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Sandia National Laboratories
Waste Isolation Pilot Plant

Evaluation of the Duration of Direct Brine Release in WIPP Performance Assessment

Author:	Ross Kirkes (6711)	[signature]	4-26-07
	Print	Signature	Date
Technical Review:	Martin Nemer (6711)	[signature]	4-27-07
	Print	Signature	Date
Management Review:	Moo Y. Lee (6711)	[signature]	4/26/07
	Print	Signature	Date
QA Review:	Janis Trone (6710)	Mario Chavez for	4/27/07
	Print	Signature	Date

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Glossary

Direct Brine Release: Direct brine release (DBR) is the release of brine containing actinides that flows from waste panels up a borehole to the surface during drilling or shortly after drilling in WIPP disturbed performance scenarios.

Kick: A flow of reservoir fluids (or gas) into the wellbore during drilling operations. The kick is physically caused by the pressure in the wellbore being less than that of the formation fluids, thus causing flow. This condition of lower wellbore pressure than the formation is caused in two ways. First, if the mud weight is too low, then the hydrostatic pressure exerted on the formation by the fluid column may be insufficient to hold the formation fluid in the formation. This can happen if the mud density is suddenly lightened or does not meet initial specifications, or if a drilled formation has a higher pressure than anticipated. This type of kick might be called an underbalanced kick.

Killing a well: To stop a well from flowing or having the ability to flow into the wellbore. Kill procedures typically involve circulating reservoir fluids out of the wellbore or pumping higher density mud into the wellbore, or both. In the case of an induced kick, where the mud density is sufficient to kill the well but the reservoir has flowed as a result of pipe movement, the driller must circulate the influx out of the wellbore. In the case of an underbalanced kick, the driller must circulate the influx out and increase the density of the drilling fluid.

Kill-weight fluids: A mud whose density is high enough to produce a hydrostatic pressure at the point of influx in a wellbore that stops formation flow into the wellbore. Kill-weight mud, when needed, must be available quickly to avoid loss of control of the well or a blowout. Thus, it is usually made by weighting up some of the mud in the system or in storage by adding barite or hematite.

Mud: A term that is generally synonymous with drilling fluid and that encompasses most fluids used in hydrocarbon drilling operations, especially fluids that contain significant amounts of suspended solids, emulsified water or oil. Mud includes all types of water-base, oil-base and synthetic-base drilling fluids. Drill-in, completion and workover fluids are sometimes called muds, although a fluid that is essentially free of solids is not strictly considered mud.

Mud pit: A large tank that holds drilling fluid on the rig or at a mud-mixing plant. For land rigs, most mud pits are rectangular steel construction, with partitions that hold about 200 barrels each. Earthen pits are used to store used or waste mud and cuttings, or used to contain emergency overflow fluid in the case of a brine blowout.

Mud weight: The mass per unit volume of a drilling fluid, synonymous with mud density. Weight is typically reported in pounds per gallon (lb/gal or ppg) or specific gravity or SG). Mud weight controls hydrostatic pressure in a wellbore and prevents unwanted flow into the well. The weight of the mud also prevents collapse of casing and the openhole.

Swab: To reduce pressure in a wellbore by moving pipe, wireline tools or rubber-cupped seals up the wellbore. If the pressure is reduced sufficiently, reservoir fluids may flow into the wellbore and towards the surface. Swabbing is generally considered harmful in drilling operations, because it can lead to kicks and wellbore stability problems. In production operations, however, the term is used to describe how the flow of reservoir hydrocarbons is initiated in some completed wells.

Tripping: The act of pulling the drillstring out of the hole or replacing it in the hole. A pipe trip is usually done because the bit has dulled or has otherwise ceased to drill efficiently and must be replaced.

Wait and Weight: A pressure control procedure used to control a well that has encountered abnormal or unexpected pressure. In this method, the well is shut in while the mud density is increased to the kill weight, and then circulated until the pressure has been overcome or balanced.

