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Date: 11/5/97

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25 November, 1996

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To: Jeff Newman, 703-H

From: Paul d'Entremont, 703-H, 208-8727

Modeling Assumptions for Tank Farm Performance Evaluation

The purpose of this note is to document a number of informal discussions between Phil Young, Phillip Fulmer, you, and me. These discussions concerned assumptions that should be made in assessing the performance of closed waste tanks in F and H area. I won't recount all the discussions, but we finally agreed on the following:

- Sludge concentrations in the bulk sludge should be estimated based on a spreadsheet developed by Bob Hester, entitled "sldginv.xls," revision of 10/31/96. The spreadsheet is documented in J. R. Hester, "High-Level Waste Characterization System," WSRC-TRI-96-0264. I have reviewed and signed a copy of the report, but it has not been issued yet.

- The concentration of Tc-99 in the residual solids left in a tank should be assumed to be 13.5 times the concentration in the bulk sludge. This estimate is based on sampling of Tank 20. In this tank, the bulk sludge was predicted to have a Tc-99 concentration of 6.94 E-05 Ci/kg but the residual solids had a measured concentration of 9.4 E-04 Ci/kg (0.94 microCi/gm). This is not believed to be representative of all waste tanks but is a conservative screening assumption (P. D. d'Entremont and D. T. Bignell, "Options for Meeting Class C Criteria During HLW Tank Closure," WSRC-TR-96-0327, 16 October 1996). Tank 20 is the only salt tank in which the composition of the residual solids after spray washing has been measured. The difference between the predicted and measured concentrations is not understood but may be due to some sort of concentration mechanism such as the cryolite formation that caused the concentration of fluoride in Tank 20. Unfortunately, the Tc-99 data in Tank 20 is the only data available at this time. Further experience with waste removal will allow the collection of further data, which will result in better estimation of the concentration of residual solids.
- Inventories to be assumed in each waste tank should be 1000 gallons of residual solids in Tank 20, 2000 gallons in Tank 17, and 1000 gallons in all other tanks. Note that this assumes that the zeolite will be removed from Tank 19. I have

discussed this assumption with Larry Ling of DOE, and he is comfortable with it. As we have discussed, these numbers will change as we get more information (such as pumping down Tank 17 to see how much sludge is actually there) and as we perform more waste removal (i.e. once we find how much zeolite is left in Tank 19, we can more accurately estimate the inventory).

- Residual solids are assumed to have the same density as sludge, i.e. 1.95 pounds of insoluble solids per gallon of sludge. For example, 1000 gallons of sludge would be 1950 pounds (886 kg) of residual solids.

The inventories computed using this methodology are different from what I reported in March (P. D. d'Entremont, "Waste Characterization Input Information for NUS Performance Assessment, 25 March 1996) but are in the ballpark. The concentrations reported by Bob Hester in sldginv.xls are based on a rigorous accounting technique that is better than what we did in March. The differences are as follows:

- Fission products: The inventories reported in March are based on ratios to Sr-90. Bob and I had some data on Sr-90 concentrations that caused us to adjust the numbers upward, but we had no data on Tc-99 at that time. The concentrations reported in sldginv.xls are based on a rigorous accounting of transfers from the canyon and should thus be more accurate than what we did in March. The rigorous accounting was not available in March, which is why we took the approach we did.
- Transuranic nuclides: The concentrations from March and today were computed the same way, i.e. rigorous accounting of canyon transfers. Several errors in the earlier spreadsheet have been corrected, but the errors should be insignificant in a performance evaluation study.

\# 20220

Distribution for WSRC-TR-96-0267, "Characterization of Tank 20 Residual Waste," 17 March 1997

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Characterization of Tank 20 Residual Waste

BY

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17 March 1997

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1. Introduction

Plans are to close Tank 20, a type IV Waste Tank in the F-area Tank Farm, by filling it with pumpable backfills. Most of the waste was removed from the Tank in 1988, so only residual waste remains. More details on the planned closure can be found in the Closure Plan for the HLW Tanks[1] and the specific closure module for Tank 20.[2]

To show that closure of the tanks is environmentally sound, a performance evaluation has been performed for Tank 20.[2] The performance evaluation projected the concentration of contaminants at various locations and times after closure.

This report documents the basis for the inventories of contaminants that were used in the Tank 20 performance evaluation.

2. Summary

Photographs of Tank 20 show that most of the tank is covered by a thin layer of brown solids. The volume of this solids layer is estimated to be approximately 1000 gallons, which is equivalent to about 1950 pounds of dried solids. The tank also contains a number of piles of white solids that have precipitated from the ballast water that has been left in the tank. The solids are a mixture of cryolite, sodium sulfate, and sludge. The volume of the white piles is estimated to be less than 50 gallons.

The composition of these two different types of solids has been estimated by two means: 1) predictions based on the knowledge that the material entering the tank was PUREX Low-Heat Waste, and 2) samples. The samples have shown that the predictions based on process knowledge were reasonable, although a few adjustments are in order. HLWE recommends that the process knowledge estimates of the inventory be used for all contaminants except for Tc-99 and Pu-238. For these two radionuclides, the inventory estimates should be raised to reflect what was learned from sample results.

The recommended inventories to be assumed for modeling purposes in Tank 20 are shown in Tables 1 and 2 at the end of the report.

The contaminants reported in Tables 1 and 2 are contained in the waste, which is primarily on the bottom of the tank. In addition, the risers on the top of the tank each contain lead. Based on the prints, a reasonable estimate is 500 pounds per riser, or 3000 pounds (1400 kg) of lead for the whole tank. Also, we recommend that an amount of waste be assumed to be outside of the tank to account for spills and other

equipment in the Tank 17-20 area, such as the 1F Evaporator and CTS. An allowance of 20% of the tank inventory in these four tanks should be sufficient to bound contributions from the other sources.

Plans are for the contaminants currently in Tank 20 to be left in the tank during the closure. However, if plans change, and more sludge is removed from Tank 20, the inventories of sludge and white solids should be re-evaluated to accurately estimate the inventory of contaminants.

3. Background

Tank 20 is a type IV waste tank in the F-area Tank Farm. The tank is an underground carbon steel waste tank, 85 feet in diameter, and has a working capacity of 1.3 million gallons. Tank 20 was placed into service in 1960 as an evaporator concentrate receipt tank. Concentrated waste in the form of saltcake was removed from the tank in several campaigns from 1980 to 1988. Waste removal, which included spray washing of the dome and sides with water, was completed in 1988.

A liquid heel of approximately 20,000 gallons of ballast water was added in 1990. The purpose of the heel was to prevent uplift of the bottom of the tank if water were to collect in the leak detection system underneath the tank. From 1990 to 1996, inhibitors (sodium nitrite and sodium hydroxide) were added to the tank to ensure that inhibitor concentrations stayed sufficiently high to prevent corrosion of the carbon steel wall.

