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Sandia National Laboratories
Waste Isolation Pilot Plant

Implications of New (Post-CCA) Information for The Probability of Significant Microbial Activity In the WIPP

Work carried out under the Analysis Plan for CRA Response Activities, AP-112, Rev. 0

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1 INTRODUCTION

The U.S. EPA provided the following request (Cotsworth, 2004, enclosure entitled "First Set of CRA Comments," General Comment G-9; hereafter referred to as "Cotsworth, 2004"):

> "DOE has continued to employ a conceptual model developed by Wang and Brush (1996a and 1996b) that assumes a 0.5 probability of significant microbial degradation of CPR occurring in the repository. This probability estimate was based on limited data, at the time of the CCA, regarding whether microbes capable of consuming CPR will be present and active in the repository, whether sufficient electron acceptors will be present and available, and whether sufficient nutrients will be present and available. However, experimental evidence developed since the time of the initial CCA (e.g., Francis and Gillow, 2000; Gillow and Francis, 2003) has indicated viable microorganisms capable of degrading CPR are likely to be present in the repository (Appendix BARRIERS-2.5.2). In addition, sulfate present in brine and in minerals in the Salado Formation surrounding the repository are likely to be available for reaction, so sufficient electron acceptors may be expected to be present. Current inventory estimates also include phosphate in the waste, which could be a source of nutrients for microbial degradation (Leigh and Sparks-Roybal, 2003). Please clarify how DOE considered this information and whether it will increase the probability of significant microbial degradation of CPR in the repository, and provide documentation of the analysis.
>
> "In summary, DOE needs to evaluate whether the assumed probability of significant microbial degradation of CPR in the repository should be increased given the experimental data developed since the CCA and the current inventory estimates. DOE also needs to assess the potential impact of a higher probability of significant microbial populations existing in the repository on microbial colloid formation and mobilization of actinides, as well as on microbial gas generation rates."

This analysis responds to the EPA's request that the "DOE … evaluate whether the assumed probability of significant microbial degradation of CPR in the repository should be increased given the experimental data developed since the CCA and the current inventory estimates." It considers the implications of new (post-CCA) information – if any – on the sources of the uncertainty pertaining to the probability of significant microbial activity and significant microbial gas generation in the WIPP. It then determines whether and – if so – how the new information affects the contribution of each of these sources to the probability of significant microbial activity. "The potential impact of a higher probability of significant

microbial populations existing in the repository on microbial colloid formation and mobilization of actinides, as well as on microbial gas generation rates" is addressed elsewhere.

This work was carried out under the Analysis Plan for CRA Response Activities (Kirkes and Wagner, 2004).

2 BACKGROUND

Wang and Brush (1996a and 1996b) developed a conceptual model of microbial gas generation in the WIPP and established ranges and probability distributions of microbial gas-production rates. The conceptual model includes two components: (1) the probability of significant microbial activity, and (2) sequential use of electron acceptors by microbes in the event of significant microbial activity. The EPA request pertains to the first component of this model.

The U.S. DOE (2004, Appendix BARRIERS, Subsection BARRIERS-2.3.2) reiterated the conceptual model of the probability of significant microbial activity used in the CCA PA, the PAVT, and the CRA-2004 PA:

> "There are large uncertainties as to whether significant microbial activity will occur during the 10,000-year WIPP regulatory period (Brush, 1995). Therefore, it is assumed that significant microbial CO_2 production is possible, but by no means certain. To incorporate these uncertainties in the 1996 PA, Wang and Brush (1996a, 1996b) developed a conceptual model for microbial activity in the repository. According to this model, there is a probability of 0.50 for significant microbial activity. In the event of significant microbial activity, microbes would consume 100% of the cellulosic materials in the repository. Furthermore, there is a conditional probability of 0.50 that microbes would consume all plastic and rubber materials after consuming all cellulosic materials. Thus, there is microbial consumption of all cellulosic materials, but no plastic or rubber materials, in about 25% of the PA realizations (vectors); microbial consumption of all CPR materials in 25% of the vectors; and no microbial activity in the remaining 50% of the vectors. This model was used in the CCA PA, the 1997 PAVT, and the CRA-2004 PA."

The laboratory study of microbial gas generation at Brookhaven National Laboratory (BNL) was designed to quantify the rates of microbial gas production under possible combinations of conditions expected in the WIPP if significant microbial activity occurs. However, it is possible to apply some of the results of this study to some of the issues that contribute to the uncertainty associated with the probability of significant microbial activity in the WIPP (see Subsection 3.1, 3.3, and 3.5 below).