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1 Introduction:

This analysis reports the results of selected activities described in AP-131, "Analysis Plan for the Modification of the Waste Shear Strength and Direct Brine Release Parameters," (Kirkes and Herrick, 2006). Specifically, this report contains the results of activities 1 through 4 of Table 1 in AP-131, which pertain only to the modification of Direct Brine Release (DBR) parameters. These tasks are identified below in Table 1. Note that activities relating to waste shear strength parameters are not addressed in this report. Furthermore, activities 5 and 6 (identified in Table 1 below) will be addressed in a subsequent Analysis Report documenting the impacts (if any) of implementing the change(s) suggested in the DBR parameter, MAXFLOW.

Table 1: Task List and Estimated Schedule for Direct Brine Release Changes.

Task	Description
1	Request new data from WRES (Update of Leonard, 1996)
2	Re-evaluate supporting documentation in parameter records package 231034 for DBR MINFLOW and MAXFLOW[1]
3	Document results of information review for DBR in Parameter Justification Report
4	Implement NP 9-2 for MINFLOW and MAXFLOW
5	Perform impact analysis using DBR_BRAGFLO
6	Document results of DBR_BRAGFLO impact analysis in final analysis report

(Modified from Kirkes and Herrick, [2006])

2 Duration of DBR in WIPP Performance Assessment

Direct brine releases (DBR) are releases of contaminated brine originating in the repository and flowing up an intrusion borehole during the period of drilling. In order for DBR to occur, two criteria must be met (Stoelzel and O'Brien, 1996).

1. Volume averaged pressure in the vicinity of the repository encountered by drilling must exceed drilling mud hydrostatic pressure (assumed to be 8 megapascals [MPa]).

2. Brine saturation in the repository must exceed the residual saturation of the waste material (Sampled from a uniform distribution ranging from 0.0 to 0.552).

If both of these criteria are met, DBR is calculated using the code BRAGFLO with a two dimensional, semi-horizontally oriented grid, which represents the vicinity of the waste panels. If either of these conditions is not satisfied, no DBR is calculated (Stein et al., 2005).

If these conditions are present, the current model is constrained to flow for at least 3 days (represented in BRAGFLO as the parameter MINFLOW), or for as long as 11 days (represented in BRAGFLO as the parameter MAXFLOW). Between these two limiting values, flow may continue until either of the two conditions cease to be met, or until the flow rate drops below 100 thousand cubic feet per day (Stoelzel and O'Brien 1996). Stoelzel and O'Brien state that this flow rate is low enough that a driller could easily regain control at this point. This analysis has made no attempt to modify this cut-off flow rate. Instead the focus has been on the 11-day maximum duration, which is based on a catastrophic blowout at the South Culebra Bluff #1 in 1978.

3 Justification of Minimum and Maximum Durations for DBR

This section will address Tasks 1 and 2 from Table 1 of AP-131.

Most assumptions used in the DBR model are based on current drilling practices in the Delaware Basin, as directed by WIPP regulations. The wellbore model description assumes a typical WIPP-area oil or gas well completion, including bit size, casing size and depths, drilling mud, etc. The duration of flow is based on how a present-day driller might react to the pressures and flows predicted by the model when encountering high pressure.

Currently, DBRs are assumed to take place over a relatively short period of time (i.e., 3 to 11 days) following the drilling intrusion. The minimum duration for DBR (MINFLOW) is currently set at 3 days, and is based on the time required to continue drilling beyond the repository depth of 2,150 ft until the intermediate casing string is set and cemented, effectively isolating the repository from other units. This value is based on information taken from a regional driller's survey conducted in 1996, as reported by Westinghouse Electric and the Delaware Basin Monitoring Program (Leonard, 1996). This minimum duration of 3 days applies to a brine flow from the repository that is not sufficient to impede or delay drilling, casing, and cementing activities. The driller may not notice such a flow, and mitigating actions may not be taken as a result. It should be noted that a duration of 3 days is also consistent with recommendations by the EPA (1996), where they state in the Background Information Document (BID) for the 40 CFR 194 Certification Criteria, Section 9.3.1.2:

> *"...It is estimated that this critical section of a borehole would remain uncased for no more than three days during drilling."*

The Delaware Basin Monitoring Program has re-evaluated information provided by Leonard (1996) in order to evaluate if the 3-day limit should be modified. This new information continues to support the values provided in 1996 (Kouba, 2007). Therefore, the minimum duration for DBR is appropriate and should not be revised from the current value of 3 days. This information satisfies Task 1 identified above in Table 1.

The review of supporting documentation in parameter records package 231034 for DBR parameters MINFLOW and MAXFLOW shows that the maximum duration for DBR (MAXFLOW) is currently set at 11 days, and is based on a worst-case gas well blowout incident that occurred in 1978 at the South Culebra Bluff #1. This maximum value is justified in a memo from Dan Stoelzel to Mel Marietta (Stoelzel, 1996). Stoelzel states that the Westinghouse recommendation is specifically targeted at brine flows and does not mention unexpected gas encounters in the WIPP horizon, inferring that a gas flow from the WIPP horizon would be treated differently than a brine flow. Stoelzel therefore bases the selection of the 11-day maximum duration on the blowout and subsequent fire that occurred at the South Culebra Bluff Unit #1, in 1978. This blowout occurred while drilling in the Atoka Formation, at a depth of 11,769 feet below ground surface (bgs) (more than 9,000 feet below the WIPP repository).

3.1 Investigation of the South Culebra Bluff Blowout as an Appropriate WIPP Analog

Stoelzel cites a draft SAND report (Boak et al., 1996) as justification for the selection of this well blowout as a suitable upper bound for the maximum duration of DBR. Subsequently, however, the draft SAND report was finalized (Boak et al., 1997), and clearly states that blowouts from brine-bearing zones are not suitable analogues to blowouts from typical gas-producing zones:

> *"Note that a blowout in a pressurized brine formation is not an accurate analogy to a blowout in a gas formation."*

Based on this statement, one can assume that the reverse is also true: A blowout from a pressurized gas zone is not an accurate analogy to a blowout from a pressurized brine zone.

One additional point should be made about statements made in Boak et al. (1997) relative to the maximum duration of DBR. The primary purpose of this study as stated in its Executive Summary was to evaluate and document

> *"...cases in which petroleum wellbores were enlarged beyond the nominal bit size (hole diameter) as a consequence of erosion from a blowout during drilling."*

It is in this context that co-author D. Powers states on page A-6:

> *"In summary, the South Culebra Bluff #1 well may be the best single analog available to WIPP."*

This statement has been construed as suggesting that the South Culebra Bluff blowout is the best available analog for the maximum duration of DBR. The following points illustrate that characteristics of the South Culebra Bluff blowout are different from what a driller would encounter from a pressurized WIPP repository.

1) The South Culebra Bluff blowout originates from the Atoka Formation (11,769 ft bgs). Formation pressures from this depth would be significantly higher than any pressure possible in the WIPP horizon. It is commonly understood that deeper units have higher pressures. Drilling experience in the WIPP area shows that shallow blowouts are very rare (Kirkes, 2007a).

2) The South Culebra Bluff blowout lasted 11 days because it was on fire. Special well-fire experts were flown in and several days elapsed before the requisite resources (human and material) were staged at the location to extinguish the fire. Gas flows from the WIPP repository would be at a considerably lower pressure, thus easier to control. Loss of control due to very high pressure and subsequent hardware failure at the South Culebra Bluff #1 allowed circumstances to deteriorate until the uncontrolled flow to the surface ignited.