4. Estimating the Mass of Residual Waste

Estimating the inventory of contaminants in Tank 20 required estimating 1) the mass of residual waste in the tank and 2) the concentration of contaminants in this waste. This section discusses the mass estimates. Section 5 discusses waste concentration estimates and inventories.

Photographs of the floor of Tank 20 taken after the ballast water was pumped out have shown that, except for a few small regions, the entire tank floor is covered by liquid approximately 1 inch high. The liquid is the remainder of the ballast water that was not picked up by the pump. Over the last 10 years, inhibitors have been added to protect the tank steel, so this ballast water contains inhibitors (sodium nitrite and sodium hydroxide) and other compounds that were in the waste, mainly sodium nitrate, carbonate, and sulfate.

Underneath the liquid are precipitated solids left after waste removal. Two areas of the tank appear to have no smearable solids (i.e. the floor of the tank as seen through the liquid appears to be clean). The rest of the tank contains predominantly brown solids, which have been shown to be similar in composition to PUREX low-heat waste sludge. The tank also contains a number of small deposits of white solids that have been shown to be primarily cryolite (see section 5.2, "Samples"). The mass of cryolite solids is small; however, because cryolite is over 50 wt% fluoride, these solids contribute significantly to the fluoride inventory in the tank.

The sections that follow describe the method of determining the volumes of precipitated solids in the tank.

4.1 Lifting Plates

The depth of the brown sludge on the floor of Tank 20 was estimated by observing the sludge relative to lifting plates that were placed on the tank floor during construction. The purpose of the plates was to allow the plates forming the floor of the tank to be butt-welded from both sides during construction. The procedure for constructing the tank bottom was as follows:

- The steel plates that formed the tank floor were placed on top of the concrete pad, the top half of all welds was completed, and the lifting plates with lugs were welded into place.
- Using a lifting frame (Print W164197, 2/16/56), the tank floor was lifted off the ground.
- The bottom half of each weld was completed by welders crawling underneath the lifted plates.
- The tank floor was lowered to the concrete pad, and the lifting lugs were ground off.

Although the lifting lugs were removed during construction, the lifting plates were left in place. Thus, they now provide convenient "depth gauges" for estimating the depth of solids on the tank floor.

Figure 1 shows the arrangement of lifting plates (print W164197). The lifting plates are 12 by 12 inches, 3/8 inches high, and have a 1/4-inch weld bead around their perimeter.

4.2 Estimating Sludge Volume

The depth of sludge at each point in the tank was estimated from photographs of the tank floor. Figure 2 shows the sludge and other equipment that was seen in the photographs. The photographs show a numbe of pieces of abandoned equipment in the tank, including a transfer jet, several pieces of rope, several pieces of conduit, and a number of steel tapes underneath the steel tape riser.

4.2.1 Clean Regions

The regions underneath the southwest and center risers have no smearable solids contamination. This conclusion is based on 1) photographs, which show what appears to be oxidizded tank steel in these locations, and 2) an unsuccessful attempt to swipe contamination underneath the southwest riser. The attempt was made with an absorbent swipe wrapped around a weight. Although the swipe was dragged across the bottom of the tank repeatedly, no visible solids were collected.

Photographs of the area underneath the southwest riser and the center riser show circular regions on the floor underneath the risers (HLW File Photograph 1028:25). The location of the regions under spray washing nozzles suggest that they are clean regions where the sludge has been swept away by the spray washing nozzles. The regions are light brown, approximately 15 feet across, and are noticeably lighter in color than other parts of the tank floor, which range in color from medium brown to dark brown. The tops of the lifting plates in the clean regions are approximately the same color as the floor, unlike other regions of the tank, where the lifting plates are lighter in color than the floor, presumably because the tops of the lifting plates have a thinner layer of sludge than the surrounding floor.

Also, the edges of the clean regions have a "spoke" pattern of short, clean lines radiating outward from the centers of the regions. The "spokes" average about a foot in length. The pattern is the cleaning pattern of the spray nozzle. Each pass of the rotary spray nozzle created another clean "spoke" in the pattern.

