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Addendum
Carnallitic Brine Conversion BAS-3

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2 Objective

This addendum has been prepared to consolidate the interpretations concerning the conversion to carnallitic brine that has been observed in cavern BAS-3 and to reconcile the current status of the cavern with the analyses of this case made in the study 'FRISIA Cavern Abandonment BAS-3 v.17 Final', issued on 24 December 2010.

To determine if the current situation poses increased risks or threats, particular emphasis will be placed on the differences between the abandonment study and the current situation in the BAS-3 cavern. The plan is to abandon the cavern at short notice and sidetrack the well to develop a replacement cavern at circa 500 m distance from the current cavern.

3 Background

Continuous leaching operations in cavern BAS-3 had to be stopped in January 2010 when a leak occurred in the 11 ¾" outer leaching string causing blanket diesel returns in the brine. The 7" leaching string broke off near the roof level of the cavern and became bent during the same event, precluding access to the cavern.

During operations to retrieve all diesel in preparation for abandonment of the well, the 13 3/8" x 11 ¾" annulus became blocked in October 2010, noting also pressure loss from this annulus that indicated a pinhole leak in the 13 3/8" casing. The blockage was suspected in the neck area near the roof of the cavern. Pump in – bleed off operations, also called 'Huff and Puff' (H&P) operations, were commenced in January 2011.

After prolonged and unsuccessful H&P operations to remove a suspected blockage in the 11 ¾" outer leaching string x open hole annulus of the neck area, increased background levels of Mg^{++} and K^{+} were observed in June to August 2011, as shown in figure 1. Due to a lack of progress with the H&P operations and the observed changes in brine quality it was decided to stop the operations and to start the abandonment of the cavern. At this stage bent leaching strings prevented access to the cavern.

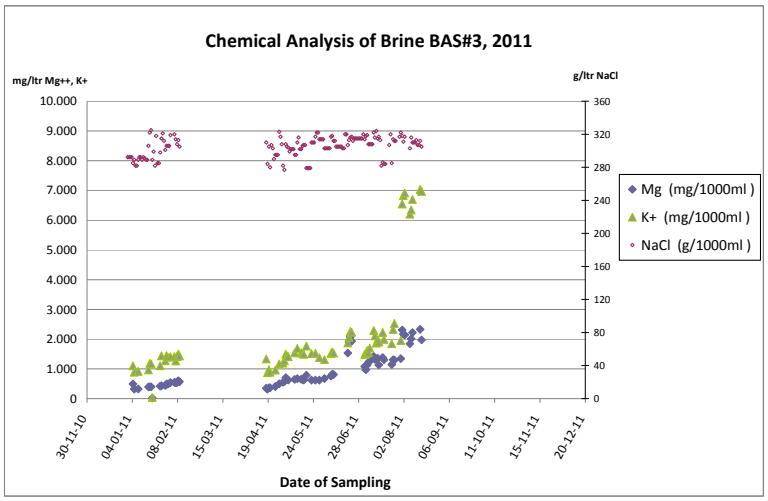


Figure 1: Development of brine composition during H&P operations

The 11 ¾" string was successfully cut with split shots just inside the 14" last cemented casing and dropped off into the cavern, see figure 4 for a well sketch. The cavern became accessible and an echo survey was made on 6 December 2011. This survey revealed that the cavern had progressed unintentionally to 3912 m ah, circa 6 m below the bottom of the carnallitic interval, as shown in figure 2.

