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LETTER REPORT

A DISCUSSION OF CERTAIN SAFETY ISSUES ASSOCIATED WITH THE TANK 241-SY-101 MITIGATION MIXING TEST

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EXECUTIVE SUMMARY

This paper addresses certain safety issues associated with the Hanford Tank 241-SY 101 hydrogen mitigation mixing test. Specifically, the study, performed at Pacific Northwest Laboratory (PNL),[a] is concerned with the effect of pump shearing, jet mixing, and piling-up on the following areas:

- gas generation
- gas retention
- gas release (immediate)
- gas release (long-term)
- saltcake.

The findings for each issue area of concern are these:

1. Effect of Pump Shearing on Gas Generation. The possible combination of radiation and an increase in solid surface area is not anticipated to increase the reaction rate. It has been shown using synthetic wastes that the presence of solids actually decreases the rate of generation of gases. However, since the mass of solids per unit volume of solution has not changed significantly over the past six years, the effect of solids is thought to have reached a steady-state rate. Increased mixing should not change this aspect.

2. Effect of Pump Shearing on Gas Retention. Although large gas bubbles that pass through the pump could be broken into smaller bubbles, the expected minimum size would be much larger than the particles and, with the reduction in viscosity caused by the pump shear, should allow rapid coalescence and release from the pumped material.

3. Effect of Pump Shearing on Immediate Gas Release. Pump shearing is expected to substantially enhance the release of flammable gases from Tank 241-SY-101, primarily by altering the rheological properties of the nonconvecting solids.

4. Effect of Pump Shearing on Long-Term Gas Release. Since it is unlikely that the pump action will change the fundamental particle size, the long-term retention ability of the waste should be unaffected. The pump would have to be used intermittently to release a fraction of the retained gas.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

5. Volume Effects of Jet Mixing on Gas Generation. It is not anticipated that there will be a change in the rate of gas generation in the affected volume. If the temperature of the volume were to increase due to power input from the pump or some other chemical reaction not directly associated with the gas generation reactions, the rate of reaction could increase due to the size of the affected volume. Some opposing cooling processes are also postulated.

6. Volume Effects of Jet Mixing on Gas Retention. The purpose of the test is mainly to determine this factor. Release of the larger gas bubbles from the affected volume is not likely to affect the retention in the settled slurry.

7. Volume Effects of Jet Mixing on Immediate Gas Release. The possibility of a large immediate release is highly dependent on the predicated distribution of the releasable gas in the tank and on the assumptions concerning the gas content and the releasable fraction. The material properties also have an effect. Calculations are ongoing concerning the sensitivity of this release to the parameters.

8. Volume Effects of Jet Mixing on Long-Term Gas Release. Analysis suggests that the basic particle size would not be changed by the mixer pump, because the particles (crystals) are so small relative to the viscous dissipation eddies generated by the pump. Shear rates generated in the affected volume are also too low to break the tiny particles. Over an extended time period the average particle size in the mixture might change (Ostwald ripening), allowing the saltcake crystals to change the gas release properties, but the tank has had a long time for this to occur already.

9. Volume Effects of Jet Mixing on Saltcake. There is little reason to believe that the action of the mixer pump might dissolve or scour away precipitated salts on the tank wall that may be plugging wall perforations, if they exist. Pinhole leaks that have been sealed by salt precipitation would be unaffected by fluid motion within the tank.

10. Gas Generation Effects of Piling-Up from Jet Mixing. Previous studies are inconclusive, but suggest that piling-up does not occur and thus has no effect on gas generation. Thermal analysis shows that with extreme piling-up, the volume of the nonconvective slurry heated to a given temperature would be less than for the undisturbed condition and therefore should generate less gas. If the piling-up is as a flat slab, increased gas generation may result because more volume reaches an elevated temperature.

11. Gas Retention Effects of Piling-Up from Jet Mixing. An increase in retention is unlikely, because the buoyant instability of the piled-up material is higher than it is for level sludge. In the flat slab case the production may be higher, but turnover instability would occur earlier also, resulting in a small difference in relative gas release event (GRE) sizes.

Some of the arguments used in arriving at the above conclusions (e.g., generation effects) assume a similarity between the synthetic wastes and the material that exists in the tank. This inference gives some uncertainty that cannot be eliminated until a more representative sample is obtained or a set of in situ measurements is made. Until these measurements are made the element of risk associated with this test cannot be removed, since not all the possibly important considerations and facts are known.

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R. T. Allemann
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H. Babad (WHC)
T. M. Burke (WHC)
M. R. Elmore
M. D. Northey (WHC)
L. R. Pederson
D. M. Strachan

CONTENTS

1.0 INTRODUCTION

The purpose of this study is to assess certain safety issues resulting from the Hanford Tank 241-SY-101 hydrogen mitigation mixing test. Specifically, the study is concerned with the effect of pump shearing, jet mixing, and piling-up on the following areas:

- gas generation
- gas retention
- gas release (immediate)
- gas release (long term)
- saltcake.

The immediate, or short-term, effect deals with what happens in the short time of initial and short-term testing. The long-term effects deal with changes in tank conditions that result from continued use of the pump over years, or in changes in tank conditions that manifest themselves long after the pump is shut down (or removed).

The mixing test is being conducted to evaluate the ability of jet mixing to prevent or reduce the accumulation and provide a steadier release of gases generated in Tank 241-SY-101. However, installing a pump and mixing the tank contents are themselves cause for concern; thus, the need for this study.

The document is organized as follows:

- In Section 2.0, the effects of pump shearing are addressed.
- In Section 3.0, the effects of volume change resulting from jet mixing are addressed.
- In Section 4.0, the effects of piling-up caused by jet mixing are addressed.
- Additional supporting information can be found in the appendixes at the end of the document.

The various subsections are identified in Table 1.1.

TABLE 1.1. Issues and Effects Addressed in This Safety Issue Discussion for the Tank 241-SY-101 Mixing Test

Section Where Discussed						
ISSUES		Effect on Generation	Effect on Retention	Effect on Immediate Release	Effect on Long-Term Release	Effect on Saltcake
Pump Shearing	2.0	Section 2.1	Section 2.2	Section 2.3	Section 2.4	
Jet Mixing	3.0	Section 3.1	Section 3.2	Section 3.3	Section 3.4	Section 3.5
Particle Size				Section 2.3	Section 2.4, 3.4	
Densification	2.5		Section 2.5		Section 2.5	
Piling-Up	4.0	Section 4.1	Section 4.2		Section 4.2	
Heating/ Cooling		Section 3.1,4.1	Section 3.4		Section 3.4	
Corrosion	3.5					
Foaming		Section 2.2	Section 2.3	Section 2.4	Section 3.4	

2.0 SAFETY ASSESSMENT OF PUMP SHEARING

Pump shearing refers to the turbulent mixing action that the fluid undergoes in passing through the intake, impeller, and piping of the pump. The high-speed conditions in the pump give increased shear rates relative to those in the material outside the pump. The shearing effects on material outside the pump (in the jet-affected region) are discussed in Section 3.0.

2.1 PUMP SHEARING EFFECT ON GENERATION

The concern is that increasing the shear rate while pumping the waste might cause an increase in the gas generation rate because it decreases particle size or increases the solid-liquid interaction. If the reaction that yields the gases is a surface reaction, then increasing the surface area of the solids will increase the gas generation rate. In Section 2.4 it is suggested that the particle size will not be changed by pump shearing action. It is not anticipated that increasing the shear rate of the waste will cause an increase in the gas generation rate.[a]

If yielding or generating gases was due to heterogeneous catalysis between species in solution and reactions that occur on the surface of a solid, one might expect the reaction rate to increase with increasing solid surface area. Studies with synthetic wastes have not yielded results that are consistent with the mechanism of gas generation being dependent on heterogeneous catalysis. Also, the gas generation data from Tank 241-SY-101 are

(a) During a rollover, the shear in the tank is increased above the stagnant condition. But subsequently, there is no noticeable change in the gas generation rate as interpreted (op cit.) from the level rise rate. Hence, at this level of turbulent shearing an increase in generation rate is not detectable. The mechanism for an increase in generation rate would be based on an increased rate of contact between species involved in the reaction. By the methods discussed in Appendix A, the eddy size is estimated in the pump to be on the order of 60 μm. This is 60 times the molecular diffusion mean free path (see Section 3.1) for solid-liquid reaction; hence, little change in the reaction rate would occur by mixing. Similarly, if the rate limiting step was diffusion of species in the liquid, and since the species are probably already uniformly distributed in the waste, the reaction rate would not be aided by eddy diffusion at this eddy scale.

inconsistent with a heterogeneous catalysis mechanism. During the course of a gas release event (GRE), solids are distributed between the convecting and nonconvecting layers. At this time, with the looser packing, the rate of gas generation should be maximum. As the solids settle the convecting layer becomes depleted in solids, and the nonconvecting layer becomes nearly entirely solids with some gas voids. The gas generation rate appears to be constant[a] over the approximately 100-day period between GREs. Hence, an increase in the solid surface area, if it occurs, is not expected to yield an increase in the gas generation rate.

The combination of radiation and an increase in solid surface area is not anticipated to increase the reaction rate. It has been shown using synthetic wastes that the presence of solids actually decreases the rate of generation of gases. However, since the mass of solids per unit volume of solution has not changed significantly over the past six years, it is anticipated that the effect of solids has reached a steady-state rate. Increased mixing should not change this aspect.

2.2 PUMP SHEARING EFFECT ON RETENTION

The issues are the effects of the pump shearing on gas bubbles, discussed here, and on particles, which is discussed in Section 2.4. A possibility exists that pump shearing could cause increased retention of gases in the nonconvective layer of the wastes in Tank 241-SY-101. This might occur if relatively large gas bubbles are present in the material that passes through the pump and these would be broken into smaller bubbles that adhere to, rather than release from, the particle mixture. If the material then moved or settled to an undisturbed region of the tank (and the newly created bubbles did not coalesce), the smaller bubbles would be slower moving and less likely

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(a) The level rise appears constant (see Strachan, D. M., "Minutes of the Tank Waste Science Panel Meeting, Feb. 7-8, 1991," PNL-7709), and this is associated with the retention. Hence, if the generation rate were changing, the retention fraction would have to be changing too, to give the constant rate of retention. This would require more complex mechanisms.

to overcome the shear strength or cohesiveness of the slurry. Hence, larger bubbles that otherwise would have been released have been made into smaller bubbles that do not release.

Several factors tend to reduce the seriousness of this postulated effect:

- The inlet to the pump is in the convective layer, so the material taken in would have a reduced amount of large bubbles. The bubbles should be more mobile in the convective layer and would have already been released to the head space. If an inlet boundary to the pump has a 42-in. diameter, at maximum pump flow the inlet velocity would be on the order of magnitude of the velocity of rise of a .04-in.-diameter bubble rising in the Stokes flow regime in the supernatant liquid. Larger bubbles would rise faster at a velocity that would far exceed the pump inlet velocity. These larger bubbles would largely rise past the pump inlet region and not be recycled (see Appendix D). In addition, the pump inlet region represents about 0.2% of the area of the tank available for the bubbles to rise through. Hence, a small fraction of bubbles of all sizes would pass near the zone of higher velocities of the pump inlet.

- The shearing action of the pump, while making some bubbles smaller, would also be making the surrounding slurry less viscous. Hence, the bubbles would become more mobile than before, and even the small bubbles created (or a fraction of them) would be releasable from the material that had passed through the pump.

- An estimate of the bubble size that is stable against breakup in the turbulence inside the 90% efficient pump is 1000 μm in diameter (see Appendix A). This size is an order of magnitude larger than the particles. With this size bubble, any attached single particles would be floated to the top and not resettle in the nonconvective layer. To sink to the nonconvective layer, bubbles of this size would have to be attached to an agglomerate of particles. But agglomerates of particles are expected to be broken up by the pump shearing action if they pass through the pump. A great deal of energy and high shear stresses are required to reduce the bubble size to about the size of the particles--a situation that would be needed to form a stable foam. Such a foam would break slowly as the tiny bubbles coalesce. If retained gas were transformed into foam, GREs would be reduced or eliminated, but the liquid level would rise. Although foam formation is not likely since a small fraction and only the smaller of the bubbles would be ingested by the pump as discussed above, the test plan controls include monitoring for foam through the video camera and through level and density measurements.