Figure 1. Tank 20 Top and Floor

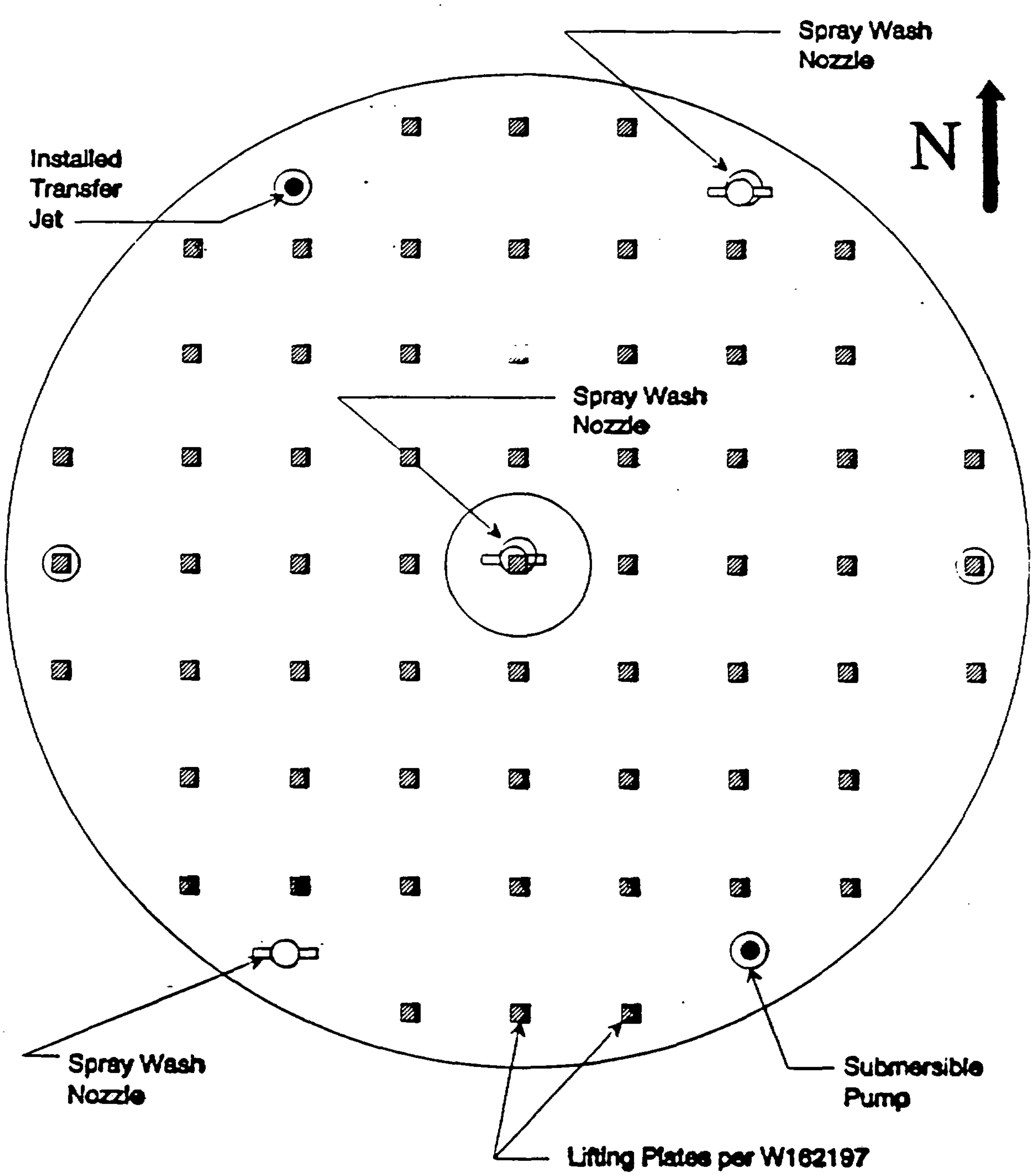
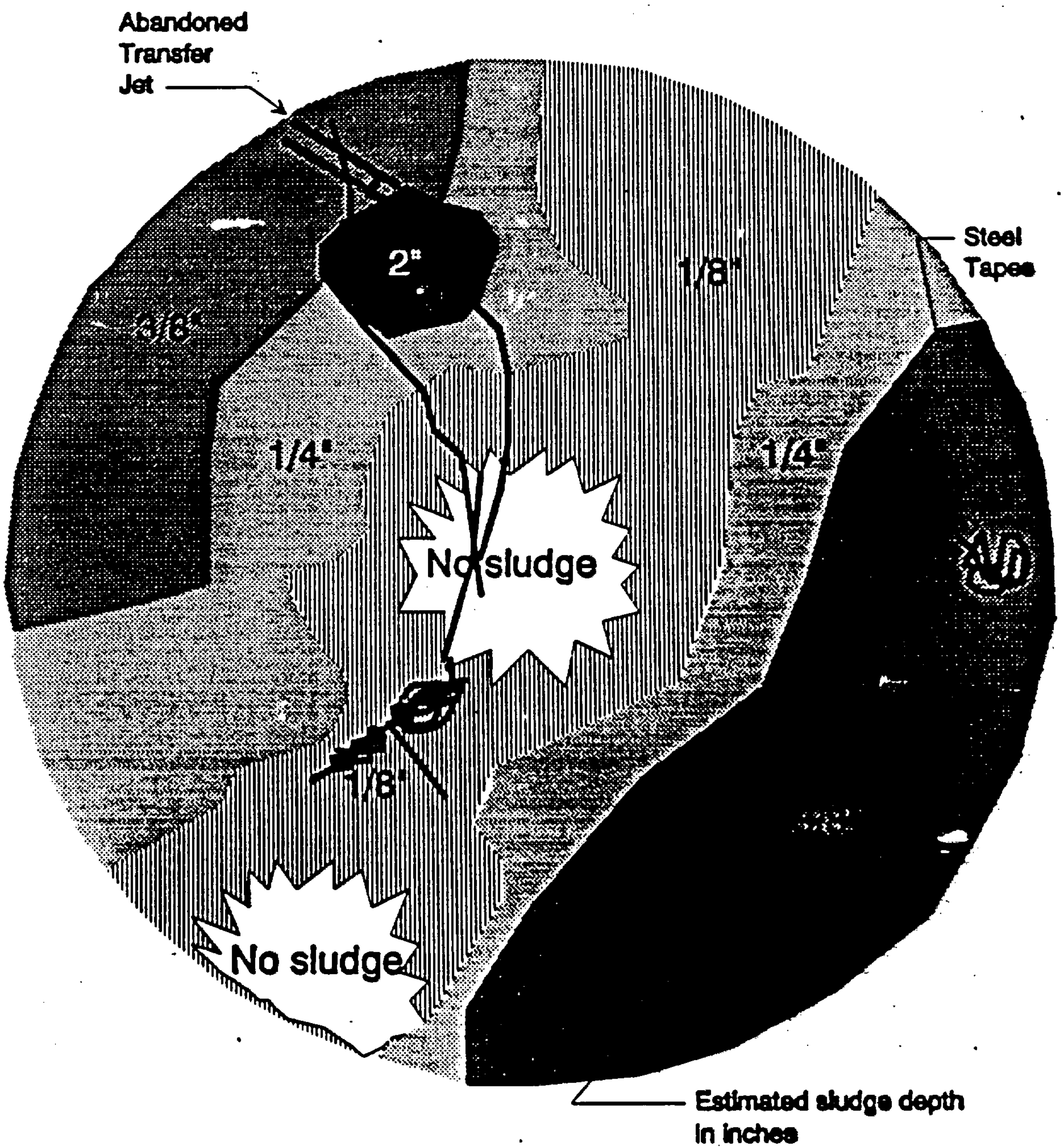


Figure 2. Sludge and Abandoned Equipment in Tank 20



4.2.2 Brown Solids

As mentioned previously, most of the floor of the tank is covered by brown solids. The solids range from very thin (the areas immediately surrounding the clean regions) to a fraction of an inch (underneath the northwest and southeast risers). Also, there is an "island" near the northwest riser that sticks above the water level and has sludge that is noticeably deeper than the rest of the tank.

Figure 2 shows the estimated depths at each spot in the tank. In estimating depths, the following guidelines were used:

- The light brown regions under the southwest and center spray wash nozzles were estimated to have no sludge, as explained in the previous section.
- In places where some sludge was evident on the floor (darker brown than the clean regions) but the tops of the lifting plates appeared to be free of sludge (as evidenced by the same light brown color as the clean regions), the sludge depth was estimated to be less than 1/8 inch sludge. Several plates with this appearance are located immediately at the periphery of the clean zones, indicating that this appearance signifies a thin layer of sludge.
- In places where the lifting plates were a darker color than the clear regions but are still noticeably lighter than the surrounding sludge, the sludge depth was estimated to be 1/4 inch of sludge. The depth in this region is obviously higher than the thin region (1/8 inch) but lower than the top of the lifting plate (3/8 inch), which is the basis for the estimate of 1/4 inch.
- In places where the lifting plates were not visible or only barely visible the sludge depth was estimated as 3/8 inch of sludge or more. In these places, the sludge has evidently partially covered or completely covered the lifting plates, which are 3/8 inch in height.
- The "island" between NW and NE risers was estimated as having 2 inches of sludge. In photographs taken immediately after the first pump-out operation, when the liquid level was about 1 1/2 inches, this region appeared to rise only slightly from the liquid.

The areas of the regions identified in Figure 2 were estimated using a manual grid technique, in which each region was overlaid with a grid pattern of known size. The number of grid squares within each region was manually counted, and the area of the region was estimated by multiplying the number of squares by the size of each square. The estimated areas of each region were then multiplied by the estimated depth to obtain an estimate of the volume of sludge in each region. The estimated volumes were then summed.