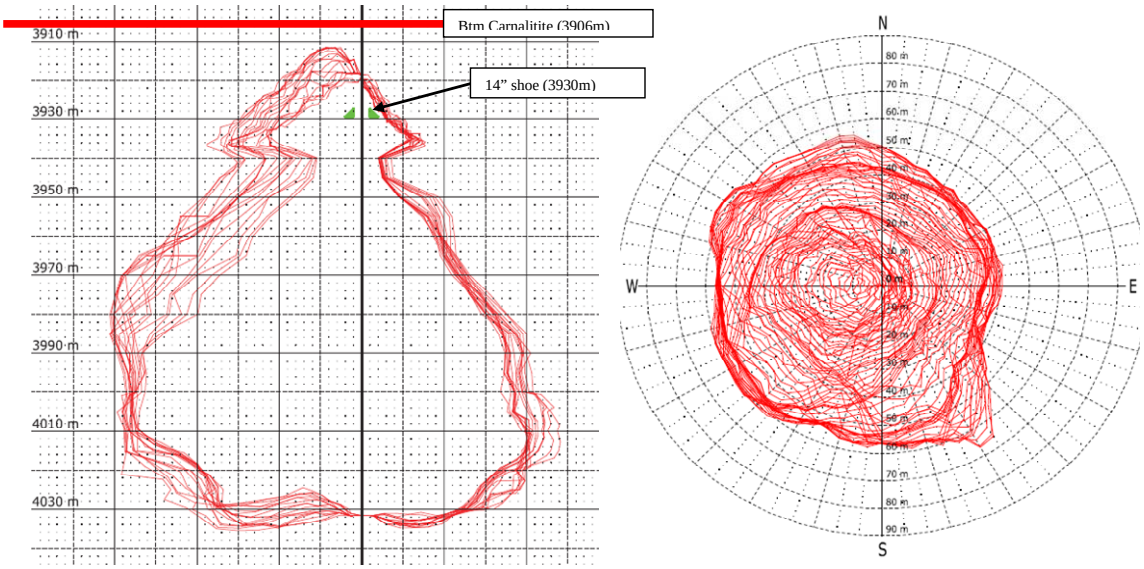


Figure 2: Echo survey results BAS-3 cavern in December 2011

When bleeding down the cavern in June 2012 in preparation for snubbing operations, carnallitic brine was observed. Brine with a specific gravity of 1.27 kg/l, containing 286 g/l $MgCl_2$, 65 g/l KCl and 27 g/l NaCl, was recovered from the well, after dilution.

Subsequent attempts to drop off more 11 ¾" casing string by making split shots at several positions in order to provide an adequate interval in the 14" casing for an abandonment plug were unsuccessful and a solid hold-up was encountered at 3908 m, circa 2 m below the bottom of the carnallitic layer. A video run in June 2012 showed a cut connection at 3865 m with a displacement of slightly more than the make-up length of the connection (ca 15 cm).

Figure 3: Video shot of the 11 ¾" connection at 3816 m

During the HWU intervention in July 2012 the 7” casing was removed from the well and an unsuccessful attempt was made to push the 11 ¾” section below 3865 m into the cavern. The HWU operation was suspended awaiting further abandonment operations. In figure 4 the current well situation is shown.