Recently a report has been issued[a] that gives the results of high-speed stirring tests on composite samples from Tank 241-SY-101. The homogenizer caused an increase in gas content, apparently by entraining air from above the mixed sample. The author concludes that this "forced gasification" would not be expected to occur in the tank pumping tests. The bubble size observed in the mixed samples was on the order of 10 μm, and the homogenizer did not break up "sponge crystals" (agglomerations of crystals surrounding gas bubbles). The report suggests that bubbles larger than 18 μm will move out of the mixed tank in less than 100 days (the typical GRE interval). So if gas bubbles are not reduced to a size smaller than 18 μm, they will continue to rise in the tank and be released. An estimate of the stable bubble size issuing from the pump based on power dissipation (Appendix A) is 1000 μm, which is quite large enough to be released by rising to the surface. Person also found that bubbling larger bubbles through the mix tended to increase the density; a fact he attributed to the removal of smaller gas bubbles from the homogenizer-processed material. Thus, if the large bubbles are not broken up or eliminated by mixing, they would tend to sweep out smaller bubbles as they rise.

Since the shear rate in the homogenizer tests was insufficient to break up bubbles to below about 10 μm diameter, what diameter would be the expected limit diameter in the pump with a shear rate 140 times lower? A dimensionless relationship that applies in this case is the "two-phase flow" number, the ratio of the viscous force to the surface tension force. The viscous force in the velocity gradient across the bubble tending to stretch and break the bubble into a smaller size is balanced by the surface tension force tending to keep the bubble from breaking. Thus,

$$\text{Two-phase flow number} = \frac{\mu d_b V}{\sigma L} = \frac{\mu d_b \dot{\gamma}}{\sigma} \qquad (2.1)$$

(a) Person, J. C. September 2, 1992. Gas Retention Tests on 101-SY Tank Waste After Mixing. WHC 12110-PCL-068, letter report to J. W. Lentsch, Westinghouse Hanford Company, Richland, Washington.

where μ = viscosity

d_b = diameter of bubble

V = velocity

σ = surface tension

L = characteristic length and

$\dot{\gamma}$ = shear rate.

In this relationship, it is seen that the bubble size will be inversely proportional to the shear rate if the other parameters are held constant. Therefore, one would expect the minimum bubble size in the pump impeller casing to be 140 times larger than in the homogenizer tests done by Person. This would imply that a bubble of about 1.4 mm in size would not be broken up by the impeller shear forces. This value is the same order of magnitude calculated from energy dissipation considerations in Appendix A. This bubble size is also well above the size needed to rise to the top of the Tank 241-SY-101 waste slurry within the typical burp time interval. These bubbles would tend to scavenge smaller bubbles as they rose past them.

2.3 PUMP SHEARING EFFECT ON IMMEDIATE RELEASE

The pump takes in fluid from the convective layer, which has little gas or gas associated with the lesser amount of solids. Pump shearing is expected to substantially enhance the release of gases from the pumped material in Tank 241-SY-101, primarily by altering the rheological properties of the convecting layer solids.

Pump shearing is not expected to completely separate solid particles from adhering gas bubbles. In laboratory tests performed using synthetic wastes, interaction energies between solids and gas bubbles appeared to be reasonably large. Ultrasound energy input, for example, did not result in gas bubble-solid particle separation. However, if the gas bubbles were sufficiently large that the equilibrium contact angle were exceeded, pump shearing could separate a portion of the gas bubbles from the solid particles; this portion could either attach to another solid or perhaps float to the surface of the waste.

2.4 PUMP SHEARING EFFECT ON LONG-TERM RELEASE

The concern is that the pump shearing action will change the particle morphology to a more uniform size distribution, which might change the retention capacity of the nonconvective layer and increase the fraction of gas that would release in a subsequent GRE.

Person[a] discusses particle size effects of high-speed stirring on composite samples from Tank 241-SY-101. A tissue homogenizer was used to stir the samples. In the manner that the stirring tests were done, the average shear rate (tip speed/clearance) imposed on the sample was 42,000 sec^{-1} for about 80 throughputs through the homogenizer. This is to be compared with a shear rate of 300 sec^{-1} for the 10-in. impeller with 2-in.clearance[b] at 1180 rpm (full speed) in the tank test pump. The pump might be operated for 11 throughputs in three months at one hour per day, according to Person. Thus, these stirring tests with the homogenizer subjected the waste to 140 times the shear rate for about seven times the duration that could be expected with the pump test in the tank. The results showed little difference in the particle size distributions, and the tentative conclusion was that the particle size is unaffected by vigorous mixing.

One of the conclusions from the synthetic waste studies is that the main reason the gas adheres (as small bubbles) to the solids is that the solid surface is rendered hydrophobic when organics sorb onto the surface. Increasing

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(a) Person, J. C. September 2, 1992. Gas Retention Tests on 10-SY Tank Waste After Mixing. WHC 12110-PCL-068, letter report to J. W. Lentsch, Westinghouse Hanford Company, Richland, Washington.

(b) Clearance is great enough for 2-in. particles, according to manufacturer letter R-276877, page 1. W. D. Haentjens, Barrett, Haentjens & Co., Hazelton, Pennsylvania, to Brian Gifford, WHC, Richland, Washington, July 23, 1992.

the surface area might increase the amount of hydrophobic surface to which bubbles will adhere. Thus, it might become more difficult to release bubbles from the waste during pumping.

Like the homogenizer tests, the following theoretical discussion also suggests that the pump mechanical action would not change the particle size and surface area significantly from that currently existing in the tank. The mixing could break up agglomerations of particles, which would be beneficial because the ability to retain gas bubbles would be reduced.

The particle size distributions that have been measured from samples from windows C and E show that the particles are extremely small. The size distributions of the samples measured tend to be bimodal, log-normal distributions with the small size mode having a median diameter of 5-10 μm and the large size mode 50-150 μm. The particles larger than 100 μm are calculated to contain about 50% of the solids volume.[a] The particles are much smaller than the gas bubbles that are released. Videos of a GRE show that large upwellings of material are associated with pressure pulses (about 0.2 in. of water) in the tank head space. On the basis of adiabatic compression of the headspace for this typical size of pressure pulse as gas is expanded into the head space, a typical gas release would be about 12 ft^3 and could be made up of gas bubbles of any size that move rapidly and would, therefore, be large relative to the size of the particles. The main gas release in other videos of GREs (e.g., December 4, 1991) appears to be made up of even larger pulses of gas. The videos also show a longer-term "fizzing" release of gas as smaller bubbles that appear to be about 1 in. (0.0254 m) in diameter. Even these smaller bubbles are over 250 times as large as the larger particles in the slurry.[b] Hence, the gas that tends to be released is in a bubble size range much larger than the typical measured particle size.

(a) D. A. Reynolds. April 1992. "101-SY Window C Core Sample-Evaluation of the Chemical and Physical Properties." Westinghouse Hanford Company, Richland, Washington.

(b) The ratio of in situ bubble diameter to the diameter at the waste surface is as the $(\text{pressure ratio})^{-1/3}$; hence, at the waste surface the bubbles would be about 1.26 times larger than at the in situ pressure of two atmospheres. On this basis, the observed bubbles would be near the in situ size.

The retention of such large gas bubbles would not be due to surface tension holding the gas to a particle. Many small particles might be attached to surface of a bubble by surface tension as in a flotation process, but these would not greatly hinder the bubble from rising. However, if the bubble is in the matrix of particles, it would be the cohesiveness of the matrix that prevents the gas bubble from rising. If the matrix were a purely viscous (liquid) medium, the bubbles would move and be released continuously. It is the cohesiveness that prevents the large, otherwise releasable, gas bubble from moving. When the buoyancy of a body of this material overcomes both the weight of material above it and the cohesiveness of the matrix around it, it will rise and release gas in a GRE. The gas that was held can be released because expansion, reorientation of the rising mass, and shear action cause a change in the forces of cohesion.

How can the shear action of the pump affect this process in the long term? One of the first assumptions is that the pump would affect the particle size. This is not likely from a mechanical standpoint, even if the waste is stirred up enough that the solids are ingested into the pump. The pump impeller clearances are 1 in. or more, so no direct metal-solid-metal grinding action is possible. The particles can therefore be broken only by fluid shear or direct particle-to-particle impact. The maximum fluid shear occurs in the pump, not in the jets, and is on the order of 1200/sec. This would give a stress of 60 Pa on a 100 μm particle in a 50 cP[a] viscosity liquid (larger than typical of the Tank 241-SY-101 liquid). This stress is less than 0.01 psi and is insufficient to break most solids. For example, gypsum plaster (plaster of Paris, hydrous calcium sulfate), a rather weak solid, has a shear strength of more than 50 psi. The individual crystal strength would be higher with the sodium nitrate and sodium nitrite crystals in the Tank 241-SY-101 waste. Therefore, fluid shear in the pump would not produce shear forces sufficient to effectively reduce the particle size below the small size already present in the tank.

(a) The typical waste supernatant viscosity is about 30 cP at 50°C, according to core sample measurements given in Gillespie, B. M., 1992, "101-SY Hydrogen Safety Project, Chemical Analysis Support Task: Physical Characterization." Pacific Northwest Laboratory, Richland, Washington.

Particle-to-particle contact is also unlikely to cause particle breakage to less than the 100 μm size that is present. If two particles collided at the velocity of 100 fps, a stress of about 200 psi would be produced. The stopping distance of 100 μm particles traveling 100 fpm in the 50 cP liquid would be about 350 μm.[a] Thus, only a very few particles would maintain enough speed to cause breakage in colliding with another particle. Any broken particles would increase the already huge number of smaller particles present. Therefore, there would be no expected detectable change in the particle size distribution due to particle collisions, even at velocities up to the maximum jet velocity.

Since it is unlikely that the pump action will change the fundamental particle size, the long-term retention ability of the waste should be unaffected. The smaller size particle mode would be even less affected than the larger mode. Agglomerations of particles might be expected to be broken by the pump if they are pushed through the inlet and impeller. It is indeed the breakup of such agglomerations that may allow the gas to move through the matrix and be released, and which may be an important mechanism of mitigation by the pump. If the destruction of the agglomerations of particles had an adverse affect on retention (made larger) during long-term use of the pump, the long-term operation controls (such as too high a level increase or rate) would indicate the condition, and the planned remedy would be initiated. The initial test plan calls for short-term operation for which there would be a minimum effect. Based on the experience acquired in the Phase A testing, the long-term protocols would be established. If the long-term pump operation were halted, agglomeration of the particles would be allowed to occur by

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(a) The initial Reynolds number of such a particle is about 130. A formula in W. C. Hinds, Aerosol Technology (Wiley-Interscience, 1982), p. 111, gives the stopping distance as:

$$S = \frac{\rho_p D}{\rho_l} \times [Re_o^{1/3} - \sqrt{6}\arctan(Re_o^{1/3}/\sqrt{6}]$$

where: D is the particle diameter and Re_o is the particle Reynolds number at the initial velocity.

diffusion, as currently happens. The tank would restore itself to the retention conditions it currently maintains, because the fundamental nature of the particles would be essentially unchanged by using the pump.

Heating and mixing a saturated solution, however, has another effect. Under conditions in which the waste is warmed, the small and more angular particles tend to dissolve, leaving behind "rounder" particles. This effect underlies the so-called digestion step in many analytical laboratory operations. Such changes in crystal morphology could affect gas retention. Such driving forces are involved in Ostwald ripening, a field that G. S. Barney (WHC) studied in 1975-1976. As discussed above, in the mixer pump one would not expect shearing effects, and industrial experience with organic acid salts (e.g., MSG) suggests that extended mixing (4 to 48 hr) has only a small observable effect on filterability (crystal size), although longer crystal residence times were somewhat better.

2.5 DENSIFICATION

The concern is that the solids in the nonconvecting layer, having gotten rid of gas by virtue of the pump action, may settle to the bottom of the tank more densely than before the use of the pump. A second type of densification postulated is that the packing factor of the solid-liquid matrix is increased by having liquid removed. If densification were to occur the material properties might be changed, perhaps to a higher yield strength, such that more gas would be retained before enough buoyancy was created to initiate a GRE. Hence this GRE would be larger than typical. Also, if the dense material settled on top of gas-containing material, then that gas would be more highly compressed and would thus need more gas to create enough buoyancy to overturn the sludge in a GRE, and a larger-than-typical GRE would result.

With the state of knowledge about the tank material, it may be possible to estimate the bounds of these postulated effects. Some gas content has been observed in the actual waste samples and in synthetic wastes. Some of this gas is very difficult to remove and requires centrifuging for long periods; additional gas is so tightly bound that dilution and dissolving of the solids is required before is released.[a] This tightly bound gas contributes to the low density of the mixture of fluid and solid relative to a theoretical high solids packing density. This tightly bound gas is in the form of very small bubbles and shows as a foam when the material is centrifuged. The volume fraction of this gas may be more than 12%, which would be about 6% at an in situ pressure of 2 atmospheres. Since this gas is almost impossible to remove in the sample experiments, it would be virtually impossible to remove in the tank conditions. This forms a lower bound to the type I densification than would be possible by any mixing action of the pump.