Results were as follows:

Sludge Depth (in.)	Estimated Area (Square feet)	Estimated Volume (cubic feet)	Estimated Volume (gallons)
0	369	0	0
0.125	1557	16	121
0.25	1475	31	230
0.375	2151	67	503
2	123	20	153
Totals	5675	135	1007

This is the basis for the estimate that the volume of sludge solids in Tank 20 is about 1000 gallons.

Previous studies have demonstrated that there are approximately 1.95 pounds of dry sludge solids per gallons of settled sludge.[3] The solids density of the solids in the bottom of Tank 20 is not known, but it is expected that the density of a thin layer of solids left after waste removal should be less than deep sludge in a waste tank, which is compacted due to compressive settling. Therefore, 1.95 pounds of dry sludge solids per gallon is probably a reasonable upper bound for the solids density in Tank 20. This is equivalent to an estimated 1,950 pounds of dry sludge solids in Tank 20.

4.2.3 White Solids

In addition to the brown solids in Tank 20, the tank also contained a number of piles of white solids. The piles have been determined to be primarily cryolite and sodium sulfate (see "Samples" section). Figure 3 shows the locations of the piles of white solids in Tank 20 as recorded in file photographs 1028:24 through 1028:29. At the time the photographs were taken, there were ten piles of white solids in the tank. The size of the white piles was significantly reduced between the initial inspection of the tank and later inspections.

Figure 3.
Location of White Solids

The location of the piles and the fact that they decreased in size between the two inspections suggests that they were formed in locations where rainwater dripped into the tank. Each of the piles is at a spot below a riser where water could have dripped into the tank. The piles underneath the center riser are near the periphery of the riser, where the riser plugs meets the riser, which is the location that rainwater could leak in. Also, inspections of the center riser show small "stalactites," perhaps a couple of inches long at the bottom of the riser, confirming that liquid entered the tank through this riser. Such stalactites are routinely found in the tank farm underneath risers that have experienced rainwater inleakage. There are also piles of white solids underneath the slurry pump in the west riser and the spray wash jet in the northeast riser; both are spots where water could leak in the tank.

Further evidence that dripping caused the piles is the appearance of the piles at the time during the second inspection. A number of piles had localized craters, which appear to have been formed when liquid dripped into the pile and dissolved the white solids. There were hard rains between the two inspections, which is consistent with the hypothesis that rainwater leaking in caused the craters.

The main compound in these piles was identified to be cryolite (See section 5.2, "Samples"). The evidence suggests that this compound became supersaturated in the ballast water. Between 1990 and 1996, the sodium concentration in the tank climbed slowly as sodium hydroxide and sodium nitrite were added to maintain inhibitor concentrations in the tank. Apparently, at some time during this period the solution exceeded the solubility product for cryolite, became supersaturated in cryolite, and the cryolite precipitated. The location of the piles suggests that they precipitated in spots where the solution was disturbed by dripping water. When the ballast water was pumped out the tank, and the piles were exposed to unsaturated rainwater, the solids dissolved.

The volume of white solids in the tank is estimated to be less than 50 gallons, with a total dry solids weight of less than 100 pounds. This estimate was derived as follows. The seven piles of solids underneath the center riser are all estimated to be much less than 2 feet in diameter and 4 inches tall. The piles underneath the northeast riser and the west riser are larger than the piles underneath the center riser, but the volume of all of the piles can be conservatively estimated as 10 piles of solids with a diameter of 2 feet and height of 4 inches. For the purposes of estimation, the surface of the pile is assumed to be roughly spherical in shape. The volume of a spherical section with a height of 4 inches and a circular base two feet in diameter is computed as follows:

Volume of a Spherical Dome = $\pi \cdot h \cdot \left(\frac{c^2}{8} + \frac{h^2}{6}\right)$ Reference: Machinery's Handbook, p. 16

Where: c = diameter of the base of the dome (2 feet)
h = height of the dome (4")

$$\pi \cdot \left(\frac{4}{12} \cdot ft\right) \cdot \left[\frac{(2 \cdot ft)^2}{8} + \frac{\left(\frac{4}{12} \cdot ft\right)^2}{6}\right] = 0.543 \cdot ft^3$$

This is equivalent to about 4 gallons per pile, or, conservatively, about 50 gallons for 10 piles. Assuming that the material has the same density as ordinary sludge (1.95 pounds of dried solid per gallon of settled sludge), this is approximately 100 pounds of dry white solids in the tank.

5. Waste Composition and Inventory

As mentioned previously, most of the solids in Tank 20 appear to be sludge solids, even though the tank was never a sludge receiver. Apparently, the sludge entered the tank entrained in the concentrated salt solution. Previous samples of supernate and salt have shown that all supernate and salt contains small quantities of sludge that have not completely settled out of the liquid.[4] When supernate is evaporated, the entrained sludge is carried into the evaporator system and is deposited into the concentrate receiver tank.

The residual waste at the bottom of a waste tank (either a sludge tank or salt tank) at the end of waste removal is always expected to be primarily sludge. The concentration of entrained sludge in salt, as deposited by evaporation, is small. However, the sludge in a salt tank will be concentrated during waste removal. The reason for this is that hydraulic slurrying techniques are more effective at removing salt than sludge. Salt readily dissolves and is easily removed from the tank. Sludge is not soluble, and so it must be suspended by the slurry pumps. Even if the sludge can be completely suspended, when the sludge slurry is pumped from the tank it begins to settle when the slurry pumps are turned off (The slurry pumps must be turned off during transfers to prevent the pumps from sucking air, which causes accelerated wear). Thus, no matter how good the suspension, some sludge is always left behind at the end of the transfer. If the slurry pumps are not able to suspend some spots in the tank, due to their distance from the pumps, then even more sludge is left in these spots.

5.1 Process Knowledge Estimates

Estimates of the residual sludge in Tank 20 were derived from the Waste Characterization System (WCS).[5]

The estimated composition of Tank 19 sludge was used as the estimate for the composition of the residual sludge in Tank 20. As explained in the previous section, the sludge in Tank 20 probably entered the tank entrained in supernate that passed through the evaporator system. Tank 19 received sludge derived from the same type of waste (Purex low-heat waste) as in Tank 20. Therefore, the composition of sludge in both tanks should be similar, and the estimated composition of Tank 19 sludge, which has been derived from production records, is a reasonable estimate of the residual sludge composition in Tank 20.