3 RESPONSE

The U.S. EPA stated (Cotsworth, 2004):

> "This probability estimate was based on limited data, at the time of the CCA, regarding whether microbes capable of consuming CPR will be present and active in the repository, whether sufficient electron acceptors will be present and available, and whether sufficient nutrients will be present and available."

This statement lists three of the important issues pertaining to the probability of significant microbial activity in the WIPP. Brush (1995) described seven such issues:

> "The most important issues ... [are] whether: (1) microorganisms will be present in the repository when it is filled and sealed; (2) sterilization of the waste and other contents of the repository will prevent microbial activity; (3) microbes will survive for a significant fraction of the 10,000-year period of performance of the repository; (4) sufficient H_2O will be present; (5) sufficient quantities of biodegradable substrates will be present; (6) sufficient electron acceptors will be present and available; and (7) enough nutrients, especially N and P, will be present and available. This subsection considers these issues and concludes that, although significant microbial gas generation is possible, it is by no means certain."

The discussion below describes the current status of each of these seven issues. It also addresses the specific EPA comments on three of these issues (Cotsworth, 2004).

3.1 Presence of Viable Microbes in the WIPP Underground Workings at the Time of Filling and Sealing

Issue 1 was not considered to be a significant source of the uncertainty pertaining to the probability of significant microbial activity at the time of the CCA. Brush (1995) stated:

> "Halophilic microorganisms capable of carrying out the respiratory pathways described below [denitrification, SO_4^{2-} reduction, and methanogenesis] ... probably exist throughout the WIPP underground workings. However, the source of these microbes is unclear. They have probably entered the WIPP underground workings since excavation on dust particles transported from the salt lakes in Nash Draw, nearby soils, and the WIPP tailings pile by wind and the mine ventilation system, or by various human vectors. The salt lakes in Nash Draw contain an abundance of

halophilic and halotolerant microbes, which occur both in the waters in these lakes and in the underlying sediments. These lacustrine waters and the underlying sedimentary pore waters are concentrated brines with salinities similar to those of brines that could enter the repository after filling and sealing. It is also possible that the halophilic microbes that currently exist in the WIPP underground workings were present in the Salado Formation prior to excavation. In either case, these halophilic microbes have evolved under saline conditions. Therefore, they are better adapted to expected repository conditions than any halotolerant or potentially halotolerant microbes in the waste, and would probably affect the behavior of the repository more than halotolerant species. At least some of the halophilic microbes in the WIPP underground workings will probably survive until the interval between filling and sealing and container rupture. In fact, unless these microbes are present in the Salado Formation prior to excavation, waste emplacement will probably increase the number of microbes present.

"The WIPP Project has not carried out a systematic survey to determine the numbers and types of microorganisms in TRU waste or the WIPP underground workings, nor has it attempted to determine the source(s) of these microbes. Such a survey would not be feasible or useful for the waste (most of these microbes will lyse when exposed to saline conditions), or useful for the repository (waste emplacement could significantly alter the characteristics of the microbial population). Instead, investigators such as Francis and Gillow (1994) at Brookhaven National Laboratory (BNL) have collected halophilic, halotolerant, and nonhalophilic microbes from a variety of sources, including the salt lakes in Nash Draw and the WIPP underground workings, and enriched them in the laboratory. They have then subjected these microbes to various combinations of conditions possible in the repository after filling and sealing to quantify microbial gas-generation rates (see B.2.3 and B.2.4)."

Cotsworth (2004) noted that recent results from the long-term BNL study of microbial gas generation imply that viable methanogens are present in the WIPP underground workings. U.S. DOE (2004, Appendix Barriers, p. 21) summarized these results:

"Furthermore, results from the microbial gas-generation study have confirmed that viable halophilic fermenters and methanogens capable of metabolizing cellulosic materials under expected near-field conditions are present in the WIPP underground workings. Francis and Gillow (2000, pp. 2 and 10) detected CH_4 in initially oxic, unamended, and uninoculated experiments, and in initially

> anoxic, unamended, and uninoculated experiments. The most likely explanation for microbial gas production in these uninoculated experiments is that G Seep, the brine used for these inundated experiments, was collected from the WIPP underground workings. This brine contained a small but viable microflora, including methanogens, and was not sterilized prior to use."