There are two main actions of the pump mixing on the gas. The first is that it triggers the rise of material that is near the point of unstable buoyancy. This material would rise and release gas in a manner similar to the normal rollover. That is, a gob of material would rise and release the excess buoyancy gas and then sink again. The second action is that the sinking may be slightly slower against the upward drift of the pumped fluid, so more gas would have to be released before the sinking began. This material would, in principle, be "densified" relative to the normal sludge after a rollover, but

(a) This was reported by D. L. Herting (WHC) in a memo to G. L. Johnson (WHC), "Dilution/Heating Mitigation Testing with Tank 101-SY Window E Samples," 121110-PCL92-039 May 7, 1992. It was also reported in "Laboratory Characterization of Samples Taken in December 1991 (Window E) from Hanford Waste Tank 241-SY-101," D. L. Herting, D. B. Bechtold, B. E. Hey, B. D. Keele, L. Jensen, and T. L. Welsh, Section 6.5, WHC-SD-WM-DTR-026 Rev 0, August, 1992. After heating, mixing, and centrifuging, the density of the sample was invariably higher than before. In every case a layer of foam ranged from 3-8 vol% with an average of 5.3% of the initial sample volume. Based on the measured centrifuged density of about 1.70 g/mL and assuming a packing factor of 0.65 for the solid-liquid mix, the calculated void fraction in the fuged material is about 11-12%. This would be compressed to about one-half this void fraction at the in situ pressure. It was not possible to determine from the measurements that were made whether the entrained gas that produced the foam had always been present in the sample or had become entrained during the homogenization process used in preparing the samples. However, in synthetic waste centrifugation tests, R. T. Allemann (Progress Report, Physical Modeling to Support Flammable Gas Waste Tank Mitigation, December 31, 1991) observed tiny gas bubbles in the synthetic waste material and a foam that was released upon centrifugation of a non-homogenized sample. This suggests that the gas is present in the sample and is not a byproduct of homogenization.

the factor of change would be very small. For example, the average upward drift at maximum speed in the tank is 0.087 fpm (about 1 in./min). A gob of material 2 ft in diameter would have a changed sinking velocity by this amount with a changed void fraction of 9%. Thus, to sink past the midway point of the convective layer, the settling mixture would have about 9% less retained gas than without the upward drift caused by the pump. This material would therefore be denser because of that difference in amount of gas and how it is compressed by the hydrostatic head. The "densified" sludge in this case would have 91% of the gas that it would have without the pump. This change should not be a serious problem from the standpoint of further mobilization, but it would take longer to generate sufficient buoyancy for it to rise again. Assuming a pressure ratio of 2, the time required to generate enough gas for neutral buoyancy would be about 18% longer, or about 18 days for the typical 100-day period between events. The packing and strength would not be expected to have been changed by the upward drift effect, so the size of the typical burp would not be changed. The actual mixing case would not have the uniform upward velocities assumed here. Thus, in the actual situation, there will be regions of higher and lower upward velocities that could be affected by the location of the overturned material. The floating material would tend to settle in the regions of low upward velocity, away from the directed jets. The regions of low velocity would allow settling of material with about the same void fraction as would be expected after a normal GRE.

The second type of densification that has been postulated involves removing liquid from between the particles so that they are packed more tightly together. This would occur if the material were pressed or if the particles were altered to allow them to rest more tightly against one another. In Section 2.4 it is illustrated how unlikely it is that pumping could result in changing the particle size to smaller ones that might pack more tightly. There are already very many small particles to fill the interstices. Allemann et al.[a] found that a large packing factor of 0.65, typical of clays, will

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(a) Allemann, R. T., T. M. Burke, D. A. Reynolds, and D. E. Simpson. August 1992. "Assessment of Potential Gas Accumulation and Retention-Tank 241-SY-101." Westinghouse Hanford Company, Richland, Washington.

predict the density of the material that is neutrally buoyant in the convective layer liquid if a density of a sodium nitrate-sodium nitrite mix of crystals is taken as the solid phase. Although higher packing factors are not often found in nature, a relatively high value of 0.7 would increase the buoyant void fraction and the retained gas volume by 5-6%. Thus, if a densification were to occur, bringing the packing fraction to 0.7, the typical GRE based on neutral buoyancy considerations would be 6% larger and would generally be within the range of GREs that have historically occurred. If the increased packing increased the yield strength in proportion, as might be expected, a higher buoyancy would be needed to overcome that as well, raising the ratio of typical GRE size to 1.12 of the previous average. This also is within the range of historical variation. The accumulation of the extra gas required to give a release would probably require a longer time between GREs than currently exists, but that effect too is within the variation that has occurred historically with Tank 241-SY-101. The viscosity of the mixed material is affected most by the particle concentration (see Appendix F) once the material has yielded or begun to mix. Therefore, a higher density would have a relatively small effect once mixing had taken place.

3.0 SAFETY ASSESSMENT OF JET MIXING: AFFECTED VOLUME EFFECTS

The jet mixing-affected volume refers to the region in the waste tank that is moved or lifted or in some way affected by the jet pushing its way into the slurry. The volume would include the region of the jet and the fluid dynamic action that results elsewhere in the tank. The affected volume generally increases with the time that the pump is operated. If the volume is defined as that material that has a shear rate greater than some value (e.g., 0.1 sec^{-1}), the code calculations of affected volume would show a rapid increase in about a minute to 8,000 ft^3 (10% of nonconvective layer) and then little further change as the pump recirculates.[a]

3.1 AFFECTED VOLUME EFFECT ON GENERATION

The concern is that although jet mixing may not increase the rate of gas generation, the volume of affected waste might increase the rate because the waste being mixed will have a lower viscosity. An increase in the reaction rate might be expected if the reaction were diffusion-controlled and the path length over which the reacting species would have to diffuse were relatively long. For some of the same reasons given in Section 2.1, it is not anticipated that the size of the affected volume will cause a change in the rate of gas generation. If the temperature of the volume were to increase due to power input from the pump or some other chemical reaction not directly associated with the gas generation reactions, the rate of reaction could increase depending on the size of the affected volume.

Recent data suggest that the tank is cooling at about 2°C or more per year. If the cooling rate and the gas generation rate are correct, the activation energy associated with these two data sets is consistent with diffusion control (10 kJ/mol to 25 kJ/mol) of the reaction. The mean free path over which diffusion probably takes place is on the order of 1000 nm. (This is suggested by the work of Meisel at Argonne National Laboratory (ANL), in which it was determined that the distance between the "spurs" in which the

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(a) This example is for low-speed (15 fps) jets and a stable, cohesive slurry layer.

reactive species were generated is on the order of 1000 nm.) Actions such as stirring might be expected to affect diffusion controlled reactions if the diffusion distances were on the order of tens of millimeters, and this is not likely, according to the discussion in Section 2.4.

If the temperature of the affected volume were increased by the power input from the pump, the rate of gas generation might be expected to increase. The power input is expected to be relatively small for the anticipated affected volume. If, however, the affected volume were significantly smaller than anticipated, the power density and the resulting temperature will be higher. Using the observed activation energies from the synthetic waste studies should allow bounding the maximum increase in gas generation rate due to small increases in temperature.

3.2 AFFECTED VOLUME EFFECT ON RETENTION

The purpose of the mixing pump test beyond the initial phases discussed in this Safety Assessment is to find out if mixing will affect gas retention, especially in the affected volume. The expectation is that the mixing, by keeping the particles in suspension in the affected volume, will not allow the slurry to become thick enough to keep the gas bubbles from releasing. Thus, the newly generated gas will diffuse to the releasable size (larger) bubbles and be passed to the dome space. The holdup and episodic release will thereby be eliminated. These purposes are limited in the initial phases of the test because of the need for care and the assessment of what can be learned about the nature of the material and the jet effects during the progressing test program.

There are some suggested mechanisms that may give an increased retention of gas in the affected volume. One concern is that the release of some bubbles, probably the larger sizes, from the affected volume may make the remaining mixture more dense and less susceptible to suspension. If the mixing jet cannot keep this material suspended, the mixture may settle to a denser layer in some regions of the tank. If these regions cannot be stirred by the jets, it might be a longer time until sufficient buoyancy is generated to raise the material from these regions again. Thus, under these assumptions, the mixing might extend the time between burps but not greatly influence their size. This effect would not be readily observable until the jet orientation had been moved through all of its positions. After that time, a GRE could be attributed to resettled or unaffected regions of the tank. Matters concerning generation rate and particle size would not occur on the time scale of the affected volume question and are discussed under long-term effects (Section 2.5).

3.3 AFFECTED VOLUME EFFECT ON IMMEDIATE RELEASE

The concern is that the affected zone may be large. The concern and control logic is discussed in Section T, 2.0, of the Safety Assessment Report. The size of the affected zone that is predicted depends very much on the predicated initial conditions.

Calculations with fluid dynamic codes that include the presence of an expandable gas in the nonconvective layer have shown that the jets could trigger a general turnover if the gas is held in a metastable condition in the nonconvective layer. Such a condition would exist if the gas content were distributed such that the layer has the same void fraction everywhere. In that situation a displacement of a parcel of gas-containing slurry upward or downward makes it unstable relative to the slurry (it might not be unstable with respect to the convective layer in the tank) and it tends to continue to move in the displaced direction. According to the calculations, the viscosity does not sufficiently dampen the motion to keep it from spreading into the convective layer and a buoyancy-pumped rollover occurs. The viscosity used in the calculations is based on the measured values but includes the physics and theory of viscosity of particulate suspensions (as shown in Appendix F) as the material becomes diluted by mixing.

It is difficult to explain how the material would have achieved the predicated metastable condition or maintained it through the GRE that opened the window for the pump installation and operation. A calculation with

TEMPEST,[a] in which the same total gas content was held in the nonconvective layer in a stable condition (uniform mass concentration), showed the jet triggering did not occur in this case, and the gas stayed in the lower region in spite of motion occurring there.

The immediately releasable gas can be expressed by the following equation:

Gas releasable [G_R] = number of jets [n]
x Volume affected per jet [V_a]
x Fraction of gas in volume [f_g]
x Fraction of gas releasable [f_R]
x Pressure ratio (at gas location/at 1 atm) [r_p]

that is: $$G_R = n \bullet V_a \bullet f_g \bullet f_R \bullet r_p$$

This equation bypasses the use of detailed or speculative models of release mechanisms and can allow bounding calculations based on broad assumptions concerning the values of the specific factors. The releasable gas is dependent on the assumptions concerning the values of these terms.

The following is an example calculation:

The number of jets = 2

The volume affected may be calculated from fluid dynamic analysis and bounded by an effect criterion. Such a criterion may be a shear rate boundary, a velocity, a particle concentration, or a viscosity An example calculation by TEMPEST for five minutes of a nonbuoyant layer case gives about 10,000 ft^3, within a shear rate boundary of 0.01 sec^{-1}, for a 15 fps jet at five minutes.

(a) Trent, D. S., and L. L. Eyler. 1990. TEMPEST, A Computer Program for Three-Dimensional Time-Dependent Hydrothermal Analysis. PNL-4348 (Base Version), Pacific Northwest Laboratory, Richland, Washington.

The fraction of gas may be estimated from Allemann at the neutral buoyancy condition as 0.24.

The fraction of gas that is releasable depends on how the gas is held, how the holding power of the material in the affected volume changes, and how the release occurs (i.e., does the gas separate and rise independent from or with the slurry and, after rising, how much will pass into the dome space. An estimate in Allemann et al. is that about 12 vol% of gas is tightly held and is nonreleasable (except by extraordinary methods), and would be recompressed to about 6% nonreleasable at the location in the nonconvective layer. This gives the fraction releasable as

$$f_R = \frac{f_g - 0.06}{f_g} = \frac{0.24 - 0.06}{0.24} = 0.75$$

An average pressure ratio for gas in the nonconvective layer is 2.1. Thus, an estimate of the gas releasable by the startup of the jets is

$$G_R = 2 \times 10{,}000 \times 0.24 \times 0.75 \times 2.1 = 7560\ ft^3$$

New examples of the gas release calculation are being prepared for cases including gas buoyancy in the nonconvective layer.