The inventories and compositions of major sludge constituents in WCS are based on tank fill histories. WCS sludge inventories are based on sludge transfers from the canyons to the tank farms and between tanks. WCS contains the following information about each sludge transfer:

- Date
- Source - canyon or tank
- Destination - tank
- Process - PUREX or H Modified (HM)
- Stream - High Heat Waste (HHW), Low Heat Waste (LHW), or Mixed
- Volume
- Major chemical compound weights - Fe(OH)3, NaAlO2, Ni(OH)2, and MnO2
- Major actinide weights - Th-232, U-233, U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242

5.1.1 Chemical Contaminants

For each transfer, WCS keeps track of which tank received the waste and how much of each compound was in the transfer. For major chemical compounds (the four listed above) the information comes directly from canyon records. These four compounds account for about 80% of the weight of SRS sludge. The minor compounds are estimated by multiplying the weight of Fe(OH)3 by the flowsheet ratio of that constituent to Fe(OH)3. WCS computes the inventory of chemical contaminants that were received in each waste tank by simply summing up the quantity of chemicals in each transfer.

To determine the concentration of each compound, the inventory of that compound is divided by the calculated total mass of sludge in the waste tank. In the case of Tank 20, the concentration of each compound in the Tank 19 sludge was computed. These concentrations were then multiplied by the estimated mass of sludge in Tank 20 (1950 pounds) to derive an estimate of the total chemical inventory in the tank, which is reported in Table 2.

5.1.2 Radionuclides

The radionuclide inventory was estimated only for the sludge because the primary salt radionuclide, Cs-137, would have been preferentially washed out during spray washing.

WCS computes the inventory of fission and activation products (H-3 through Eu-155 in Table 1) using concentrations based on yield distributions in SRS reactor assemblies and solubility data. The concentrations predicted by WCS were used to estimate the inventory in Tank 20, with the exception of Tc-99, which is discussed in the section below.

WCS computes the inventory of sludge actinides (U-232 through Cm-245 in Table 1) using a combination of techniques used for chemicals and fission and activation products. The mass of major actinides in each transfer are known from canyon accountability records or process records. The concentration of minor actinides was estimated from yield distributions in SRS reactor assemblies.

Similar to the treatment for chemical constituents, the concentration of each radionuclide in Tank 20 was computed by dividing the estimated inventory in Tank 19 by the estimated total mass of sludge in Tank 19. Each of these concentrations was them multiplied by the estimated mass of sludge remaining in Tank 20 to derive the inventories that are reported in Table 1.

5.1.3 Tc-99

The process knowledge inventory reported in Table 1 for Tc-99 is based on a concentration that is 13.5 times the concentration reported by WCS. This is the only nuclide for which the process knowledge concentration has been adjusted. The value for this radionuclide was adjusted for two reasons:

- The performance evaluation predicts that the dose at the seepline will be predominantly due to Tc-99. Therefore, it is important to estimate this radionuclide conservatively.

- Sample results indicate that the concentration of Tc-99 in the residual sludge in Tank 20 is elevated relative to the concentration predicted by WCS for the bulk sludge. In particular, the ratio of Tc-99 to iron (iron is an indicator for sludge) is extremely high in the white deposits in Tank 20. The presence of highly enriched Tc-99 in these deposits suggests that the Tc-99 might have precipitated in the cryolite, so that the residual deposits have a higher amount of Tc-99 than the bulk sludge.

The adjustment factor of 13.5 was chosen in September 1996. At that time the Tc-99 concentration predicted for Tank 20 by process knowledge was 6.95 E-05 Ci/kg, whereas the measured concentration in the Tank 20 sludge is 0.94 microCi/gm, which is equivalent to 9.4 E-04 Ci/kg.[6] Since that time, the process knowledge estimate has changed slightly due to refinements in the method of calculation. WCS currently predicts that the sludge in Tank 20 should have a concentration of 6.252 E-05 Ci of Tc-99 per kg. Thus, the appropriate adjustment factor to be used in the performance evaluation should have been be 15 (9.2 E-04 divided by 6.252 E-05), about 11% higher. However, the error introduced by using the old adjustment factor is small, and there are no plans to revise the Tank 20 performance evaluation.

5.2 Samples

There were four sampling attempts made in Tank 20 to validate the estimates obtained from process knowledge. For the purposes of this report, the samples will be referred to as Samples 1, 2, 3, 4. The location that each of these samples is indicated in Figure 4. The samples were as follows.

Sample	Location	Description
1	Southeast riser	Mudsnapper* sample of white solids underneath riser
2	Southeast riser	Absorbent swipe of brown solids a few inches northwest of riser
3	Southwest riser	Absorbent swipe of bottom. No solids were collected on the swipe
4	North of Southwest riser	Scrape sample of brown solids to the north of the riser

*The mudsnapper was a spring-loaded, clam-shell sampler that was used to collect thick solids beneath the southeast riser.

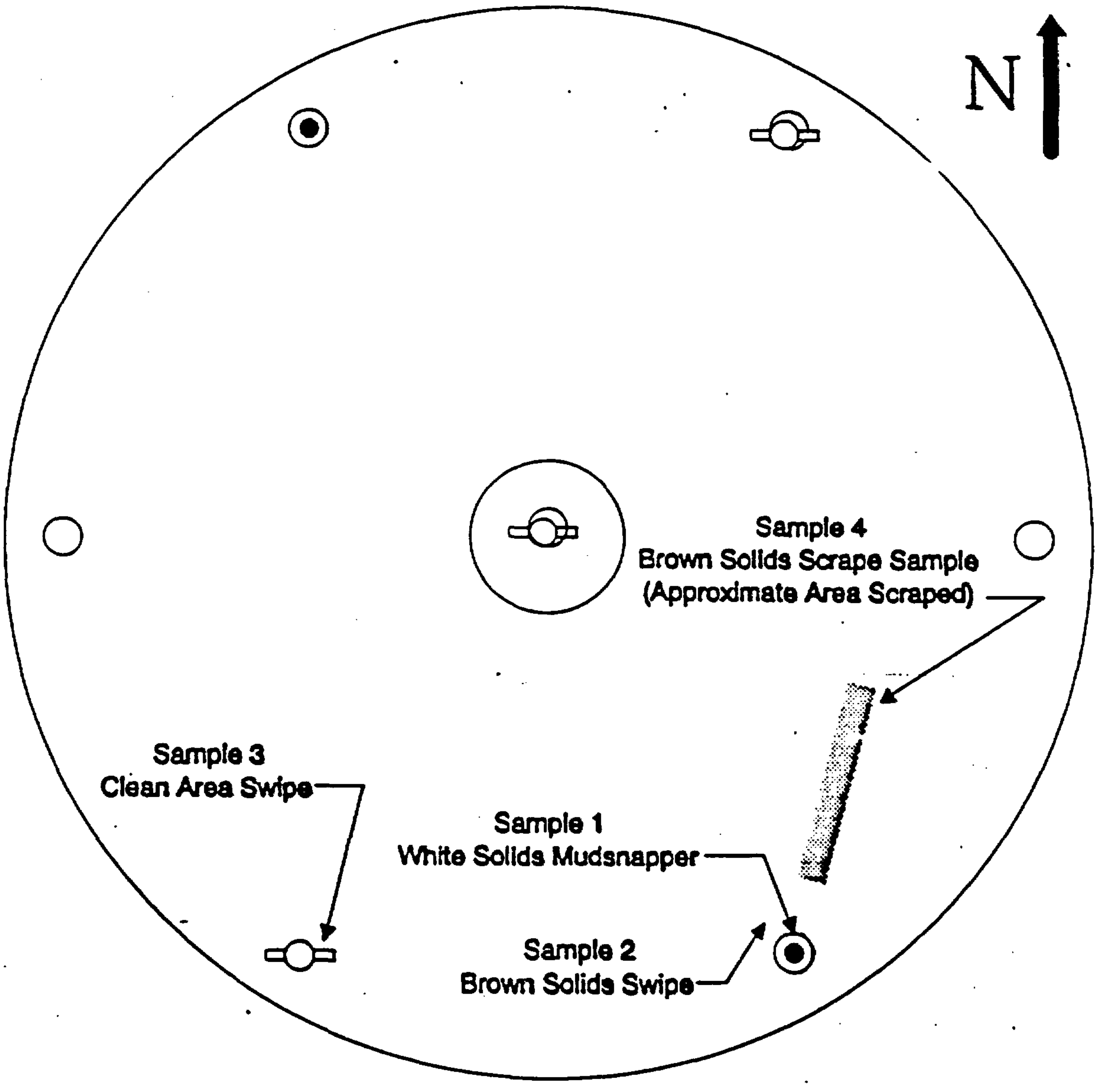
Each of these samples was transported to SRTC for analysis. The analyses performed and results are documented in Reference 7.