The two characteristics above differentiate the South Culebra Bluff blowout from a hypothetical blowout at the WIPP at some time in the future. First, the reservoir properties of the Atoka gas zone and the WIPP are dramatically different. The Atoka is a prolific gas reservoir that has been highly produced over 30 years. In fact, the South Culebra Bluff well flowed initially at 50 million cubic feet per day and flowed a total of approximately four billion cubic feet of gas over a five month period that ended in June 1978 (Boak, et al. 1997). In contrast, the maximum predicted DBR from the WIPP is approximately 70 m^3 over 11 days (Stein et al., 2005). Such a small volume of brine flowing from the WIPP is miniscule when compared to the high volume flow from the South Culebra Bluff blowout (50 million cubic feet per day) (Stoelzel, 1996). The Atoka at the location of the South Culebra Bluff well appears to have a far greater production potential and ability to cause a loss of well control than a postulated pressurized WIPP repository. Finally, the maximum WIPP predicted DBR of 70 m^3 (over 11 days) is quite insignificant compared to the mud pumping volumes during normal operations. That is, normal pumping rates used while drilling the WIPP interval are 400 gallons per minute, or 2,140 m^3/day (Kirkes, 2007a). Seventy cubic meters of total flow from the WIPP would not present any alarm or hindrance to drilling. In fact, it is unlikely that such a flow would be noticed at all.

Second, because of the highly pressurized zone in the Atoka, hardware components and safety systems failed, allowing the high pressure gas to flow uncontrolled. The high-pressure gas flowing to the surface ignited, and the conditions were so dangerous that blowout experts from Houston, Texas were dispatched. After days of staging equipment and preparation, the well was extinguished by using high explosives to blow off the damaged blow-out preventer (BOP), which also blew out the fire. Clearly, the dangerous conditions of this burning well prolonged the duration of the blowout.

Using the South Culebra Bluff blowout as justification for the maximum duration for DBR in WIPP performance models is clearly bounding. No reasonable WIPP drilling scenario could envision a more catastrophic or longer-lived event. However, bounding the maximum flow (as implemented by the MAXFLOW parameter) on this occurrence is not in keeping with regulatory guidance (EPA, 1996) which states that the borehole should be assumed to remain uncased for no more than three days during drilling. It is the conclusion of this analysis that a maximum duration of 11 days should be modified in consideration of additional information and further investigation into the original basis in a way that more accurately represents the expected conditions of the WIPP repository upon intrusion. This conclusion completes Task 2 from Table 1 above.

The remainder of this analysis investigates how a driller would treat an over-pressurized brine (or gas) flow from the WIPP horizon, and will apply this information to determine a suitable and justifiable maximum flow duration for DBR (MAXFLOW).

4 Drilling Measures Taken to Control High Pressure Zones

To determine what measures would be taken should an over-pressurized zone be encountered while drilling the WIPP interval, interviews have been conducted with drilling personnel that have experience in the vicinity of WIPP. Prior to submittal of the Compliance Certification Application (CCA), a survey of drillers was conducted by Westinghouse Electric Company and reported in Leonard (1996). Drilling procedures typical of the area are also presented in CCA Appendix DEL (DOE, 1996). More recently, interviews were conducted with area drillers and mud engineers to determine if activities and procedures have changed since those reported previously (Kirkes 2007a, 2007b).

4.1 Hypothetical Maximum Pressure in the Salado Formation

Questions posed to professionals in the drilling industry were based on predicted maximum pressures in the repository at the time of intrusion (Leonard, 1996). In the WIPP repository model, it is assumed that the repository pressure cannot exceed lithostatic pressure (See Section 2.2.1.3 of DOE, 1996), which is 14.8 MPa (2,149 psi) at WIPP depth of 2,150 ft (Stone, 1997). This assumption is based on the fact that the host rock will fracture at this pressure (if not below), thus creating additional repository volume, effectively limiting repository pressure to this maximum level. Allowing fracturing to occur at repository pressures near lithostatic is fundamental in the WIPP repository model. Should pressures drop due to leaking borehole plugs (from a previous intrusion), a subsequent intrusion, or by some other mechanism, fractures created by high pressures may close. WIPP models allow this phenomenon to occur and reoccur, if warranted by conditions in the repository over the modeled performance period. This assumption is important to the DBR model in that repository pressure provides an upper bound to one of the most influential conditions in DBR. The DBR model receives repository pressure and saturation values from BRAGFLO. Therefore, questions posed to drilling personnel are based on the premise that the maximum repository pressures possible are near lithostatic.