3.4 AFFECTED VOLUME EFFECT ON LONG-TERM RELEASE

The concern is that in the affected volume the jet may change the nature of the particles in a way that will adversely change the long-term retention capability of the slurry. The discussion that follows suggests that the basic particle size would not be changed by the mixer pump because the particles (crystals) are so small relative to the viscous dissipation eddies generated by the pump. Shear rates generated in the affected volume are also too low to break the tiny particles. In the 1991 Annual Report, R. T. Allemann has reported that initial shear strengths of synthetic wastes that had been allowed to settle for extended periods were considerably higher than values obtained after momentary stirring. One possible explanation is that the shear strength of the nonconvecting solids is strongly influenced by the presence of dendritic sodium nitrite grains. Once these dendritic grains are fractured or dissolved, the shear strength of the waste should fall. With less shear strength resistance, gas bubble-solid particle rafts, if sufficiently buoyant, would be more likely to rise to the surface of the waste tank.

Gas release would be enhanced if some of the solid/gas-bubble combinations from the nonconvecting layer were mixed into the convecting layer. Because solid/gas-bubbles in the convecting layer do not have to overcome the shear strength associated with nonconvecting solids, the requirements for buoyancy and size of gas bubble that can release are less. If mixing were stopped it is expected that settling of the solids and reformation of dendritic strength would continue as before.

The other influence, heating the slurry by pump operations, would tend to reduce the strength and viscosity of the slurry and thus beneficially reduce the amount of gas that can be retained to produce a GRE.

As discussed in Section 2.4, the effect of shear within the pump is insufficient to change the fundamental particle size modes that have been measured in the waste core samples. The shear stresses in the jet-mixing zone are an order or two of magnitude smaller than in the pump; therefore, it is even more unlikely that the fundamental particle size would be changed by shear in this zone. However, the jet-affected zone definitely contains particles, and the particle size could change due to a shift in temperature caused by long-term pumping or mass transfer changes brought about by the changes in fluid motion.

The amount of temperature change due to the pump-work heating is possibly significant. If the 150-hp pump were left on continuously it would insert about 10 times the heat rate that currently results from the radioactive decay of the cesium and strontium in the tank. A temperature rise could be expected but would be controlled to remain within the design specifications of the tank. The test plan suggests that the pump would be run only about one hour per day; therefore, a temperature rise of 14°C (25°F) would take many months.

Temperature increases have been shown to reduce the viscosity and the shear strength of the samples of waste from Tank 241-SY-101.[a] If the temperature of the tank were allowed to increase due to pump work, the ability of the waste to retain gas would be reduced because of the changed properties of the slurry. Indeed, heating has been suggested as one means of mitigation that should be tested in the tank. Thus, operation of the pump that raises the temperature of the waste should make the material capable of retaining less gas before buoyancy overcomes the cohesive strength and the weight of material above, and a GRE, when it does occur, would be smaller. There is the possibility that an increased temperature would also increase the generation rate of gas. This increase is typical of a chemical reaction, but may be somewhat moderated by radiation-induced intermediate reactants that control the overall rate of gas generation. If the increased temperature increases the gas generation rate, the smaller GREs would occur more frequently, according to a long-term mass balance equation:

$$\dot{G} = f \cdot S_E$$

where $\dot{G}$ = generation rate of retained, and then released gas

f = frequency of gas release events

S_E = size of release of gas in a GRE (in consistent units).

With S_E smaller and $\dot{G}$ larger due to temperature, the frequency would increase. This smaller, more continuous release is a desirable mitigation result.

Another consideration concerning long-term mixing effects is whether the mixing will change the particle morphology, giving the slurry a higher cohesive strength and thus a higher gas retention capability. Crystal morphology or habit in a saturated crystallizing mother liquor is a complicated function of certain conditions. The crystallization depends on the nucleation and growth rates, and the heat and material balances in the tank. The tank has

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(a) Tingey, J. M. February 1992. Physical Characterization of Tank 101-SY Core Samples from Window C. Pacific Northwest Laboratory, Richland, Washington.

existed in the saturated condition for many years and has achieved a condition of crystal size that reflects the balance of the processes that are occurring. These processes may involve the creation of new nuclei that grow at the expense of larger crystals, thus bringing the average crystal size to that observed in the tank. Mixing is not likely to change the rate of creation of new nuclei since these occur at a microscopic size that is not influenced by the mechanical mixing action.

It is also possible that the dynamic equilibrium of particle morphology in the tank does not involve growth from new nucleation but is a balance of the rates of growth and dissolution of the crystals that are present. Growth and dissolution depend on the mass transport to and from the surface of the crystal. Generally, mixing would increase the rates of transport and allow a faster approach to the equilibrium size distribution if eddy diffusion is the rate controlling process. In some systems the rate controlling process for crystal growth is the integration of the solute molecule into the crystal face, and mixing does not have much effect on the rate. As mentioned in Section 3.1, the mean free path for molecular diffusion is on the order of 1000 nm, which is much smaller than the eddy size. The tank has had many years to approach a dynamic equilibrium condition and establish the crystal habit through the processes occurring in the tank. It is doubtful that speeding the process by mixing would result in conditions much different from those already reached.

Although in industrial crystallization large crystals are generally obtained in stagnant conditions and smaller crystals in mixed conditions, mixing by the pump in Tank 241-SY-101 is not likely to have this effect, because the crystals in the tank are so small already, and the length scale (eddy size) at which energy dissipation to molecular motion occurs is larger than the crystal size (see Appendix A). The mixing turbulence that the pump produces is therefore dissipated before it can influence the diffusion of the material to the crystal faces. The rate controlling step will therefore still be the molecular diffusion processes as in a non-mixed case.

In summary, the mixing pump will not affect the boundary layer controlled mass transfer to the crystals because the crystals are so small relative to the viscous dissipation eddies generated by the pump.

3.4.1 Foaming and Crust Formation

It has been discussed that the tiniest bubbles would not be expected to be created by the mixing pump action nor would they be encouraged to release. Person suggests that the increased viscosity of the convective layer may be a cause for increased foam and crust formation. His idea is that mixing will reduce the viscosity in the nonconvective region so that more bubbles will be able to rise from that layer, and because of the higher viscosity created in the convective layer, the bubbles created or transported there will move more slowly. He suggests that on balance more bubbles will reach the surface than do currently and that they may form a thicker foam and a thicker solid crust than currently exist. "Bringing large bubbles to the surface is much better than bringing many small bubbles, as the large bubbles burst, while the small bubbles form crust." The small bubbles do not burst because they are stabilized against film draining and from coalescence by their small size and perhaps by the presence of small particles that inhibit contact and coalescence. The crust might be formed from the foam by evaporation, which leaves a high void fraction structure of interlocking solids (crystals).[a] If this structure were continuous across the tank it could act as a thermal and mass transfer resistance, but the softer, damp foam probably acts in this manner anyway. The photos and videos of the tank show that the GREs effectively preclude the formation of a continuous hard crust. If the rollovers were stopped by using the pump and a continuous hard crust formed instead, it would not be sufficiently tight to prevent the gas from diffusing through (see Appendix F, Section F.4).

In the long term, the mixing pump should maintain the waste in the form of a somewhat uniform mixed/floating slurry. This slurry would still generate gas throughout, and this gas will be mobile enough to rise and release,

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(a) The crust might also be formed from carbon dioxide in the dome space air reacting with the sodium hydroxide to form sodium carbonate crust at the air liquid interface.

whereas currently, half the generated gas is captured in the nonconvective layer, where it forms large bubbles (as seen on the turnover videos). The gas retained in the nonconvective layer appears to cause GREs by achieving a buoyancy and turnover, releasing the large bubbles. The other half of the generated gas was assumed to be generated in the convective layer and is lost steadily because of bubble mobility. With the pump operating to keep most of the waste as a mixed slurry, all of the gas will have to be released by the steady general mechanisms that now occur in the convective layer. The difference is that the viscosity of the entire mixed waste volume will be higher than it is for the current convective layer alone.

Calculations shown in Appendix F indicate that the higher viscosity of the entire mixed waste volume compared with the current convective layer will limit release to a larger size of bubble, and that the holdup required to produce the larger bubbles at the same overall gas generation rate (for the entire tank) would be only about 0.007 vol%. Thus, in the stirred condition, the waste would have some additional bubbles in the mixed waste that would raise the level a negligible amount from a fully collapsed level of about 374 in. This level is less than the current level of over 400 in. that presumably results from about 20,000 ft^3 of gas being retained in the nonconvective layer. Most of that retained gas in the nonconvective layer, being of very large bubble size, would be released by mixing. The minor amount of holdup would be in the form of bubbles which, upon reaching a large enough size, will rise to the top and release gas. The diffusion rate of these bubbles is fast enough to make their numbers and volumes small. The holdup mode of gas release is expected to be smooth and not to be the episodic GRE behavior.

3.4.2 <u>Gas Transport out of Foam</u>

A stable foam is generally not possible in a saturated liquid because the surface tension cannot change with concentration. Increased concentration in normal foams tends to increase surface tension and prevent the film from breaking. However, another foam stabilization mechanism is that of particles that prevent the bubbles from contacting each other and coalescing. The bubbles that rise through the mixed waste may carry small particles with them.

This is the mechanism that is believed to give the existing crust in Tank 241-SY-101. The mixed waste will be a thicker slurry of particles that may tend to wipe off adhering particles and let the bubbles contact each other. Since the bubbles that are mobile will generally rise upward, they would collect at the top and either form a foam that is stable and must therefore lose its gas by diffusion, or they will coalesce until the gas can move out under the pressure gradient that drives permeation transport.

Diffusion will cause small bubbles under the influence of surface tension to lose gas to the larger bubbles. This mechanism would aid the coalescence and eventual benign release of gas.

If an increased amount of stable foam did form with the mixed waste condition, it would be detected by the level rise. Shutting off the pump mixing should allow the lifted particles to begin to resettle and reform the two-layer waste. The tank would revert eventually to its pre-mixed condition, because the fundamental nature of the particles would not be changed by the pump. Eventually, the waste would begin to roll over again and break up any new (continuous) crust that had formed.

3.5 AFFECTED VOLUME EFFECT ON SALTCAKE

One concern raised by the safety review group regarding plans for the mixer pump test scheduled for Tank 241-SY-101 is based on the following postulations:

- If the chemistry of the waste in Tank 241-SY-101 has not always been controlled within the tank farm operating specifications established for corrosion control, the tank wall could have become perforated due to pitting corrosion.
- If the tank wall had started leaking into the annulus through pin holes, salts in solution in the waste might have crystallized in the holes or on the surface of the tank, sealing the holes and acting as a barrier to further leaking.

From this premise a concern has been raised that the action of the mixer pump (that is planned to be tested in Tank 241-SY-101 for hydrogen mitigation) might dissolve or scour away precipitated salts on the tank wall that may be plugging these perforations, if they exist. Tank waste might then leak into the annulus between the inner and outer walls of the tank. This concern is based at least in part on an observation made at the Savannah River Site (SRS), where a photograph or photographs taken from the annulus of a double-wall tank showing streaks down the wall of the tank where solution apparently leaked from pin holes. Later, the leaking stopped. It is postulated that salts have crystallized in the holes or on the inner surface of the tank wall and sealed the leaks.

Not enough is known about the specific chemistry of the waste in Tank 241-SY-101 now, what it has been historically, or how it may have interacted with the tank steel to say unequivocally that the postulated concern is either valid or invalid.

It is important to know if the interpretation of the SRS tank pitting/sealing observation is based on a detailed examination of tank history and tank waste chemistry, and also to know whether the sealed perforations were at a level corresponding to the vapor space, liquid/vapor interface, or below the liquid level of the waste. The relative positions of the holes would indicate which wall areas might be affected by the impinging jets from the mixer pumps.

Any pin holes located below the liquid/vapor interface (especially along the tank floor away from the pump and on the lower portion of the vertical wall) would have the highest potential for problems. Any saltcake removal would be highest in the area of highest impinging jet velocity. The hydrostatic head of the waste lower in the tank would also increase the potential for leaking if perforations existed.

Holes located at the liquid/vapor interface, a more likely location (localized corrosion is frequently more severe at the liquid surface, where the waste chemistry may vary significantly from the bulk solution), would be less likely to be affected by the action of the mixer jets, since analyses show that the fluid velocity is essentially zero at this point. Also, hydrostatic head would be essentially zero.

Perforations above the liquid level would not be impacted by the mixer jets. In corrosion tests performed for West Valley with mild steel coupons in simulated tank waste, the heaviest corrosion, including pitting, occurs in the vapor space where uninhibited (little or no hydroxide and nitrite ion) condensate keeps the coupons wetted. Therefore, vapor space holes in the tank wall could exist without creating problems for the mixer pump test.