A summary of the sample results is as follows:

Sample 1 was a mixture of cryolite, sodium sulfate, and sludge. The cryolite (Na_3AlF_6), which comprises about 60% of the sample, was identified by X-ray diffraction. Also the ratio of Al to F in the sample is consistent with the formula for cryolite, although the sample has an excess of sodium relative to Al and F. Excess sodium is to be expected because sodium is also the main cation for the other anions found in the sample.

As mentioned previously, the cryolite was deposited in locations where water dripped into the tank. Apparently, the solution in the tank became supersaturated with cryolite because of sodium additions. The location of the piles suggests that they precipitated in spots where the solution was disturbed by dripping water.

Figure 4
Locations of Samples from Tank 20



Sample 2 was a swipe of the brown solids. It was not possible to quantitatively analyze the sample because the sample was entrained in the swipe material. Therefore, the entire swipe was dissolved in aqua regia, so it was not possible to measure the actual weight of the dry solids collected. The ratios of sludge constituents were compared to ratios in known sludge and shown to be comparable, but no quantitative information on contaminant concentration was obtained from this sample.

Sample 3 had no observable solids (because the area underneath the southwest riser is clean) and was not analyzed.

Sample 4 was a sample of brown solids that was scraped from the floor. The composition of the sample was similar to sludge, although it also contained about 8% sulfate and 15% oxalate, which is not characteristic of sludge. Apparently, these two salts precipitated out of the ballast water. The sample results are shown in Tables 1 and 2.

5.3 Estimated Inventories

The estimated inventories of contaminants in Tank 20 are reported in Tables 1 and 2.

5.3.1 Radionuclide Inventories

Table 1 shows the radionuclide contaminants. Columns 2 and 3 show the inventories predicted from process knowledge, as discussed previously. Columns 4 and 6 show the concentrations in Samples 1 and 4, respectively. Column 8 shows the inventory predicted from sample results, using the assumption of 50 gallons of white solids and 1000 gallons of brown solids.

The predicted inventory of Se-79, 0.003 Ci, is below the detection limit for Se-79, so the result of less than 0.9 microcuries per gram was expected. However, Se-79 is a fission product, so the inventory predicted from fission product yields should be reasonably accurate.

The inventories of Cs-137 and Pu-239 were below the predictions.

Tc-99, Pu-238, and Np-237 were notably higher than predictions. As noted previous, the concentration of Tc-99 was sufficiently high that the process knowledge estimate was adjusted upward by a factor of 13.5.

Eight curies of Pu-238 were found in Tank 20, although none were predicted. Production records do not indicate that any Pu-238 went to Tank 20, which contains Purex Low-Heat Waste. It had long been recognized that some small amount of Pu-238 would be present in Purex Low-Heat Waste, but the amount was expected to be small enough to be neglected. The sample result from Tank 20 shows that this assumption is not correct, because Pu-238 is, in fact, the alpha radionuclide that is present in highest concentration.

For the performance evaluation, Pu-238 is not a concern because it is relatively immobile in the environment and has a half life of only 86 years. Therefore, virtually no Pu-238 will travel through the environment and outcrop at the seepline. However, the Pu-238 is a concern because of its Class C implications (see next section). Plans are to revise the assumptions in the WCS to specify that some fraction of the Pu-238 goes to Low-Heat Waste.

The last nuclide that occurred higher than its predicted concentration was Np-237. Similar to Pu-238, Np-237 was thought to be present in low enough concentrations that it could be neglected. The inventory estimated of Np-237 in Tank 20, 5.5 E-04 Ci, is low. However, of the nuclides of concern in Tank 20, Np-237 is unique in that it has a high ingestion dose conversion factor, a long half life, and travels through the environment relatively easily (Most nuclides with high dose conversion factors, such as Pu-239, are relatively immobile). Therefore, it is important to estimate Np-237 conservatively.

For the purposes of Tank 20, Np-237 can be neglected. For example, a performance evaluation was done for Tank 17, which has about 20 times the Np-237 as Tank 20 (The estimated quantity is 0.013 Ci in Tank 17). The Tank 17 performance evaluation showed the concentration at the seepline to be a small fraction of the limit for alpha-emitting nuclides. Therefore, there are no plans to revise the performance evaluation for Tank 20. However, as a result of the discovery of Np-237 in Tank 20 and 17, plans are to revise the WCS to account for Np-237 in Low-Heat Waste. It appears likely that Np-237 may be a significant dose contributor to the performance evaluation for some tanks.

5.3.2 Class C Calculation

The rightmost five columns of Table 1 include a Class C calculation for the waste in Tank 20. The column entitled "Class C Upper Limit" shows the Class C limit for each radionuclide. The units for the value in the column are shown in the next column, entitled "Class C Units." The next column, "Tank 20 Concentration in Class Units," shows the computed concentration of the Tank 20 sludge converted to the appropriate units.

In the column "Factor relative to Class C Limit" the computed concentration in Tank 20 is divided by the limit to obtain a Class C factor for each radionuclide. To be within the Class C designation the sum of all of these factors must be less than or equal to 1. As can be seen from the sum at the bottom of the column, the sludge in Tank 20 is currently 174 times the upper limit for Class C.