4.2 Dealing with a Gas Kick or Blowout

According to Grace (2003), kick or blowout may result from one of the following:

1. Mud weight less than formation pore pressure
2. Failure to keep the hole full while tripping
3. Swabbing while tripping
4. Lost circulation
5. Mud cut by gas, water, or oil

The hypothetical WIPP blowout would occur due to insufficient mud weight relative to the formation (or repository, in this case) pressure.

Typical drilling practice in the area near WIPP is to use a 10 lb/gal brine "mud" (Leonard, 1996). A mud of this weight would exert 1,118 psi (7.7 MPa) hydrostatic force at repository depth of 2,150 feet (Stoelzel and O'Brien, 1996). At a maximum repository pressure of 14.8 MPa (2,149 psi), brine would flow from the repository into the drilling mud, as the mud would not be heavy enough to keep formation fluids (in this case, repository fluids) in zone. Should mud returns be significant enough to create a problem, the driller would shut in the well, using the method known as "wait and weight." (Grace, 2003) Using the wait and weight method, a driller shuts in the well, and monitors the "shut-in drill pipe pressure" (SIDPP), while mixing a heavy mud sufficient to "kill" the flow. In this case, assuming a maximum repository pressure of 14.8 MPa (2,149 psi), the SIDPP would be approximately 1,031 psi (2,149 psi minus hydrostatic load of 10 lb/gal brine (1,118)).

The following calculation shows that a kill weight mud of 19.22 lb/gal is required:

(SIDPP ÷ 0.052 ÷ True Vertical Depth) + Present Mud Weight = Mud Kill Weight

Or

(1,031 psi ÷ 0.052[1] ÷ 2,150 ft) + 10 lb/gal = **19.22 lb/gal**

Area drillers indicate that mud additives necessary to mix a mud of this density are usually on hand at the rig location, especially if the area is known to possess over-pressurized zones (Kirkes, 2007a). However, if such materials are not on hand, a service company would be called to deliver the proper materials. Problematic brine flows that cause a cessation of drilling activities are not common in the WIPP vicinity (Leonard 1996, Kirkes 2007a, Kouba 2007). Therefore it is conservative to assume that the additives necessary to create a heavy 18-19 lb/gal mud are not available at the drill site, and would be dispatched from the nearest available service location (Hobbs, Carlsbad, or Artesia, New Mexico) (35 to 60 miles).

In discussions with area oilfield service companies, it was estimated that up to 4 hours would be required to prepare 400-500 barrels of 19 lb/gal mud (Kirkes, 2007b). The mud would then be trucked to the well location. Transport is estimated to take up to 3 additional hours. Once at the location, the heavy mud would be circulated using common kill procedures, requiring another hour. Therefore, necessary steps taken to kill a high pressure kick from the WIPP repository would take approximately 8 hours. If mud additives were available on site, this time would be significantly less (Kirkes, 2007a). Conversely, inclement weather or other conditions that could affect transport could lengthen this time as well. For example, rare but intense rainfall and flooding have been known to make remote roads impassable for up to 24 hours. Therefore, it is reasonable

[1] The constant 0.052 is the fluid density conversion factor used to simplify hydrostatic pressure calculations.

(and conservative) to assume that in no case would such an event take more than an additional 36 hours to control. Therefore, it is recommended that the value for MAXFLOW be set at 4.5 days. This is based on the initial 3 day minimum duration necessary to continue drilling to the terminal depth of the intermediate section of the borehole (approximately 4,000 feet), set casing, and run cement, plus 36 additional hours should kill-weight mud be ordered, mixed, and delivered to the rig.