No corrosion testing has been performed specifically with a simulated Tank 241-SY-101 waste to evaluate pitting potential. However, a large number of corrosion tests have been conducted with simulated wastes in a variety of concentrations of hydroxide, nitrate, and nitrite, the major components that determine the corrosiveness of the wastes. In a corrosion study by J. R. Divine (PNL) (ca. 1985) simulated wastes, some of which included relatively large concentrations of organics (like the Tank 241-SY-101 waste), were tested. The apparent effect of the organics in the simulant was to inhibit rather than increase corrosion of the steel. These results suggest that the waste in Tank 241-SY-101 may be more inhibiting to corrosion than similar wastes with lower organic concentrations.

Periodic samples have been taken from most of the double-shell tanks (DSTs), including 241-SY-101, to monitor compliance with tank farm operating specifications. Analyses of those samples indicate that Tank 241-SY-101 is within waste composition specifications for proper corrosion control. Only one DST (107-AN) is known to be outside the limits for inhibitor concentrations; the problem has existed for quite some time and has not been corrected, yet no evidence of primary tank failure has shown up through leak detection or annulus air sampling. No annulus inspections of the other DSTs have indicated perforations or leaking of the inner shell.

The possibility of the Tank 241-SY-101 inner wall being perforated is quite small. However, because this has not been proven, the possible action of the mixer pump jets on the tank walls and any adhering salt crystals should be addressed. Previous analysis and impinging jet corrosion testing[a] has shown that the jets from even larger mixer pumps and with higher exit velocities than planned for the 241-SY-101 test have little or no scouring action on

(a) Smith, H. D., and M. R. Elmore. January 1992. Corrosion Studies of Carbon Steel Under Impinging Jets of Simulated Slurries of Neutralized Current Acid Waste (NCAW) and Neutralized Cladding Removal Waste. PNL-7816, Richland, Washington.

the tank walls. Jet velocities are high enough to increase mass transport of reactants and reaction products involved in corrosion reactions of the tank steel, but not sufficient to erode the surface with solids in the simulated wastes that have been tested. In the typical DST mixer pump configuration the mixer pumps are located off-center, closer to the tank wall than the center riser location for the Tank 241-SY-101 mixer pump. Therefore, the combination of a larger, higher-velocity jet exiting the mixer pump and the pump being located closer to the wall means that the velocities of jets impinging the walls in these analyses are significantly higher than would be expected for the 241-SY-101 test. Although the resistance of precipitated salts to the mixer pump jets is unknown, it seems unlikely that the force of the Tank 241-SY-101 mixer pump jets impinging on or flowing along the wall surface would be energetic enough to scour away any salts that are bound to the wall surface.

It also seems unlikely that any precipitated salts would be dissolved by the action of the mixer pump jets. The solution throughout the tank should be in chemical equilibrium due to the frequent turnovers of the tank contents that occur. The temperature increase from operating the mixer pumps could increase the solubility of some salts, but this effect is probably small.

A pinhole leak that has been stopped by salt precipitates is most likely to have been sealed somewhere within the pinhole and especially at the outside where evaporation causes the precipitation. The jet mixing action could not penetrate into the pinhole in a significant way to dissolve this type of seal.

In summary, there is no documentation that the Tank 241-SY-101 waste composition has been outside the tank farm operating specifications, resulting in significant potential for corrosion, especially pitting corrosion. Nor has it been shown that perforations have occurred that have subsequently resealed with crystallized salts from the waste. Next, the jet forces against the tank walls from previous analyses and impingement corrosion tests show little if any potential for "scouring" a salt layer from the tank wall. Assuming it is true that the mixer pump for the Tank 241-SY-101 test will be a smaller horse-power pump with lower jet exit velocities than previous DST mixer pump analyses, and that the pump is to be located in the center of the tank, unlike other DST configurations for waste retrieval (which means lower velocities when the jets reach the walls), the postulated concern poses no plausible threat to the Tank 241-SY-101 test.

It would be difficult and time-consuming to develop a suitable simulated Tank 101-SY waste with the proper chemical and scaled physical properties for testing, and to duplicate the necessary conditions in the tank that might crystallize a salt layer and those that may cause pitting of the tank steel. (The salt crystals on the surface of the steel are as likely to promote crevice corrosion or pitting underneath the salt as they are to plug any holes.) These properly scaled conditions would then have to be duplicated for laboratory-scale tests to simulate the mixer pump jets. It would be difficult to design laboratory tests that could simultaneously produce all the necessary waste, fluid jet, tank steel, and tank environment conditions to convincingly address this concern.

4.0 SAFETY ASSESSMENT OF JET MIXING: PILING-UP

Piling-up refers to the resettling of solids that have been stirred up or scoured from one area of the tank by the jets to other areas, forming a deeper layer of solids in some regions than would have existed without the pump mixing. The following discussion is a summary of sludge mobilization tests performed by Pacific Northwest Laboratory (PNL) using simulated waste to illustrate the likelihood of pile-up as observed in some tests.

In 1987, PNL conducted experiments with a 1/12-scale tank to investigate the effectiveness of mixer pumps to mobilize simulated sludge. Eighteen tests were conducted with different initial sludge depths, shear strengths, and mixer pump flow rates for total operating times up to 14 hours each. In these tests, the mixer pumps (either two or four) were rotated about their vertical axes, just as they will operate in the waste tanks. The results were reported in a PNL letter report,[a] including pictures of the final conditions for some of the tests after pumping out the slurry to observe the residual sludge. None of the pictures (or other unpublished pictures) from these tests show any increase in sludge depth (pile-up) at any location as a result of the mixer pump operation. In these tests, as in the actual waste tanks, the individual particle size is quite small (>90% are smaller than 50 microns), and once a particle is torn away from the sludge mass, it is quite easily maintained in suspension in the slurry because of the mixer pump action.

In 1988, PNL conducted a follow-on series of similar sludge mobilization tests, but the test vessel was a 30-in.-diameter plastic drum with a stationary nozzle mounted in the wall. Sludge was placed in the drum and allowed to consolidate to a desired shear strength. Then water was pumped through the nozzle, and the effective sludge mobilization distance was measured as a function of time and nozzle flow rate. Thirteen tests were conducted; none showed

(a) Fow, C. A., et al. September 1987. Pilot-Scale Retrieval Tests Using Simulated NCAW. Letter Report 7W21-87-15, Pacific Northwest Laboratory, Richland, Washington.

any sludge pile-up. The results, including one picture, are contained in a 1988 PNL letter report.[a]

Also in 1988, Westinghouse Hanford Company (WHC) conducted a test in a full-size waste tank (241-AP-102).[b] Fifty tons of crushed limestone (particle size unknown) were dumped into the one-million-gallon tank full of water through three separate 4-inch-diameter risers located 20 feet from the tank centerline and spaced 120 degrees apart. Also, 600 gallons of 50% sodium hydroxide were added through one of these risers. One kilogram of disodium fluorescein dye was added as a tracer for mixing tests.

A 150-hp submerged motor mixer pump, which was ordered at the same time and is essentially identical to the mixer pump to be used in Tank 241-SY-101, was installed at the center of the tank. The pump suction was 6 inches above the tank bottom, and the nozzle centerline was 18 inches above the tank bottom. It was operated at full speed (1180 rpm, ~1400 gal/min per nozzle with two 2.6-inch ID nozzles) for about two weeks while the mixer pump assembly was oscillated through an angle of $\pm$ 90 degrees at a rate of 87.1 degrees per minute (0.242 rpm). After about 12 hours the soluble contents of the tank were well mixed, but slurry samples showed that only about 10% of the limestone was suspended. Solids suspension did not improve significantly even at longer mixer pump operating times.

When the liquid contents were pumped out of the tank, video camera pictures showed that an annular pattern of residual limestone sludge was located about 1.5 feet from the wall, extending for about 75% of the circumference of the tank. The original average depth of limestone was not measured or known with accuracy, but was estimated to be 3 inches. The residual sludge depth appeared to be less than 6 inches at all locations even though the width of the residual sludge varied from 0 to about 3 feet.

(a) Whyatt, G. A., et al. 1988. FY 1988 Bench-Scale Sludge Mobilization Testing. Letter Report 7W21-88-05, Pacific Northwest Laboratory, Richland, Washington.

(b) Hunter, V. L. 1988. Operability Test Report for the In-Tank Mixer Pump (Tank 102-AP). SD-WM-OTR-81 Rev. 0, Westinghouse Hanford Company, Richland, Washington.

In this case, one might conclude that there was pile-up of the sludge. However, since 13.7 tons of limestone was originally added to the tank in three very definite piles that were much greater than 6 inches high, it is very apparent that the mixer pump operation caused a major redistribution and leveling of the sludge. It is also interesting that the sludge was not collected or piled against the tank wall, but rather the downward momentum of the liquid jet, after it impinged the wall, caused the wall-to-knuckle region of the tank to be cleaned of sludge.

Hopefully, this brief description will help in the analysis of the hydrogen mitigation mixer pump test planned for Tank 241-SY-101.

4.1 PILING-UP EFFECT ON GENERATION

The concern is that a higher temperature would be attained in the piled up region, which would cause a higher reaction rate and therefore more gas generation and retention. A thermal analysis of an extreme pile-up case in Tank 241-SY-101 (Appendix B) shows that piling-up of the nonconvective slurry due to the jet action would impact neither the temperatures nor the subsequent gas generation of the waste. The results show that temperature profiles would shift with the geometry but that the volume of waste that would be heated to a given temperature would be actually less in the pile-up scenario than in the undisturbed condition.

4.1.1 Flat Pile-up Scenario

The type of pile-up described in the previous paragraphs was considered for a heat transfer analysis by assuming that all the nonconvective slurry was removed from two opposite 30-degree wedges by the jets and deposited on top of the remaining 5/6 of the sludge cake. This scenario increases the depth of the nonconvective layer by 20% in the remaining part of the sludge layer. The results of a thermal analysis of this situation (Appendix C) indicate that in 100 days the peak temperature would be no higher than the undisturbed nonconvective layer. However, the volume of waste that would have achieved this temperature is increased by 25%. If the gas production is influenced by the temperature, the gas production rate would increase by less than 25% because the more heated region represents only a part of the total gas generation.

4.2 PILING-UP EFFECT ON RETENTION

The concern is that the pump action may tend to move and pile up the scoured sludge rather than suspending it. The sludge would then be piled deeper in some places than it had been before the pumping, and this may increase the amount of gas that can be retained. The following discussion suggests that an increase of retention is unlikely, because the buoyant instability of the pile-up material is higher than it is for level sludge (see Appendix E).

In Section 4.1 it is shown that piling up the waste would not fundamentally change the peak temperature from that existing in the tank with a level nonconvective layer. Hence, the gas generation (if dependent on the temperature) would be lower but not much different. It is estimated that in the fully piled-up condition, the amount of sludge in the 134°F contour would be about 90% of that in the undisturbed, level-layer condition. The weakening of the cohesive strength with temperature that has been observed in tank waste samples would then be maximized in the region of peak temperature in the pile. This cohesiveness would have to resist an asymmetrical hydrostatic force. The lack of symmetry suggests that the hydrostatic balance needed to retain gas would be less stable in the case of the piled sludge than in the case of the level sludge (see Appendix E). The vertical buoyancy forces of the retained gas, instead of being resisted by the vertical weight force of the overlying material and material cohesiveness, would be resisted by the skewed weight (partially hydrostatic) force of the deep sludge on one side and only partly canceled by the hydrostatic pressure force of the liquid on the other side. This skewed force would tend to reduce the angle of repose and to level the pile-up if motion were not prevented by internal friction. If more gas per unit volume were generated within the hottest contour of the pile-up, then the lifting force of the gas would be larger within this contour. The lifting force combined with the weight force along the wall would form a couple, tending to rotate the sludge, level the pile, and let the gas rise. The buoyancy or gas content required for this to occur would be less than that needed to become unstable in the level sludge case, because of the large couple formed and because the gas in the pile is at a lower hydrostatic pressure, thus giving more volume and buoyancy than in the nonlevel case. Higher viscosity would be required to maintain the pile in a condition of instability than would be required for the level layer in its Rayleigh instability situation.

The piled material would tend to overturn and release gas. The smaller amount of retained gas would thus tend to reduce the size of subsequent GREs relative to those with the level nonconvective layer. The actual size of GREs would be subject to variation due to the history of the previous releases and the degree of release that may have occurred when the pile-up was produced by the pump.

In summary, it does not appear that extreme pile-up would substantially increase the retention of gas in the waste; more probably, retention would be reduced.