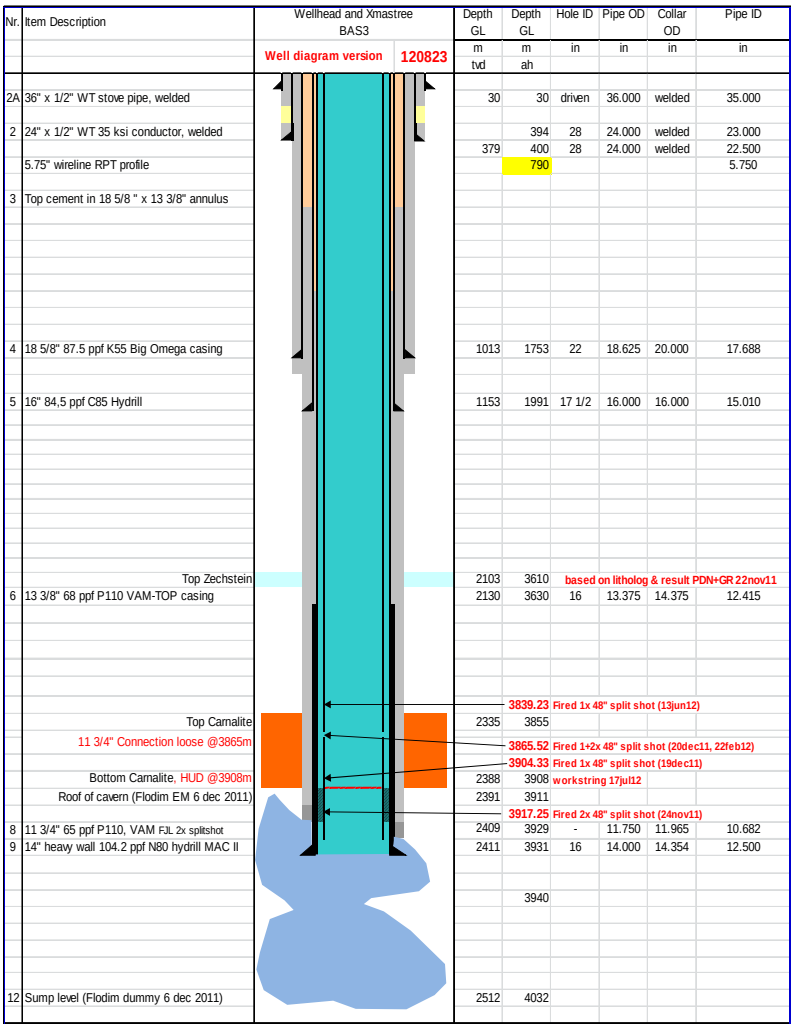


Figure 4: Sketch of BAS-3 as suspended in July 2012.

4 Analysis

In hindsight the changes in brine quality mid 2011 were the first signs of possible communication with the 51 m thick carnallitic interval from 3906 m ah (2386 m tv) to 3855 m ah (2335 m tv). The brine samples from June 2012 are representative for carnallitic brine resulting from extensive conversion of NaCl brine getting in contact with carnallite.

The result of conversion has been described in the Cavern Abandonment BAS-3 study. Scenarios have been detailed for carnallitite with 30% and 55% carnallite mineral. In the 30% case the biggest volume of rock is affected, resulting in effects furthest away from the BAS-3 NaCl cavern. The study refers to work of Grueschow providing information on the volumetric effects of NaCl brine dissolving 30% carnallitic rock, being a representative composition.

Volumenbilanz: Quinäres System; 85°C; 30% iger Carnallitit		m³	**Schütt-volumen** m³	**Poren-volumen** m³	**"Freie" Lösung** m³
Lösemittel (NaCl Solevolumen)		1,00			
aufgelöstes Carnallitgestein		3,53			
Kieserite:	10 %				
Carnallite:	30 %				
Sylvite:	0 %				
Halite:	53 %				
Insolubles:	7 %				
Summe		4,53			
Gleichgewichtslösung		2,09			1,05
Primärer Kieserit		0,27	0,38	0,11	
Primär+ Zersetzungs-Sylvin		0,22	0,30	0,09	
Primär und Kristallisierter Halit		1,92	2,69	0,77	
Unlösliches (Ton, Anhydrit)		0,18	0,25	0,07	
Summe		4,68	3,63	1,04	

Table 1: Volumetric effects of NaCl brine dissolving carnallitite with 30% carnallite in representative BAS-3 conditions (after Grueschow).

Table 1 shows that 1 m^3 of saturated NaCl brine affects 3.53 m^3 of 30% carnallite rock, resulting in 2.09 m^3 carnallitic brine and 2.59 m^3 residue. The bulked volume of the residue is 3.63 m^3 providing 1.04 m^3 pore volume. Hence, the free brine volume after conversion is 1.05 m^3 and the total net volume increase is 0.15 m^3 (3.3%).

The actual measure of conversion of the BAS-3 cavern content is difficult to determine. Conversion is expected to be a process that will take a considerable amount of time. As carnallitic rock dissolves, NaCl is precipitated which leads to blinding and poor access of the carnallite dissolution interfaces.

The low NaCl content of 27 g/l suggests that the brine that was bled off from BAS-3 in June 2012 was converted to a high degree to carnallitic brine. The s.g. of saturated carnallitic brine is of the order of 1.32 and one could expect that the entire cavern contents would have been converted due convection in the 1.2 s.g. NaCl brine. However, it is also known that inverted interfaces can exist, in which case only part of the cavern content has been converted. Since the cavern is presently inaccessible (hold-up depth at 3908 m ah) the actual cavern contents cannot be investigated.