One additional point is worth noting here: Should a high pressure kick occur (approaching an SIDPP of 1,000 psi), it is standard procedure for the driller to shut-in the well. Such is the case during the "wait and weight" method of well control (Grace, 2003). During this shut-in period, no flow to the surface occurs. Only during the actual kill procedure, when the kill-weight mud is being pumped down the drillpipe, can formation fluids (in this case contaminated brine from the repository) flow to the surface. During the kill procedure, mud returns are regulated through a choke until kill fluids have been circulated down the drill string and back up the drillpipe/casing annulus. Once the kill-weight mud has been circulated completely throughout the well, there should be zero surface pressure on the drillpipe and the drillpipe/casing annulus, indicating zero flow into the wellbore (Grace, 2003). In such a scenario, fluid from the repository could only flow into the well bore during the kill procedure, and then only at a very slow rate, due to the choking and regulating process used in the kill procedure. This may result in flow to the surface of only one-half hour or less; the period of time it takes to circulate the kill fluid (Grace 2003). Once the flow has been killed, normal drilling operations would continue until the target depth for the intermediate string is reached. The kill-weight mud would continue to be used throughout the remainder of this interval, thus keeping high pressure formation fluids in place. Finally, when setting the intermediate casing string, the heavy mud would continue to be used until the casing is set and cemented. It is likely that very little flow from the repository would occur, once the kill-weight mud was in circulation.

5 Recommendations for MAXFLOW

Based on the information reviewed in the historic DBR parameter package, historic and updated Delaware Basin Monitoring Program data (Leonard 1996 and Kouba 2007), and interviews with current drilling personnel in the WIPP area, it is recommended that MAXFLOW be set at 4.5 days. (For the purposes of input into BRAGFLO, this value is presented as 388,800 seconds.) This value is reasonable and conservative for the following reasons:

1. South Culebra Bluff #1 is not a suitable analog for a hypothetical WIPP blowout.
2. Basing the WIPP parameter MAXFLOW on the single most catastrophic blowout event in the region's history does not reasonably represent "current drilling practice," as directed by regulations (see 40 CFR 194.33 (c) (1)).
3. Well-known drilling procedures are sufficient to stop or "kill" a WIPP blowout under the most extreme anticipated WIPP pressures in a few hours (Kirkes 2007a).

4. Using 4.5 days for a maximum DBR duration is still quite conservative in that it assumes flow into the wellbore continues throughout the kill procedure and throughout casing/cementing procedures, even though kill procedures used in current practice would most likely limit flow into the wellbore only while circulating the kill-weight mud.

6 Verification Calculations

It is suggested that BRAGFLO_DBR calculations using the new MAXFLOW value of 4.5 days be conducted and compared to the most recent approved baseline calculations, the Performance Assessment Baseline Calculations (PABC). Calculations should be constructed such that only the parameter MAXFLOW is varied from those of the PABC. The results should be compared to those presented in the "Analysis Package for Direct Brine Releases: Compliance Recertification Application – 2004 PABC" (Stein et al., 2005). Scatter plots of pressure versus DBR volumes should be compared to analogous plots in Stein et al. (2005).

A subsequent report documenting and comparing these calculations shall also be prepared.

All calculations and associated documentation shall be conducted according to applicable Sandia QA procedures and requirements.

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Kirkes, G Ross

From: Chavez, Mario Joseph Mario Chavez
Sent: Wednesday, April 25, 2007 12:46 PM
To: Kirkes, G Ross
Subject: FW: Signature Authority for Evaluation of he Duration of Direct Brine Releases in WIPP Performance Assessment

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From: Trone, Janis R
Sent: Wed 4/25/2007 11:24 AM
To: Chavez, Mario Joseph
Subject: Signature Authority for Evaluation of he Duration of Direct Brine Releases in WIPP Performance Assessment

Mario - I give you authority to resolve comments on the DRC I generated for the review of the above document, and to sign the document on my behalf.

Janis Trone