These results demonstrate that microbes capable of using all three potentially significant respiratory pathways (denitrification, SO_4 reduction, and methanogens) are present in the WIPP underground workings. Furthermore, these microbes will no doubt be present (and viable) when the repository is filled and sealed. Therefore, Issue 1 is no longer a source of uncertainty as to whether significant microbial activity will occur in the WIPP.

3.1.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

It was considered likely at the time of the CCA that "halophilic microorganisms capable of carrying out [potentially significant] respiratory pathways ... probably exist throughout the WIPP underground workings" (Brush, 1995). Results since the CCA "have confirmed that viable halophilic fermenters and methanogens capable of metabolizing cellulosic materials under expected near-field conditions are present in the WIPP underground workings" (U.S. DOE (2004, Appendix Barriers, p. 21). Therefore, new results have eliminated Issue 1 as a source of uncertainty regarding significant microbial activity in the WIPP, and have thus increased the probability of significant microbial activity somewhat.

3.2 Sterilization of the Waste and Other Contents of the Repository

Sterilization was considered infeasible at the time of the CCA, and is still considered infeasible. Brush (1995) stated:

> "Sterilization of the contents of WIPP disposal rooms by autoclaving, irradiation, the use of biocides, or filtration (the four sterilization techniques used by microbiologists) is infeasible. Although autoclaving, irradiation, or biocides might delay the start of microbial activity in the repository to some extent or inhibit it somewhat thereafter, it would be very difficult, if not impossible, to defend the efficacy of these techniques. Therefore, they would not reduce the uncertainties in predictions of microbial gas generation significantly."

Furthermore, no claims were made at the time of the CCA or the CRA that the presence of brines, mildly basic conditions, high pressure, α- or γ-radiation, heavy metals, *etc.*, would preclude microbial activity in the WIPP.

Since the CCA, however, several investigators have reported that MgO possesses inhibitory or even biocidal properties (see U.S. DOE, 2004, Appendix BARRIERS, Section 2.3.4.2.2, for a review of these results). The DOE did not attempt to use these results to decrease the probability of significant microbial activity used in PA, or to decrease the microbial gas-production rates used if significant microbial activity occurs. However, these results and the large quantity of MgO being emplaced in the repository decrease the probability of significant microbial activity because: (1) the DOE is emplacing a large quantity of MgO in the WIPP disposal system, (2) the DOE is emplacing supersacks containing MgO on all stacks of waste containers in the repository, and (3) creep closure of the repository will rupture the supersacks and disperse MgO among and/or within all ruptured containers. These actions will ensure that MgO is present those throughout the waste-bearing areas of the repository.

Furthermore, hydration of MgO will maintain dry conditions for a potentially significant period of time, thereby decreasing the probability of survival of viable microbes (see Subsection 3.3 below).

3.2.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

Sterilization was considered infeasible at the time of the CCA, and is still considered infeasible. Therefore, there are no changes in the DOE position that sterilization cannot be used to defensibly rule out microbial activity in the WIPP. However, new results have demonstrated that MgO could inhibit or even preclude significant microbial activity, and have thus reduced the probability of significant microbial activity.

3.3 Survival of Viable Microbes for a Significant Fraction of the 10,000-Year Regulatory Period

Issue 3 has always been regarded as an important source of the uncertainty pertaining to the probability of significant microbial activity. Brush (1995) said:

> "Although microorganisms will be present in WIPP disposal rooms when they are filled and sealed, it is by no means certain that they will survive long enough to affect the behavior of the repository significantly if, as expected, sealing the shafts and boreholes around the repository effectively isolates its contents from the surficial environment. Microbes occur in deep, subsurficial environments ([U.S.] DOE Subsurface Science Program's Taylorsville Working Group, 1994). However, it is generally unclear how and when they arrive in these environments. Therefore, it is also unclear how long they can survive there, especially under suboptimal conditions. Furthermore, it is difficult, if not impossible, to carry out microbial survival experiments for periods long enough to be relevant to the long-

term performance of the WIPP. Therefore, it will be very difficult to determine whether the halophilic or halotolerant microbes that carry out any of the three potentially significant respiratory pathways ... will survive until containers rupture, brine enters the repository, the electron acceptors and nutrients in other types of waste diffuse through the brine to the waste containing cellulosics and other potential substrates, and the microbes that conduct preceding respiratory pathways render conditions favorable to their process."

The importance of this issue has not decreased since the CCA.