APPENDIX A

ESTIMATION OF SIZE OF DISSIPATION EDDY AND STABLE BUBBLE SIZE

APPENDIX A

ESTIMATION OF SIZE OF DISSIPATION EDDY AND STABLE BUBBLE SIZE

In turbulence theory there are several scales of turbulence that are used to describe the process of the cascade of energy from its generation in the fluid to its dissipation by molecular motion or heat. These eddy scales are the convective and diffusive, which are large, and the small-scale molecular and turbulent Kolmogorov scales in turbulent motion. On the basis of Kolmogorov's universal equilibrium theory of the small scale structure, the length scale of the dissipation eddies can be estimated if the energy dissipation rate per unit mass is known.[a]

This length scale is the eddy size at which viscosity is effective in smoothing out the flow and dissipating the energy as heat. This length is given by:

$$\eta = (\nu^3/\epsilon)^{1/4}$$

where η = Kolmogorov microscale of length
ν = kinematic viscosity
ϵ = energy dissipation per 2 unit mass.

Assume that the 150 hp pump energy is dissipated in one-sixth the tank waste volume having an average specific gravity of 1.5. This gives

$$\epsilon = \frac{150 \times 745.7\ [N \cdot \frac{m}{\text{sec}}]}{\frac{4418}{6} \times 32 \times \frac{62.4}{2.2} \times 1.5} = 0.112 \frac{m^2}{\text{sec}^3}$$

(a) Tennekes, H., and J. L. Lumley. 1972. A First Course in Turbulence. The MIT Press, Cambridge, Massachusetts.

The viscosity of warm liquid in the tank is about 20 mPa-s, so the kinematic viscosity is:

$$\nu = \frac{20 \times 10^{-3} [Pa \cdot s]}{1.5 \times \frac{1000\ kg}{m^3}} = 13 \times 10^{-6} \frac{m^2}{sec^2}$$

The dissipation scale length is:

$$\eta = \left(\frac{(13 \times 10^{-6})^3}{.112}\right)^{1/4} = 380\ \mu m$$

This size of dissipation eddy is larger than the large particle size distribution mode (100 μm diameter) in the tank waste. The flow that a particle experiences will be essentially laminar in the neighborhood of a particle. Hence, the turbulent eddies should not significantly influence the diffusion of material to the surfaces of these tiny crystals, and the crystal morphology will be little affected by the mixer pump.

CALCULATION OF LARGEST BUBBLE SIZE IN PUMP

By dimensional arguments, Thomas[a] has shown that the diameter of the largest bubble stable against breakup in a turbulent flow field is given by:

$$d_L \sim \left(\frac{\sigma}{\rho}\right)^{3/5} \epsilon^{-2/5}$$

where σ = surface tension
ρ = density
ϵ = energy dissipation.

(a) Thomas, R. M. 1981. "Bubble Coalescence in Turbulent Flows." Int. J. Multiphase Flow, 7(6):709-717.

Assuming that 10% of the pump brake horsepower (103 hp) is dissipated in an estimated pump internal volume of 0.433 m^3, a surface tension of 78 d/cm (similar to 3 <u>M</u> sodium nitrate), and a specific gravity of 1.5, the above equation yields an estimated maximum bubble size of 1000 μm. Therefore, the turbulence in the pump and initial part of the jets would tend to break larger bubbles to this (order of magnitude) diameter.

APPENDIX B

THERMAL ANALYSIS OF PILE-UP SITUATION IN TANK 241-SY-101

Westinghouse
Hanford Company

Internal
Memo

From: Fluid Systems
Phone: 376-4511 L5-07
Date: July 15, 1992
Subject: JET PUMP PILING UP

FSA-92-008

To: R. T. Alleman K7-15

cc:

T. R. Beaver	H0-33	F. J. Heard	H0-34
T. R. Benegas	H5-09	G. D. Johnson	R2-78
T. M. Burke	H0-34	W. L. Knecht	H0-34
S. C. Chang	H0-34	M. R. Kreiter	K7-90
W. L. Cowley	H5-31	J. W. Lentsch	R2-78
L. E. Efferding	H0-33	R. M. Marusich	H5-32
J. M. Grigsby	H5-32	D. M. Ogden	H0-34
F. C. Han	L5-07	K. Sathyanarayana	H0-34
C. E. Hanson	H5-09	S. A. Wood	H0-34

References:(1) Internal Memo, G. L. Fox to J. M. Grigsby, "Tank 101-SY Heat Transfer Studies," dated March 6, 1992.

SUMMARY

This thermal analysis of the SY-101 tank shows that piling up of the non-convective slurry due to jet pump action does not impact the temperatures and subsequent gas-generation of the waste. The results show that temperature profiles shift with the geometry but that the volume of waste that is heated to a given temperature is approximately equal for both the pile-up scenario and the undisturbed condition.

INTRODUCTION

The purpose of this analysis is to determine the thermal impact due to an assumed redistribution of the tank contents due to the action of the mixing pump during the mitigation test. If this were to happen, the geometry of the waste would change and possibly increase the effective path length for heat loss by conduction through the non-convective waste. The analysis presented here uses a simplified model to compare temperature profiles for both the pile-up and undisturbed conditions for a 100 day transient solution. The geometry of the model was based on information received from Z. I. Antoniak and conservatively simplified to simulate a worst case condition.

MODEL

Two models were used in the analysis, one for the pile-up scenerio and one for the undisturbed condition. Both models were generated in COSMOS/M using plane2d elements in an axisymmetric solution. The undisturbed model consists of 200 inches of non-convective slurry and 216 inches of convective slurry. The pile-up condition models the non-convective slurry with a 43 degree sloped surface projecting radially up from the center. To be conservative, the slope is assumed to be the same all the way around the tank. The resulting volume of non-convective waste for a 43 degree slope is actually 50% more than what's in the tank which results in approximately 30% more heat generation but this is considered conservative. Both models use convection off the top, bottom and sides for heat loss and internal heat generation as shown in table 1. The initial temperature for both cases is 120°F. Material properties were taken from Reference 1.

TABLE 1. MATERIAL PROPERTIES

	MP	DENSITY		CONDUCTIVITY		SPECIFIC HEAT	
		lb_f/in^3	lb_m/in^3	Btu/ft hr °F	Btu/in sec °F	Btu/lb_m • °F	Btu/lb_f • m/sec^2
SLUDGE	1	0.06139	1.59E-4	0.35	8.1E-6	0.8	309
304SS	2	0.284	7.35E-4	31	7.1E-4	0.111	42.9
AIR	3	0.00004	1.03E-7	0.014	3.2E-7	0.24	92.7
NON-CONV	4	0.04657	1.21E-4	0.35	8.1E-6	0.8	309
CONV	5	0.048	1.24E-4	0.35	8.1E-5	0.8	309

CONVECTION (TOP) = 2E-6	Btu/in^2 s °F	Ref. Temp. = 100°F
CONVECTION (SIDE) = 2E-6	Btu/in^2 s °F	Ref. Temp. = 100°F
CONVECTION (BOT) = 3.65E-7	Btu/in^2 s °F	Ref. Temp. = 90°F
NON-CONVECTIVE HEAT GENERATION = 6.9E-8 Btu/sec in^3		
CONVECTIVE HEAT GENERATION = 2.9E-8 Btu/sec in^3		

RESULTS

Figure 1 shows the temperature contours in the waste after a 100 day transient solution for the undisturbed condition. Note that the maximum temperature reached is 134°F. To calculate the volume of waste heated to 134°F, a rectangle with the dimensions shown is rotated about the center axis.

The volume is:
$(3.14)(328)^2(80)=27E6\ in^3$
$= 117{,}000$ gal.

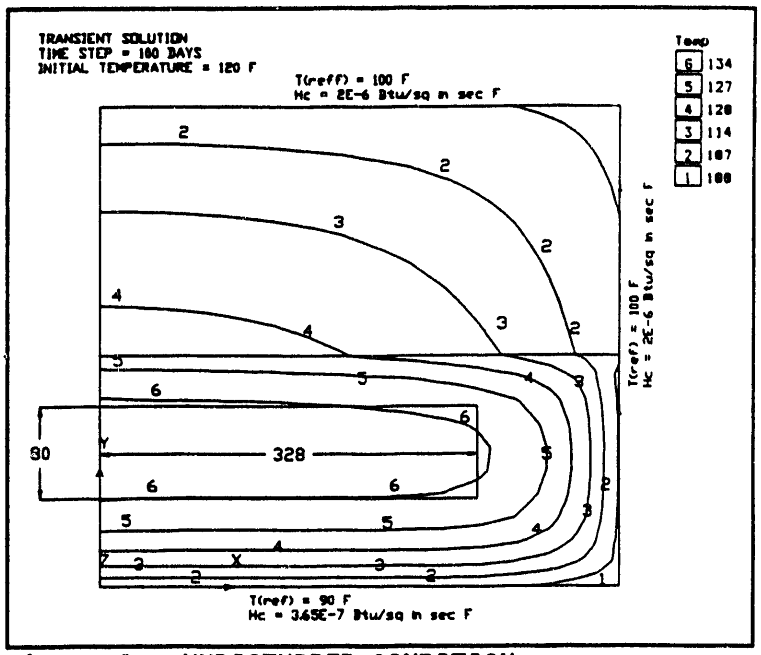

Figure 1. UNDISTURBED CONDITION

Figure 2 shows contours for the pile-up condition after a 100 day transient. The maximum temperature reached is also 134°F. The volume of waste heated to 134°F is calculated from a torrus with dimension estimated as shown in the figure.

The volume =
$(2)(3.14)^2(286)(70)^2$
$= 27.6E6\ in^3$
$= 119{,}000$ gal.

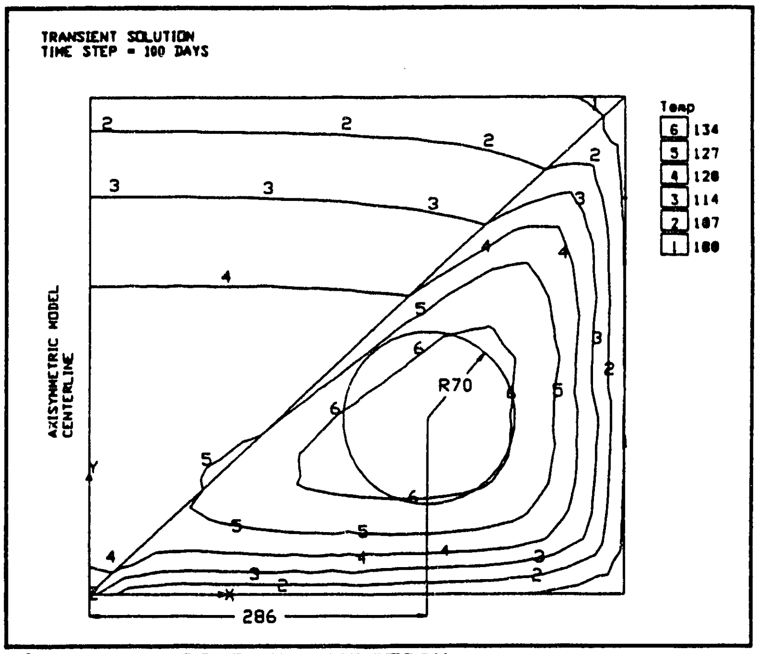

Figure 2. PILE-UP CONDITION

The difference in the two volumes is 2%. When the fact is considered that the total heat generation for the pile-up scenerio is 30% more than actual, it becomes evident that the pile-up condition will not result in increased temperature profiles within the tank.

If you have any questions please contact me at 376-4511.

M. D. Northey

M. D. Northey, Senior Engineer

CONCURRENCE:
W. L. Knecht

W. L. Knecht, Manager
Waste Characterization Analysis

Date: 7/29/92

APPENDIX C

THERMAL ANALYSIS OF FLAT PILE-UP SCENARIO IN TANK 241-SY-101

Westinghouse
Hanford Company

Internal
Memo

From: Fluid Systems
Phone: 376-4511 L5-07
Date: August 18, 1992
Subject: JET PUMP PILING UP, FLAT PILE-UP SCENARIO

To: R. T. Alleman K7-15

cc:

T. R. Beaver	H0-33	F. J. Heard	H0-34
T. R. Benegas	H5-09	G. D. Johnson	R2-78
T. M. Burke	H0-34	W. L. Knecht	H0-34
S. C. Chang	H0-34	M. R. Kreiter	K7-90
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References: (1) Internal Memo, G. L. Fox to J. M. Grigsby, "Tank 101-SY Heat Transfer Studies," dated March 6, 1992.

(2) Internal Memo, M. D. Northey to R. T. Alleman, "Jet Pump Piling Up," date April 15, 1992

SUMMARY

This thermal analysis is in response to a request by R. T. Alleman to consider an additional pile-up scenario in addition to the work performed in reference 2. The description and results of the previous analysis are included in this report for convenience. The additional scenario considers an increased depth in the non-convective waste and the results show that the maximum temperature reached for the 100 day period is the same as the undisturbed case but that about 25% more waste is heated to that temperature.