The hard hold-up depth at 3908 m may indicate that significant deformation of the casing has taken place that may have been caused by roof instability. The separation at the split connection at 3865 m ah also indicates that there has existed significant tension at the point of the connection and hence significant sticking forces between the 11 ¾" and 14" casings below 3865 m.

While the 11 ¾" x 14" annulus was open the 11 ¾" casing was hanging free in the cavern. The separation at 3865 m cannot be explained by the tension that existed at that time. After the 11 ¾" x 14" annulus became plugged, tension may have been caused by cooling down of the well. However, another cause of tension in the 11 ¾" casing may have been instability of the cavern roof and the roof pulling down on the casing.

The worst case that results from this analysis is that the entire BAS-3 cavern volume of 450,000 m^3 converts fully to carnallitic brine, affecting ca 1.6 million m^3 of 30% carnallitic rock. Major collapse of the roof cannot be excluded.

This scenario has been fully addressed in the Cavern Abandonment BAS-3 study, in particular in chapters 3.6 and 4.5. The conclusion was that conversion to carnallitic brine and roof collapse would not lead to increased threats or risks. It was thought at the time of writing the study that this scenario might happen somewhere in the distant future because of gradual cavern roof degradation, long after the termination of leaching operations in the Barradeel and Barradeel II licenses. However, it is happening at this very moment, together with a plan to re-use the BAS-3 well for sidetracking and establishing and operating a new cavern at circa 500 m distance (ca 400 m wall to wall) from the abandoned BAS-3 cavern.

5 Consequences of worst case

Full conversion to carnallitic brine will affect circa 1.6 million m^3 of 30% carnallitic rock. With an average 40 m net thickness of the carnallitic layer and a radial progression of the carnallite dissolution front, carnallitic rock up to a distance of circa 115 m away from the BAS-3 well centre will be dissolved. Formation dips and variation in the carnallite thickness will cause an irregular dissolution front, resulting in a possibly larger distance of the dissolution front from the BAS-3 well.

The undercutting of the overlying Zechstein sequence by the conversion process is unlikely to lead to progressive deterioration, because the roof remains supported by bulked residue. However, if progressive instability nevertheless happens, the roof may migrate higher up in the overlying Zechstein. This case is discussed in the Cavern Abandonment study, chapter 4.5. Due to bulking effects the cavity fills itself completely with debris and the debris stabilizes the cavern before the top of the Zechstein is reached.

Progressive roof failure lowers the maximum lithostatic pressure in the top of the cavern. In the absence of other effects, this would accelerate the squeeze rate in the lower cavern sections. However, the debris from roof fall filling and stabilizing the bottom of the cavern and the higher carnallitic brine gradient lower the squeeze rate. Therefore, slower permeation and subsidence than in the case without roof collapse is expected.

6 Impact on BAS-3 abandonment

Progressive roof failure may damage the BAS-3 casing. The evidence of possible roof failure in the current condition of BAS-3 requires emphasis on the quality of the seal in the BAS-3 wellbore across the entire Zechstein salt section above the carnallitite.

In a separate working program the final abandonment of the BAS-3 current cavern with a HWU is described. With the HWU operation the 11 ¾" leaching string will be pulled out of hole and an abandonment plug will be set in the bottom of the well. See attachment 1 for the planned well situation after the abandonment.

The abandonment program has been adjusted with an extra mechanical barrier and by optimizing the cement placement technique to achieve high quality cement columns across the entire Zechstein section.

The presence of carnallitic brine may cause deterioration of regular cement. Therefore magnesium resistant cement types will be selected.

7 Impact on BAS-3-O sidetrack

The remaining open section of the BAS-3 well will be re-used for sidetracking and operating a new cavern BAS-3-O at circa 500 m distance from the abandoned BAS-3 cavern. The planned trajectory of the sidetrack is shown in attachment 2. The bottom of cavern BAS-3-O will be situated at circa 2800 m tv.