Gillow and Francis (2003) reported final results from initially anaerobic, humid experiments after 2945 days (8.063 years); initially aerobic, humid experiments after 3334 days (9.128 years); and initially aerobic or initially anaerobic, inundated tests after 3929 days (10.76 years). These periods amounted to just 0.08603, 0.09128, and 0.1076% of the 10,000-year regulatory period, respectively. During these very brief experiments (relative to 10,000 years), the rates of microbial activity and microbial gas production were relatively high initially, but soon decreased significantly, and have quite possibly decreased to zero. Because gas production has ceased or nearly ceased after about 0.1% (or less) of the 10,000-year regulatory period, it appears less likely that microbes will survive long enough to affect repository performance than it did at the time of the CCA, when microbial gas production was occurring in these experiments.

The presence of a large quantity of MgO in the repository will also decrease the probability of survival of significant quantities of viable microbes. There are two reasons for this: (1) the inhibitory or even biocidal properties of MgO (U.S. DOE, 2004, Appendix BARRIERS, Section 2.3.4.2.2), and (2) the ability of MgO to maintain dry conditions for a potentially significant period of time. How long MgO will maintain dry conditions is not entirely clear. However, this period could be long enough - and the activity of water during this period could be low enough - to decrease the probability of survival of microbes.

Furthermore, implementation of the Option D panel-closure system in PA has decreased the H_2O content of the repository, at least during the period of undisturbed conditions prior to human intrusion (see Subsection 3.4 below), and has thus likely decreased the probability of survival of viable microbes thereafter as well. Incorporation of more realistic hydrologic properties for the disturbed rock zone (DRZ) in PA would further decrease the amount of H_2O in the repository prior to human intrusion (Subsection 3.4) and the likelihood of microbial survival.

Vreeland et al. (2000) reported the presence of viable microbes that have survived in the Salado Formation since the Permian Period, which ended about 251 Ma. If this were true, there would be little doubt that microbes would remain viable for 10,000 years. However, this claim is highly controversial (see, for example, Parkes, 2000; Hazen and Roedder, 2001; Powers et al., 2001).

3.3.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

Microbial activity and concomitant gas production have ceased or nearly ceased after just 0.08603, 0.09128, and 0.1076% of the 10,000-year regulatory period. Therefore, survival of viable microbes for a significant fraction of the 10,000-year regulatory period appears less likely than it did at the time of the CCA, when gas production was still occurring. MgO will also decrease the probability of long-term microbial survival because of: (1) its inhibitory or even biocidal properties and (2) its ability to maintain dry conditions. Implementation of the Option D panel-closure system in PA has decreased the H_2O content of the repository prior to human intrusion, and thus has also decreased the probability of survival of microbes thereafter.

3.4 Presence of Sufficient Quantities of H_2O

Issue 4 has also been regarded as an important source of the uncertainty regarding the probability of significant microbial activity. Brush (1995) stated:

> "Preliminary data summarized by Molecke (1979) suggested that the H_2O content of WIPP disposal rooms will not affect microbial gas-production rates significantly. However, Brush (1990) concluded that, with the possible exception of fermentation and methanogenesis ..., the H_2O content of the repository could affect microbial activity significantly. Brush (1990) concluded that the repository H_2O content could be an important factor because electron acceptors and nutrients, if present in the waste or the surrounding Salado Formation, will for the most part require the presence of brine for diffusive transport from the waste or rock in which they occur ... to waste containing substrates such as cellulosics, plastics, and rubbers ..."

The importance of this issue as a source of uncertainty has not decreased since the CCA.

Implementation of the Option D panel-closure system in PA has eliminated lateral migration of brine from the waste-free areas in the WIPP underground workings to the waste-bearing areas (Hansen et al., 2002; Stein and Zelinski, 2003). This modification has decreased the H_2O content of the waste, at least during the period of undisturbed conditions prior to human intrusion. This decrease in H_2O content decreases the probability of significant microbial activity prior to human intrusion, and decreases the probability of survival of microbes thereafter as well (see Subsection 3.3 above).

Incorporation of MgO hydration (U.S. DOE, 2004, Appendix BARRIERS, BARRIERS-2.3.4.1) and more realistic hydrologic properties for the DRZ (Hansen, 2003) in PA would further decrease the amount of H_2O in the repository prior to human intrusion and the likelihood of microbial survival.

