	EF-BM
cc:	M. Berrigan	5-0282	EF-33
	R. Dyer	5-0200	EF-31
	T. Eyermann	5-0119	EF-90
	T. MacDonald	5-0220	EF-BM

Subject: Cavern/Well 5 Concerns

Reference: J. Davis Letter # 5-0220-JS-88-311, Dated August 5, 1988, Same Subject (Attached)

I share your concerns about the reliability of Cavern 5 during high injection rates and concur with your incentive to transfer sour crude from overfilled caverns to provide a contingency.

Crude Oil Programming and Accountability has provided additional alternatives and actions as follows:

A. Jones Creek tankage availability during critical peaks

B. Vessel charters allow Sun Marine Terminal as alternate receipt port for SPR deliveries.

C. Intense tracking of inbound cargos with increased reporting correspondence.

Coordination with Cavern Engineering has verified your plan and adjusted the oil movement table to reflect the transfers.

Please ensure complete coordination with other site activities that could affect or limit maximum oil injection rates.

R. Girman

Attachment:
As Stated

KEM FB-K53

CAVERN ENGINEERING

AUG 15 REC'D

RETURN TO ______ ROUTE

FILE COPY MS, KEM

Rent 8/15/88

AUG . 1988

August 5, 1988
5-0220-JS-88-311

To: R. Girman, EF-32

cc: R. Dyer, EF-31
T. L. MacDonald, EF-BM
Tom Eyerman, PBKBB, EF-90

Subject: Cavern/Well 5 Concerns

On August 4, 1988 it was determined that the Well 5 brine stringer had an approximately 5" indention in the 9 5/8" casing. The anomaly was probably caused by a salt fall from the upper lobe of Cavern 5.

From this day thru September 20, 1988, the site is scheduled to inject approximately 4.5 MMBD crude oil into Cavern 5. The withdrawal of such a large amount of brine in such a short period of time has become a major concern. The oil brine interface in Cavern 5 at present is located at approximately 2800' and the anomaly in the brine casing is at approximately 2676'. If a casing failure occurs during oil injection at high rates, large amounts of oil will be automatically transferred back to the site brine pond, before the injection can be stopped.

If this occurs brine return from Cavern 5 will be reduced by half, in turn reducing oil injection capability. As a contingency, the site has requested authority to remove 500,000 barrels of oil from Cavern 104 and injection of same into Cavern 5 prior to September 1, 1988. Also oil logistics has made arrangements for tank ullage at Phillips-Jones Creek Tank Farm during September. If a casing failure did occur, Cavern 104 and Jones Creek ullage will be sufficient to handle any on line receipts from ship terminals. Remaining scheduled receipts would be delayed from that time due to reduced injection rates to Cavern 5.

Due to the anomaly and the continuing fill requirements for Cavern 5 it is requested that all consideration be given to the scheduling, at the earliest possible date before September 1, 1988 of a workover of Cavern/Well 5 to eliminate the anomaly in the brine casing to preclude a failure of the casing.

J. P. Davis

Distribution

External Distribution

Electronic copies to:

Wayne Elias (wayne.elias@hq.doe.gov) for distribution to DOE SPR Program Office, 1000 Independence Ave. SW Washington, DC 20585

Diane Willard (diane.willard@spr.doe.gov) for distribution to DOE and DM SPR Project Management Office, 900 Commerce Road East New Orleans, LA 70123

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