The last column, "Factor with 7.196 inches of backfill," shows the factors if one takes credit for the mass of 7.196 inches of grout covering the entire tank floor in computing the radionuclide concentration. The grout is assumed to have a specific gravity of 1.6, which is equivalent to light CLSM. Plans are to pour reducing grout in Tank 20, which has a specific gravity of 2.4, so this calculation incorporates a safety factor of 50%. As can be seen from the summation at the bottom of the column, 7.2 inches of grout is sufficient to bring the sum of the Class C factors down to 1.000. Thus, if one takes credit for the mass of 7.2 inches or more of grout covering the entire tank floor, the concentration of the waste plus grout in Tank 20 will be less than the upper limit for Class C.

5.3.3 Chemical Inventories

Table 2 shows the chemical contaminants. Column 2 shows the inventories predicted by WCS. Also shown are the concentrations measured in the tank, and the estimated inventories based on the samples.

Table 1
Radionuclide Inventories in Tank 20 Solids

Nuclide	Concentration from WCS (10/31/96) (Ci/kg)	Tank Inventory based on 1000 gal	Sample 1 Mudsnapper white solids (microCi/gm)	Inventory based on 50 gal of white solids (Ci)	Sample 4 Scrape Sample of brown solids (microCi/gm)	Inventory based on 1000 gal of brown solids (Ci)	Total inventory estimated from Samples (Ci)	Conservative Estimate (Highest of WCS and samples) (Ci)	Class C Upper Limit	Class C Units	Tank 20 concentration in Class C units	Factor Relative to Class C limit	Factor with 7.196 inches of backfill (SpG=1.6)
H-3	0.00E+00	0.00E+00						0	None	NA			
C-14	7.411E-07	6.56E-04						6.6E-04	8.000E+00	Ci/m^3	0.00017	2.16E-05	8.5E-07
Ni-59	4.357E-05	3.85E-02						3.9E-02	2.200E+02	Ci/m^3	0.010	4.62E-05	1.817E-06
Co-60	7.552E-04	6.68E-01	0.1	0.0044	0.116	0.103	0.107	6.7E-01	None	NA			
Se-79	3.604E-06	3.19E-03	<0.9	<0.04				3.2E-03	None	NA			
Sr-90	2.148E-01	1.90E+02	12.8	0.567	44.6	39.5	40.1	1.9E+02	7.000E+03	Ci/m^3	50.2	0.00717	0.0002816
Y-90	2.148E-01	1.90E+02						1.9E+02	None	NA			
Tc-99	6.252E-05	*7.47E-01	0.34	0.0151	0.94	0.83	0.85	8.5E-01	3.000E+00	Ci/m^3	0.22	0.0747	0.0029331
Ru-106	4.889E-07	4.32E-04						4.3E-04	None	NA			
Rh-106	4.889E-07	4.32E-04						4.3E-04	None	NA			
Sb-125	5.118E-04	4.53E-01						4.5E-01	None	NA			
Sn-126	6.696E-06	5.92E-03						5.9E-03	None	NA			
I-129	2.967E-10	2.62E-07						2.6E-07	8.000E-02	Ci/m^3	6.93E-08	8.66E-07	3.403E-08
Cs-134	2.274E-06	2.01E-03						2.0E-03	None	NA			
Cs-135	4.126E-08	3.65E-05						3.6E-05	None	NA			
Cs-137	1.478E-02	1.31E+01	37.6	1.666	44.3	39.3	40.9	4.1E+01	4.600E+03	Ci/m^3	10.83	0.0023	9.246E-05
Ce-144	1.994E-08	1.76E-05						1.8E-05	None	NA			

* The inventory reported for Tc-99 is computed assuming a concentration 13.5 times that reported in WCS. See section 5.3, "Tc-99."

Table 1 Continued
Radionuclide Inventories in Tank 20 Solids

Nuclide	Concentration from WCS (10/31/96) (Ci/kg)	Tank Inventory based on 1000 gal	Sample 1 Mudsnapper white solids (microCi/gm)	Inventory based on 50 gal of white solids (Ci)	Sample 4 Scrape Sample of brown solids (microCi/gm)	Inventory based on 1000 gal of brown solids (Ci)	Total inventory estimated from Samples (Ci)	Conservative Estimate (Highest of WCS and samples) (Ci)	Class C Upper Limit	Class C Units	Tank 20 concentration in Class C units	Factor Relative to Class C limit	Factor with 7.196 inches of backfill (SpG=1.6)
Pr-144	1.994E-08	1.76E-05						1.8E-05	None	NA			
Pm-147	8.666E-03	7.66E+00						7.7E+00	None	NA			
Eu-154	1.167E-03	1.03E+00	<0.3	<0.01				1.0E+00	None	NA			
Eu-155	0.00E+00	0.00E+00						0.0E+00	None	NA			
U-232	1.149E-08	1.02E-05						1.0E-05	100	nCi/gm	0.011	0.00011	6.59E-07
U-233	0.00E+00	0.00E+00						0.0E+00	100	nCi/gm	0	0	
U-234	0.00E+00	0.00E+00						0.0E+00	100	nCi/gm	0	0	
U-235	7.235E-08	6.40E-05	8.30E-06	3.68E-07	2.10E-05	1.86E-05	1.90E-05	6.4E-05	100	nCi/gm	0.072	0.000724	4.149E-06
U-236	0.00E+00	0.00E+00	1.30E-05	5.76E-07	3.00E-05	2.66E-05	2.72E-05	2.7E-05	100	nCi/gm	0.03	0.00031	1.761E-06
U-238	6.609E-06	5.85E-03	2.40E-04	1.06E-05	6.17E-04	5.47E-04	5.58E-04	5.8E-03	100	nCi/gm	6.6	0.066	0.000379
Np-237	0.00E+00	0.00E+00	0.0038	1.68E-04	6.18E-04	5.48E-04	5.48E-04	7.16E-04	100	nCi/gm	0	0	0
Pu-238	0.00E+00	0.00E+00			8.3	7.36E+00	7.356818	8	100	nCi/gm	9025	90.26	0.5186632
Pu-239	3.872E-03	3.42E+00	0.44	0.0195	0.941	0.834068	0.853568	3.5	100	nCi/gm	3950	39.48	0.2269152
Pu-240	8.639E-04	7.64E-01			0.2	1.77E-01	0.177273	7.64E-01	100	nCi/gm	862	8.62	0.0495417
Pu-241	5.625E-02	4.98E+01						5.0E+01	3500	nCi/gm	56100	16.04	0.0921653
Pu-242	1.782E-06	1.58E-03						1.6E-03	100	nCi/gm	1.778	0.017	0.0001022
Am-241	0.00E+00	0.00E+00			1.9	1.68E+00	1.684091	1.7E+00	100	nCi/gm	1895	18.95	0.1089193
Cm-244	1.954E-07	1.73E-04						1.7E-04	100	nCi/gm	0.195	0.0020	1.121E-05
Cm-245	1.032E-13	9.13E-11						9.1E-11	100	nCi/gm	1.03E-07	1.03E-09	5.919E-12
Total alpha emitting nuclides with half lives greater than 5 years								1.4E+01					
									Sum of Class C Factors			174	1.0000