3.4.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

Implementation of the Option D panel-closure system in PA has decreased: (1) the H_2O content of the repository prior to human intrusion, (2) the probability of significant microbial activity prior to human intrusion, and (3) the probability of survival of microbes thereafter. Incorporation of MgO hydration and more realistic hydrologic properties for the DRZ in PA would further decrease the amount of H_2O in the repository prior to human intrusion and the likelihood of microbial survival.

3.5 Presence of Sufficient Quantities of Biodegradable Substrates

Gillow and Francis (2003) reported results from initially aerobic, humid experiments; initially anaerobic, humid experiments; and initially aerobic or anaerobic, inundated experiments carried out for 3334, 2945, and 3929 days, respectively. These results clearly showed that the rates of microbial gas production, although relatively high initially (Francis and Gillow, 1994; Francis et al., 1997), have decreased significantly, and quite possibly decreased to zero.

Preliminary, posttest determinations of the quantities of cellulosic materials consumed by the time of the final analyses of the experiments at BNL imply that just a few percent of the cellulosic materials (papers) initially present at the start of these experiments were consumed by the time gas production ceased or nearly ceased. The pretest and posttest masses of paper in an anaerobic, inoculated, unamended experiment (5.00 and 4.861 g, respectively) demonstrate just 2.78 wt % of the paper initially present was consumed; the corresponding values in an anaerobic, inoculated treatment to which excess NO_3^- had been added (5.00 and 4.824 g, respectively) show that just 3.52 wt % of the paper initially present was consumed. Because gas production has ceased or nearly ceased after consumption of only about 3-4 wt % of the paper initially present, it appears less likely that microbes will consume all cellulosic materials in the WIPP than it did at the time of the CCA, when gas production were still occurring in these experiments.

The data reported by Gillow and Francis (2003) show very limited gas production from some of the irradiated plastic and rubber materials, so there is still much uncertainty as to whether significant microbial consumption of these materials will occur.

3.5.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

Microbial gas production has ceased or nearly ceased after consumption of just 3-4% of the papers initially present in the BNL experiments. Therefore, it appears less likely that microbes would consume all cellulosic materials in the repository in the event of significant microbial activity than it did at the time of the CCA, when consumption of papers and concomitant gas production were still occurring. There is also no evidence that significant microbial consumption of plastic and rubber materials would occur if microbes consume all cellulosic materials.

3.6 Presence and Availability of Sufficient Quantities of Electron Acceptors

Cotsworth (2004) stated,

> "In addition, sulfate present in brine and in minerals in the Salado Formation surrounding the repository are likely to be available for reaction, so sufficient electron acceptors may be expected to be present."

Transport of naturally occurring SO_4^{2-} from the Castile and the Salado formations into WIPP disposal rooms could increase the amount of CPR consumed by SO_4^{2-} reduction and decrease the amount consumed by methanogenesis (see, for example, Kanney et al., 2004, Table 12). However, there is no reason to conclude that naturally occurring SO_4^{2-} would increase the probability of microbial activity. This is because there is no reason to conclude that microbial activity proceeding via SO_4^{2-} reduction is more likely than microbial activity via methanogenesis, given that both processes have now been observed under expected WIPP conditions (Gillow and Francis, 2003).

3.6.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

No significant new information has been identified since the CCA that would change the contribution of this issue to the uncertainty pertaining to the probability of significant microbial activity.

3.7 Presence and Availability of Sufficient Quantities of Nutrients

Cotsworth (2004) stated:

> "Current inventory estimates also include phosphate in the waste, which could be a source of nutrients for microbial degradation (Leigh and Sparks-Roybal (2003)."

Microbes require a variety of nutrients. These include (in order of their concentrations in *Escherichia coli* cellular material): C, O, N, H, P, S, K, Na, Ca, Mg, Cl, Fe, Mn, Zn, Mo, Cu, and Co (Talaro and Talaro, 1993, Table 6.2). Many of these elements are present in WIPP brines and/or the TRU waste to be emplaced in the repository. For example, the quantity of phosphate (PO_4^{3-}) in the TRU waste inventory was estimated at the time of the CCA (U.S. DOE, Appendix B), and was updated for the CRA (Leigh and Sparks-Roybal, 2003).

Even if present, it is unclear whether nutrients would actually be available to microbes. For example, precipitation of PO_4^{3-} by highly insoluble phases such as apatite ($Ca_5(PO_4)_3(OH,F,Cl)$ could effectively sequester this nutrient, especially if apatite contains

appreciable concentrations of inhibitory, toxic, or radiotoxic heavy metals such as the actinides in TRU waste.