INTRODUCTION

The purpose of this analysis is to determine the thermal impact due to an assumed redistribution of the tank contents due to the action of the mixing pump during the mitigation test. If this were to happen, the geometry of the waste would change and possibly increase the effective path length for heat loss by conduction through the non-convective waste. The analysis presented here uses a simplified model to compare temperature profiles for two pile-up conditions against an undisturbed condition for a 100 day transient solution. The geometry of the model was based on information received from Z. I. Antoniak and conservatively simplified to simulate a worst case condition.

MODEL

Three models were used in the analysis, two for the pile-up scenario and one for the undisturbed condition. The models were generated in COSMOS/M using plane2d elements in an axisymmetric solution. The undisturbed model consists of 200 inches of non-convective slurry and 216 inches of convective slurry. The first pile-up condition models the non-convective slurry with a 43 degree sloped surface projecting radially up from the center. To be conservative, the slope is assumed to be the same all the way around the tank. The resulting volume of non-convective waste for a 43 degree slope is actually 50% more than what's in the tank which results in approximately 30% more heat generation but this is considered conservative. The second pile-up condition assumes that two 30° sections (per conversation with R. Alleman) in the non-convective waste area are replaced with convective waste and that the non-convective waste removed is deposited evenly along the top of the remaining 300° of undisturbed non-convective waste. This results in an increased depth of 40 inches in the undisturbed non-convective waste. The models use convection off the top, bottom and sides for heat loss and internal heat generation as shown in table 1. The initial temperature is 120°F. Material properties were taken from Reference 1.

TABLE 1. MATERIAL PROPERTIES

	MP	DENSITY		CONDUCTIVITY		SPECIFIC HEAT	
		lb_f/in^3	lb_m/in^3	Btu/ft hr °F	Btu/in sec °F	Btu/lb_m • °F	Btu/lb_f • m/sec^2
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CONVECTION (TOP) = 2E-6 Btu/in^2 s °F Ref. Temp. = 100°F
CONVECTION (SIDE) = 2E-6 Btu/in^2 s °F Ref. Temp. = 100°F
CONVECTION (BOT) = 3.65E-7 Btu/in^2 s °F Ref. Temp. = 90°F
NON-CONVECTIVE HEAT GENERATION = 6.9E-8 Btu/sec in^3
CONVECTIVE HEAT GENERATION = 2.9E-8 Btu/sec in^3

RESULTS

Figure 1 shows the temperature contours in the waste after a 100 day transient solution for the undisturbed condition. Note that the maximum temperature reached is 134°F. To calculate the volume of waste heated to 134°F, a rectangle with the dimensions shown is rotated about the center axis.

The volume is:
$(3.14)(328)^2(80) = 27E6\ in^3$
$= 117,000$ gal.

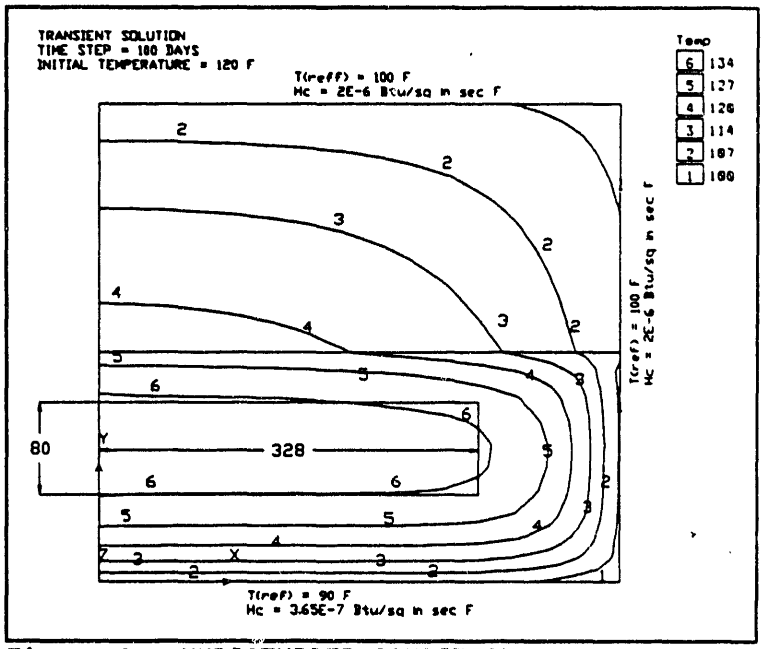


Figure 1. UNDISTURBED CONDITION

Figure 2 shows contours for the pile-up condition after a 100 day transient. The maximum temperature reached is also 134°F. The volume of waste heated to 134°F is calculated from a torus with dimension estimated as shown in the figure.

The volume =
$(2)(3.14)^2(286)(70)^2$
$= 27.6E6\ in^3$
$= 119,000$ gal.

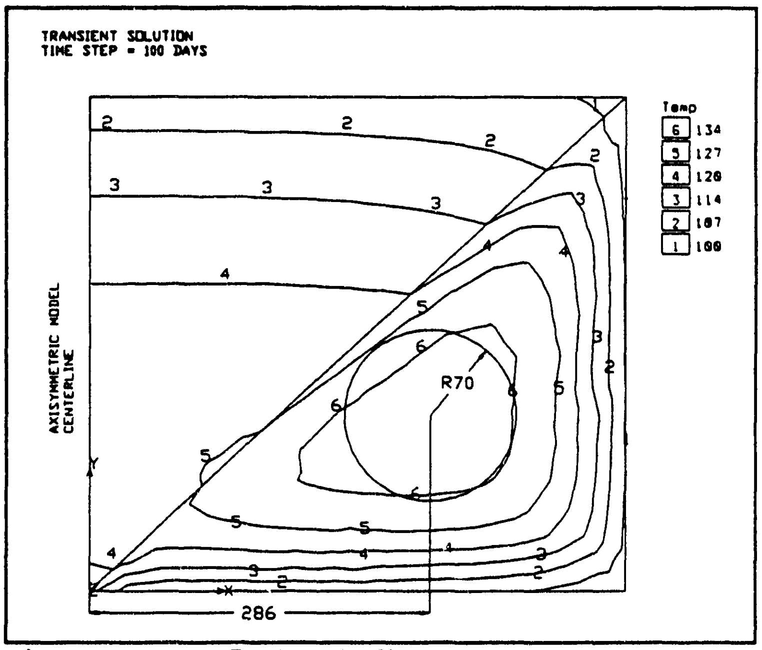


Figure 2. PILE-UP CONDITION

The difference in the two volumes is 2%. When the fact is considered that the total heat generation for the pile-up scenario is 30% more than actual, it becomes evident that this pile-up condition will not result in increased temperature profiles within the tank.

Figure 3 shows the temperature contours in the waste after a 100 day transient solution for the increased depth pile-up condition. Note that the maximum temperature reached again is 134°F. To calculate the volume of waste heated to 134°F, a rectangle with the dimensions shown is rotated about the center axis.

The volume is:
$(3.14)(335)^2(116)$=41E6 in^3
= 177,000 gal.
Less the volume of the two 30° sections (1/6*V)

= 147,000 gal.

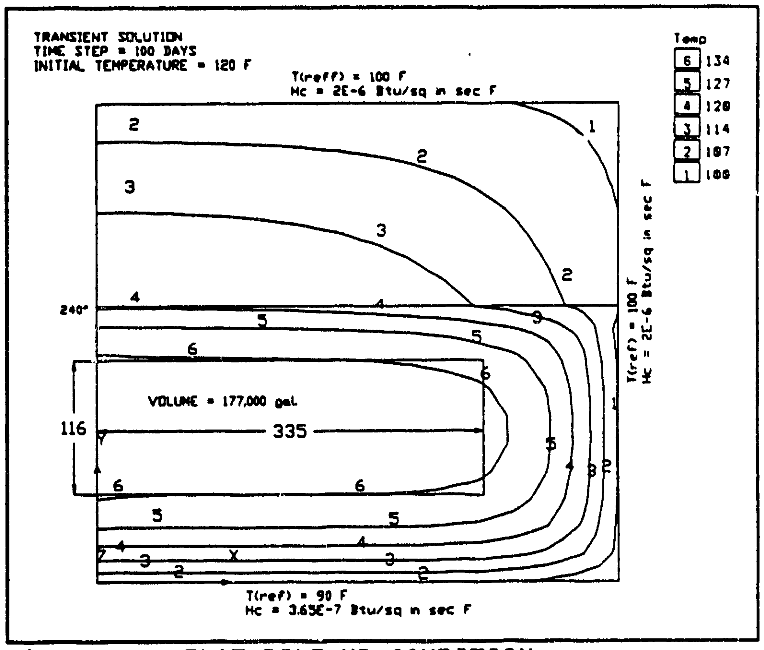


Figure 3. FLAT PILE-UP CONDITION

The resulting volume of waste heated to 134°F is about 25% more than the volume heated to 134°F in the undisturbed case. The peak temperature for all three conditions is 134°F. This is because the capacity to transfer heat is small when one considers the large volumes and subsequent long effective path lengths for conduction. The volume heated to 134°F in all three cases would be similar to heating that volume under adiabatic conditions. This can be shown by multiplying the heat generation rate by the specific heat of the waste for a unit volume:

Q*t=m*Cp*(T1-T2)
T1= (Q*t)/(m*Cp) + T1
= (5.96e-3 Btu/day * 100 days)/(0.04657 lb * 0.8 Btu/lb °F) + 120°F
T1= 136°F

Therefore, for time periods less than one year, the volume of waste that is heated to a given temperature is dependent on the geometry of the waste while the maximum temperature reached in the waste is primarily a function of time.

If you have any questions please contact me at 376-4511.

M. D. Northey, Senior Engineer

CONCURRENCE:

W. L. Knecht, Manager　　　　　　　　　　Date:
Waste Characterization Analysis

APPENDIX D

CALCULATION OF BUBBLE DRIFT INTO PUMP INLET

APPENDIX D

CALCULATION OF BUBBLE DRIFT INTO PUMP INLET

Calculation of Bubble Size Likely to be Ingested into Pump Inlet

The pump is approximately 42 in. (3.5 ft) in diameter. Assume that the material passing into the pump passes horizontally and upwards through a boundary cylinder 42 in. in diameter. This has a total inlet area of 20.6 ft^2.

At a maximum flow of 87 fps through two 2.6-in. nozzles, the pump volumetric flow is about 6.4 ft^3/sec.

Hence, the average velocity toward the inlet is 6.4/20.6 = 0.31 ft/sec.

The Stokes regime rise velocity of a bubble is given by

$$v = \frac{1}{18} \frac{d^2 g (\rho_f - \rho_g)}{\mu_f}$$

where d = diameter

g = acceleration

ρ = density

μ = viscosity

f and g = fluid and gas, respectively.

This equation can be solved for the diameter of a bubble having the inlet velocity in the supernatant liquid of viscosity 24 cP and specific gravity of 1.46. Then

$$d = \left(\frac{18 \times 0.31 \times 24 \times 6.4 \times 10^{-4}}{1.46 \times 62.4}\right)^{\frac{1}{2}} = 0.00307 \text{ ft} = 0.037 \text{ in.}$$

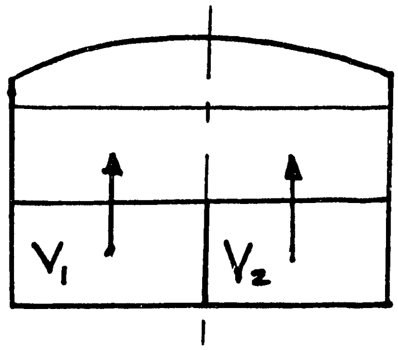
Bubbles larger than this size would travel faster and be less influenced by the inlet velocity of the pump and would be more likely to rise past the pump inlet.

APPENDIX E

ILLUSTRATION OF PILE-UP INSTABILITY

APPENDIX E

ILLUSTRATION OF PILE-UP INSTABILITY



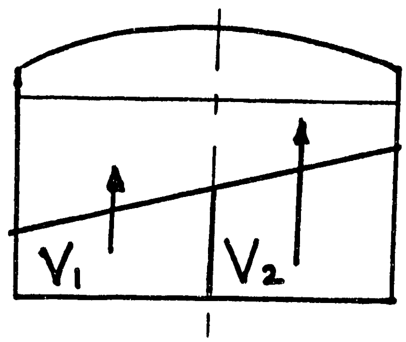
CASE 1. Level Nonconvective Layer

Buoyant force on two parts, one each side of center, depends on density difference, $\Delta\rho$.