It is important that the dissolution front in the carnallitite layer above the abandoned cavern BAS-3 does not progress to the position of the BAS-3-O sidetracked well. In attachment 3 a structure map of the local Zechstein formation is given. Seismic information suggests that there are no dipping trends in the carnallitic interval favoring brine migration to BAS-3-O. Hence, the risk of drilling the sidetrack into lithostatically pressurized free-flowing brine in the carnallitic interval is considered negligible.

In the present situation of BAS-3 the subsidence caused by cavern convergence is practically the same as for the originally planned situation. Hence the treats for the BAS-3-O sidetracked well bore with respect to possible casing damage due to formation deformation are considered acceptably low.

8 Conclusion

Based on a re-evaluation of the report Cavern Abandonment BAS-3 v.17 Final, the current condition of cavern BAS-3 with likely carnallite conversion taking place does not result in new threats or unacceptable risks.

This conclusion is supported by K+S Corporate as the mother company of FRISIA Zout BV.

9 Approval

This addendum has been reviewed and approved by the following persons:

For WEP

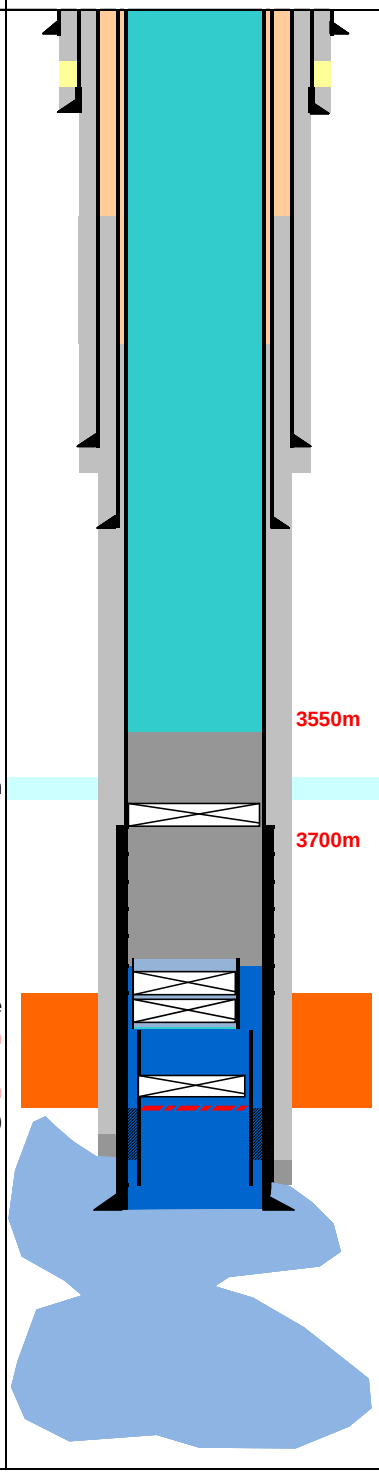
Director Technology General Director

For FRISIA

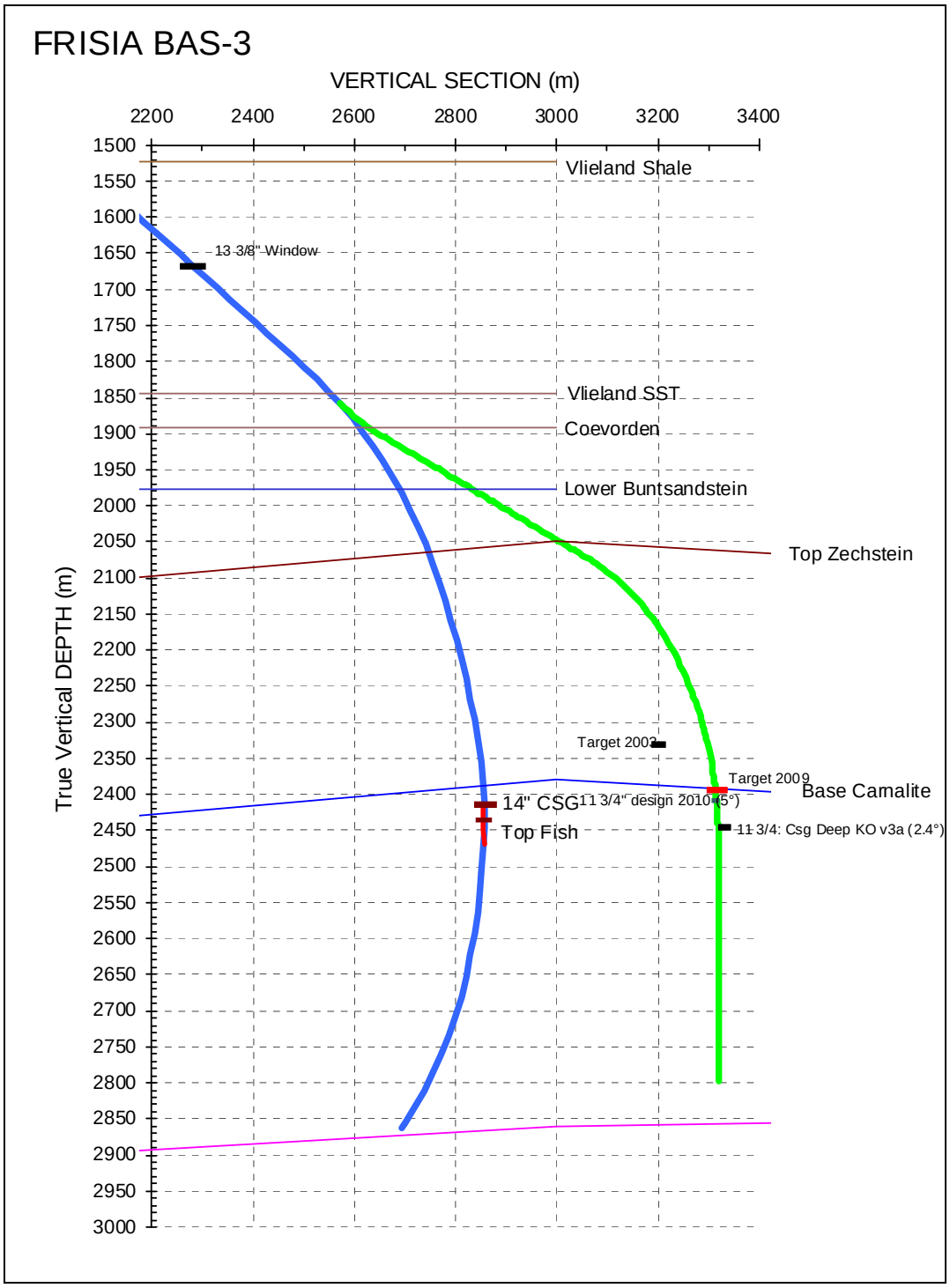
Head Mining Head Operations CEO

Attachment 1: BAS-3 Abandonment Sketch

Item Description	Wellhead and Xmastree BAS3 **Well diagram version** **Phase 2**	Depth GL m tvd	Depth GL m ah
36" x 1/2" WT stove pipe, welded		30	30
24" x 1/2" WT 35 ksi conductor, welded			394
		379	400
5.75" wireline RPT profile			790
Top cement in 18 5/8 " x 13 3/8" annulus			
18 5/8" 87.5 ppf K55 Big Omega casing		1013	1753
16" 84,5 ppf C85 Hydrill		1153	1991
	3550m		
Top Zechstein		2103	3610
13 3/8" 68 ppf P110 VAM-TOP casing		2130	3630
	3700m		
Top Carnalite		2335	3855
11 3/4" Connection loose @3865m			
Bottom Carnalite, HUD @3908m		2388	3908
Roof of cavern (Flodim EM 6 dec 2011)		2391	3911
11 3/4" 65 ppf P110, VAM FJL 2x splitshot		2409	3929
14" heavy wall 104.2 ppf N80 hydrill MAC II		2411	3931
			3940
Sump level (Flodim dummy 6 dec 2011)		2512	4032



Attachment 2: BAS-3-O sidetrack trajectory



Attachment 3: Structure map carnallitic interval