Therefore, this issue was considered to be an important source of the uncertainty pertaining to the probability of significant microbial activity at the time of the CCA, and is still considered significant despite the fact that many of the nutrients listed above will be present in the repository.

3.7.1 Net Effect of New (Post-CCA) Information on the Probability of Significant Microbial Activity

No significant new information has been identified since the CCA that would change the contribution of this issue to the uncertainty regarding the probability of significant microbial activity.

4 CONCLUSIONS

This analysis demonstrates there is still much uncertainty as to whether significant microbial activity and significant microbial gas generation will occur in the WIPP. Of the seven sources of uncertainty identified by Brush (1995), new (post-CCA) information increases the probability of significant microbial activity in the case of one source of uncertainty (Issue 1), decreases the probability in three cases (Issues 3, 4, and 5), and has no effect in three cases (Issues 2, 6, and 7) (see Table 1 below). Therefore, this analysis shows that there is no justification for increasing the probability of significant microbial activity currently implemented in WIPP PA. Furthermore, it shows that reducing the probability would actually be justified.

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6 TABLE

Table 1. Net Effects of New (Post-CCA) Information on the Probability of Significant Microbial Activity and Significant Gas Generation in the WIPP.

Source of Uncertainty	Changes since the CCA[A]	Remarks
1. Presence of viable microbes at the time of closure	↑	The presence of viable microbes in the WIPP was not considered to be a significant source of the uncertainty at the time of the CCA. Recent results imply that viable methanogens are present in the underground workings. These results have eliminated Issue 1 as a source of uncertainty regarding significant microbial activity in the WIPP, and have thus increased the probability of significant microbial activity somewhat.
2. Sterilization of the waste and other contents of the repository	No changes	The DOE position on sterilization has not changed since the CCA. However, new results have shown MgO could inhibit or even preclude microbial activity, and have thus reduced the probability of significant microbial activity.

A. Indicates whether new (post-CCA) information pertaining to each issue increases (↑), decreases (↓), or has no net effect (no changes) on the probability of significant microbial activity and concomitant gas production.

Table 1. Net Effects of New (Post-CCA) Information on the Probability of Significant Microbial Activity and Significant Gas Generation in the WIPP (cont.).

Source of Uncertainty	Changes since the CCA[1]	Remarks
3. Survival of microbes for a significant fraction of the 10,000-year regulatory period	↓	Microbial gas production has ceased or nearly ceased after just 0.08603, 0.09128, and 0.1076% of the 10,000-year regulatory period. Thus, significant microbial activity appears less likely than it did at the time of the CCA, when gas production was still occurring. MgO will decrease the probability of long-term microbial survival because of: (1) its inhibitory or even biocidal properties and (2) its ability to maintain dry conditions. Implementation of the Option D panel-closure system in PA has decreased the H_2O content of the repository prior to human intrusion, and has thus decreased the probability of survival of microbes thereafter.
4. Presence of sufficient H_2O	↓	Implementation of the Option D panel-closure system in PA has decreased: (1) the H_2O content of the repository prior to human intrusion, (2) the probability of significant microbial activity prior to human intrusion, and (3) the probability of survival of viable microbes thereafter. Incorporation of MgO hydration and realistic hydrologic properties for the DRZ in PA would further decrease the amount of H_2O in the repository prior to human intrusion and the likelihood of microbial survival.

1. Indicates whether new (post-CCA) information pertaining to each issue increases (↑), decreases (↓), or has no net effect (no changes) on the probability of significant microbial activity and concomitant gas production.

Table 1. Net Effects of New (Post-CCA) Information on the Probability of Significant Microbial Activity and Significant Gas Generation in the WIPP (cont.).

5. Presence of sufficient biodegradable substrate	↓	Microbial gas production has ceased or nearly ceased after consumption of just 3-4% of the papers initially present. It thus appears less likely that microbes would consume all cellulosic materials in the repository than it did at time of the CCA, when microbial activity was still occurring. There is also no evidence that significant microbial consumption of plastic and rubber materials would occur.
6. Presence and availability of sufficient electron acceptors	No changes	No significant new information pertaining to this issue has been identified since the CCA.
7. Presence and availability of sufficient nutrients	No changes	No significant new information pertaining to this issue has been identified since the CCA.

1. Indicates whether new (post-CCA) information pertaining to each issue increases (↑), decreases (↓), or has no net effect (no changes) on the probability of significant microbial activity and concomitant gas production.