The buoyant force on each side:

$$V_1 \Delta \rho \approx V_2 \Delta \rho$$

The buoyant forces are nearly equal, so the turning moment is small and low strength or force is needed to resist the motion.



<u>CASE 2</u>. Piled-up Surface of Nonconvective Layer

Buoyant force on two parts depends on the volumes.

The buoyant force on each side:

$$V_1 \, \Delta\rho < V_2 \, \Delta\rho$$

The buoyant forces are unequal, producing a larger turning moment that requires a higher force or strength to resist motion. Hence, turnover is more likely and the situation is less stable.

APPENDIX F

CALCULATION OF HOLDUP IN MIXED WASTE

APPENDIX F

CALCULATION OF HOLDUP IN MIXED WASTE

It has been suggested that 1) mixing will reduce the viscosity in the non-convective region so that more bubbles will rise from that layer; and 2) because of the higher viscosity created in the convective layer, the bubbles created there will move more slowly. Below is a rough estimate of the size of this effect based on some measured viscosities of the Core C samples.

F.1 CURRENT SITUATION IN CONVECTIVE LAYER

Approximately 75 ft^3/day of slurry growth gas (SGG) are being retained in the nonconvective layer until a GRE. It has been presumed that in a roughly equal volume of convective layer, an equal amount of gas is generated but is released continuously. If the generated gas forms into bubbles to release from the convective layer, one can estimate the bubble size that would drift to the top in the 100-day period that the nonconvective layer retains gas. The velocity is then

$$u = \frac{\text{height}}{\text{time}} \approx \frac{200 \times 2.54}{100 \text{ days} \times 24 \times 3600} = 6 \times 10^{-5} \text{ cm/sec} \qquad \text{(F.1)}$$

For small bubbles in Stokes rise regime the bubble size that would have this velocity in the material having a viscosity of about 30 cP is

$$D_s = \left(\frac{18u\mu}{\rho g}\right)^{1/2} = \left(\frac{18 \cdot 6 \times 10^{-5} \cdot 0.28}{1.46 \cdot 980}\right)^{1/2} = 4.6 \times 10^{-4} \text{cm} \qquad \text{(F.2)}$$

where D_s = diameter of rising bubble in Stokes regime

u = velocity of bubble

μ = viscosity of liquid

ρ = density of liquid

g = acceleration.

Thus, during the existing situation (having a convective and nonconvective layer), bubbles of 4.6-μm diameter and larger would have sufficient time to rise out of the convective layer. These bubbles may be those that collect particles and form the foam or crust near the top. The gas of about 4.6 μm and smaller that don't release would continue to grow and/or form a foam. However, gas generation versus release in the convective layer appears to be stabilized. There has been no evidence of continued level growth that would accompany foam/crust thickening. This layer is somehow allowing the gas to pass through, and indeed the calculation of Strachan[a] suggests that the crust is permeable at the rate of gas being generated. The foam or crust appears to be about two feet thick according to temperature measurements and represents about 6% of the level measured in the tank. Hence there appears to be a release from the convective layer at the bubble size that may exist there.

F.2 THE SITUATION AFTER MIXING

After using the pump, the turnover action combined with periodic pump use is hoped to bring all or most of the nonconvective layer into suspension and into a more fluid state such that gas will be mobilized and can release continuously as described above for the convective layer. In this situation, the entire tank contents producing 150 ft^3 of gas per day will be presumed to be mixed into a slurry. Person[b] has measured the viscosity of a composite

(a) Strachan, D. M. 1975. Effect of Carbon Dioxide on the Permeability of Synthetic Hanford Saltcake. ARH-ST-130, Atlantic Richfield Hanford Company, Richland, Washington.

(b) Person, J. C. September 2, 1992. Gas Retention Tests on 101-SY Tank Waste After Mixing. WHC 12110-PCL-068, letter report to J. W. Lentsch, Westinghouse Hanford Company, Richland, Washington.

mixed sample as being 500 cP. This thicker mixture will require a larger bubble to drift out. On a similar basis, the velocity of the releasing bubble from the 33-ft deep mix would be:

$$u = \frac{\text{height}}{\text{time}} \approx \frac{33 \times 30.48}{100 \times 24 \times 3600} = 1.16 \times 10^{-4} \text{ cm/sec} \qquad \text{(F.3)}$$

And the Stokes regime bubble diameter would be:

$$D_s = \left(\frac{18u\mu}{\rho g}\right)^{1/2} = \left(\frac{18 \cdot 1.16 \times 10^{-4} \cdot 5}{1.6 \cdot 980}\right)^{1/2} = 26 \times 10^{-4} \text{ cm} \qquad \text{(F.4)}$$

Thus, a 26-μm bubble[a] will be needed to drift to the top of the slurry in the same time period that has been typical of the GRE intervals.

F.3 HOLDUP

Although no new processes have been introduced, there will be a range of bubble sizes (size group) between 4.6 and 26 μm that will be collected (or held up) in the tank which were released before and these will involve the entire gas production[b] of the tank. If the entire gas production is assumed to pass through bubbles of this size range, one can estimate the number concentration of bubbles involved. Thus the number of bubbles achieving the 26 μm size (and thus rising from the mixed waste) is:

(a) In a similar calculation, Person had estimated an 18 μm diameter from the releasing bubbles.

(b) Rate of gas production for entire tank of mixed waste is about 150 ft^3/day. Thus the volumetric rate is dVg/dt = 150/(24·3600·33.3·4418) = 1.18×10^{-8} $mL_{gas}/sec \cdot mL_{waste}$.

$$\frac{dN}{dt} = \frac{\text{rate of gas}}{\text{volume per bubble}} = \frac{\dot{V}}{V_b} = \frac{1.18 \times 10^{-8}}{\frac{\pi}{6} \times (26 \times 10^{-4})^3} = \frac{1.28 \text{ bubbles}}{\text{sec}\cdot\text{mL}} \quad \text{(F.5)}$$

There would be many more bubbles required to carry the gas production if they were at the lower end of the size group (about 230/sec•mL of the 4.6 μm bubbles). It is assumed for the holdup estimation that all of the gas production is absorbed by those bubbles in the size group and that there is no creation of bubbles in the size group and no coalescence occurs.[a] Then the number of bubbles in the size group stays the same, and per unit volume (at steady state for each interval of time) 1.28 bubbles would enter the size group at 4.6 μm as 1.28 were leaving at 26 μm. The entering bubbles would carry the equivalent of $(4.6/26)^3 * 150 = 0.83$ ft^3/day into the size group, and this will be considered negligible for this analysis.

The size group is like a reservoir. At steady state a reservoir can be any size and still have the inflows and outflows equal. The holdup is represented by the size of the reservoir, i.e., the amount of gas in the size group. For this group, gas flows in by diffusion to the bubbles in the group and flows out by virtue of some bubbles reaching the 26 μm size. The longer time it takes for the bubbles to grow, the larger the holdup.

A simplified[b] estimate of the time for the bubbles to grow will be made by considering the diffusion rate expected to an area-average-size[c] bubble in the size group and the number of bubbles that would absorb the gas generation rate. Since this is a rough estimate calculation at this point,

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(a) Coalescence would reduce the holdup by increasing the size of the bubbles to releasable size more rapidly. Creation of new bubbles would take some of the generated gas from that assumed to be growing the bubbles present.

(b) A more complete analysis would consider the changing bubble size with diffusion gain and how this would affect the relative growth rate of the bubbles within the size distribution.

(c) Area average size bubble for group is $[(4.6^2 + 26^2)/2]^{\frac{1}{2}} = 18.7$ μm diameter.

considerations of solubility, local hydrostatic pressure, and surface tension are disregarded as being of secondary importance.

Within the size group then the total volumetric gas generation rate is assumed to be diffused by molecular diffusion to the number of average size bubbles. Hence,

$$\dot{V}_g = cD_{AB} \frac{dx}{dz} N\overline{A_b} \frac{24000}{MW} \qquad \text{(F.6)}$$

where V_2 = gas generation

c = concentration of gas in solution

D_{AB} = diffusivity of gas

$\frac{dx}{dz}$ = gradient

N = number of bubbles/volume

$\overline{A}_b$ = mean area of bubble

$\frac{24000}{MW}$ = gas volume per unit mass.

This equation is an adaptation of mass flux equations found in textbooks on mass transport.[a] The equation can be solved for N if the other factors can be estimated.

If the bubble size is small relative to the volume, the concentration gradient dx/dz will be approximately the saturated concentration divided by 1/2 the distance between bubbles. The distance between bubbles is roughly $(1/N)^{1/3}$. Then

(a) Bird, R. B., W. E. Stewart, and E. N. Lightfoot. 1960. Transport Phenomena, John Wiley & Sons, New York.

$$N = \left(\frac{2\dot{V}_g}{x c D_{AB} A_b} \times \frac{MW}{22400} \right)^{3/4} \qquad (F.7)$$

The most rapidly diffusing gas is hydrogen; it will determine the spacing of new bubbles and will be assumed to be representative of the diffusing gases in this estimate. Hydrogen accounts for about 1/3 of the generated gas, so:

$Vg = 1.18x10^{-8}/3 = 3.9x10^{-9}\ mL/mL_{waste}$

$MW = 2\ gm/mole$

$x \cdot c = 1.6x10^{-6}$ g H_2/mL based on Hydrogen Solubility[a]

$D_{AB} = 5x10^{-5}\ cm^2/sec$ in water[11].

But D_{AB} is inversely proportional to the viscosity according to the Stokes-Einstein equation; i.e., $D_{AB} \sim C/\mu$. Thus, for the 500 cP waste mixture,

$D_{AB} = 1x10^{-7}\ cm^2/sec$ in the waste mixture

$A_b =$ mean bubble surface area $= \pi D^2 = \pi(18.7x10^{-4})^2 = 1.1x10^{-5}\ cm^2$.

Using the above values, the estimated number concentration of bubbles in the 4.6 to 26 μm size group is $1.6x10^4$ bubbles/mL. The volumetric average size of the bubbles is $[(4.6^3+26^3)/2]^{1/3} = 20.7\ \mu m$. Hence, the volume of gas contained in the size group, or holdup is:

Volume fraction holdup $= 1.6x10^4 \cdot \pi/6 \cdot (20.7x10^{-4})^3 = 7.4x10^{-5}\ mL/mL_{waste}$.

(a) Allemann, R. T., et al. 1991. Mechanistic Analysis of Double-Shell Tank Gas Release. Progress Report, November 1990. PNL-7657, Pacific Northwest Laboratory,, Richland, Washington.

F.4 GAS TRANSPORT THROUGH CRUST

An estimate can be made of the resistance of a crust formed on top of the mixed waste to the permeation of generated gas through it, if it is assumed that the crust becomes continuous above the waste when pump mixing is successful and eliminates the episodic energetic rollovers that currently break up the crust.

Strachan[(a)] measured the permeabilities of synthetic Hanford salt cake made up and packed, eliminating gas inclusions. This material had a measured permeability of about 1 Darcy,[(b)] which can be taken as a conservative value for the crust that develops on top of the foam in Tank 241-SY-101 and on the samples of waste taken from the tank.

The Darcy equation

$$\frac{\Delta P}{L} = -\frac{\mu u}{k} \qquad \text{(F.8)}$$

where ΔP = pressure difference across material, atm.

L = distance across material, cm

k = permeability, Darcys

μ = viscosity, cPoise

u = superficial velocity of gas, cm/sec,

can be solved for ΔP using

L = 3.3 feet = 100 cm

k = 1 Darcy

(a) Strachan, D. M. 1975. Effect of Carbon Dioxide on the Permeability of Synthetic Hanford Salt Cake. ARH-ST-130, Atlantic Richfield Hanford Company, Richland, Washington.

(b) Amyx, J. W., D. M. Bass, and R. L. Whiting. 1960. Petroleum Reserve Engineering, p. 71. McGraw-Hill, New York.

μ = 0.015 cP (typical value for gases)

u = $-Q/A = -[150\ ft^3/day/\ (24 \cdot 3600)/\ 4418] \times 30.48 = -1.2 \times 10^{-5}$ cm/sec

Thus, the pressure difference across 100 cm of crust like Hanford salt-cake, that would allow the total gas generation rate to permeate through the crust is

$$\Delta P = 1.8 \times 10^{-5} \text{ atm} \tag{F.9}$$

The pressure created by the weight of the crust would be about:

$$1.3 \times 3 \text{ feet}/33.9 \text{ (ft } H_2O/\text{atm)} = 0.11 \text{ atm} \tag{F.10}$$

This pressure is well above that needed to transmit the gas through the crust. This indicates that large bubbles do not have to reach a liquid free-surface to release their gas benignly. Sufficient gas release can be obtained by permeation from gas under the crust.

END

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