Table 2
Chemical Inventories in Tank 20 Solids

	Inventory from WCS (10/31/96) based on 1000 gal (kg)	Sample 1 ~~Mudsnapper~~ White Solids (wt%)	Estimated White solids Inventory Based on 50 gal (kg)	Sample 4 Scrape Brown solids (wt%)	Estimated Brown solids Inventory Based on 1000 gal (kg)	Estimated Total Inventory based on samples (kg)
			50.0		1000.0	
Silver	3.068375	<0.02				
Aluminum	50.86222	8.2	3.6	3.0	26.9	30.5
Barium	1.789763					
Fluoride	1.619407	33.0	14.6	1.0	8.9	23.5
Chromium	2.159336	0.1	0.0	0.3	2.5	2.5
Copper	1.53426	0.0	0.0			0.0
Iron	247.4876	2.7	1.2	7.9	70.0	71.2
Mercury	0.630674					
Nitrate	16.62612					
Manganese	11.41312	0.4	0.2	1.3	11.7	11.9
Nickel	0	0.0	0.0	0.1	0.8	0.8
Lead	2.556964	<0.05				0.0
Uranium	17.41831					
Zinc	3.067194					
Sodium	33.8	30.0	13.3	27.8	246.4	259.7
Silicon	7.6	0.8	0.3	0.5	4.8	5.2
Boron		<0.02				
Calcium	22.5	0.5	0.2	1.4	12.2	12.4
Lithium		<0.008				
Magnesium	0.7	0.1	0.1	0.5	4.3	4.3
Molybdenum		<0.003				
Titanium		<0.005		0.0	0.1	0.1
Zirconium	4.4	<0.019				
Cadmium		0.1	0.0	0.2	1.7	1.8
Phosphate	1.0	0.1	0.1			0.1
Chloride	10.8					
Sulfate	6.1	13.0	5.8	8.0	70.9	76.7
Oxalate	0.0			15.0	133.0	133.0

5.4 Other Contaminants

The risers in Tank 20 contain lead, which was intended to act as radiation shielding. Plans are to leave these risers in place when the tank is closed. The estimated mass of lead is approximated 500 pounds per riser. There are six risers on the tank, for an estimated total of 3000 pounds of lead.

In addition to the contaminants in Tanks 17-20, there will be contamination in other equipment in the area, such as the 1F Evaporator, the 1F Concentration Transfer System, ventilation systems, and transfer piping. The inventory of contaminants in these locations is expected to be small relative to the amount of contamination in the tanks.

To account for contamination outside of the tank, we recommend that an inventory of contaminants equal to 20% of the waste inside the tank be added to the performance evaluation for each waste tank (i.e. performance modeling of the Tank 17-20 area should add 20% of the inventory in these four tanks). Based on engineering judgment, this 20% should bound the contamination in these locations. As closure modules are prepared for these locations, the modules will show that the contamination left behind is smaller than this estimate, or the estimate will be revised and the performance evaluation repeated.

6. References

[1] "Industrial Wastewater Closure Plan for F- and H-Area High-Level Waste Tanks," Rev. 1, 10 July 1996

[2] "Industrial Wastewater Closure Module for the High-Level Waste Tank 20 System," Rev. 1, 8 January 1997

[3] L. F. Landon and T. T. Thompson, "Technical Data Summary for the Defense Waste Processing Facility, Stage 2," DPSTD-80-39-2, December 1980

[4] J. R. Fowler, "Analysis of Tank 20 Saltcake," DPST-80-424, 16 June 1980

[5] J. R. Hester, "High Level Waste Characterization System," WSRC-TR-96-0264, December 1996

[6] P. D. d'Entremont and D. T. Bignell, "Options for Meeting Class C Criteria During HLW Tank Closure," WSRC-TR-96-0327, 16 October 1996

[7] M. S. Hay, "Analysis of Samples for Tank 20 Closure," WSRC-TR-97-XXXX (in draft)

HIGH-LEVEL WASTE ENGINEERING
CONCENTRATION, STORAGE,
AND TRANSFER

WSRC-TR-97-0066
REVISION: Revision 0

KEYWORDS:
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RETENTION: PERMANENT

CLASSIFICATION: U
Does not contain UCNI

Paul P d'Entremont 17 Sep 97
ADC/RO

Characterization of Tank 17 Residual Waste

BY

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Table of Contents

1. Introduction

Plans are to close Tank 17, a type IV waste tank in the F-area Tank Farm, by filling it with pumpable backfills. Most of the waste was removed from the tank in the late 1980s, and the remainder of the waste was removed in a short spray washing campaign that began on 11 April 1997. More details on the planned closure can be found in the Closure Plan for the High-Level Waste (HLW) Tanks[1] and the specific closure module for Tank 17.[2]

To show that closure of the tank is environmentally sound, a performance evaluation has been performed for Tank 17.[2] The performance evaluation projected the concentration of contaminants at various locations and times after closure. This report documents the basis for the inventories of contaminants that were used in the Tank 17 performance evaluation.

2. Summary

Inspections of Tank 17 show that most of the tank is covered by a thin layer of brown silty solids. Dispersed throughout this layer of brown solids are some light gray flakes that appear to be cement-like debris from the tank ceiling. The total volume of these solids in the tank was estimated to be approximately 2400 gallons, equivalent to about 4700 pounds of dried solids. About 200 gallons of the solids are estimated to be cement-like solids, so the volume of high-level waste sludge is estimated to be 2200 gallons.

The composition of the brown silty solids has been estimated by two means: 1) predictions based on the knowledge that the material entering the tank was Purex Low-Heat Waste, and 2) two samples. The samples showed that the predictions based on process knowledge were reasonable, although a few adjustments were in order. Concentration, Storage, and Transfer Engineering (CSTE) recommends that the process knowledge estimates of the inventory be used for all contaminants except for Tc-99 and the plutonium isotopes. For these radionuclides, the inventory estimates should be raised to reflect what was learned from sample results on Tank 17, and also Tank 20,[3] the first HLW tank to be closed at SRS.

The recommended inventories to be assumed for modeling purposes in Tank 17 are shown in Tables 1 and 2 at the end of the report.

The contaminants reported in Tables 1 and 2 are contained in the waste, which is primarily on the bottom of the tank. In addition, the risers on the top of the tank each

contain lead. Based on the design basis drawings, a reasonable estimate is 500 pounds per riser, or 3000 pounds (1400 kg) of lead for the whole tank. Also, we recommend that an amount of waste be assumed to be outside of the tank to account for spills and other contaminated equipment in the Tank 17-20 area, such as the 1F Evaporator and the Concentrate Transfer System (CTS) pump tank. An allowance of 20% of the tank inventory in these four tanks should be sufficient to bound contributions from the other sources.

3. Background

Tank 17 is a type IV waste tank in the F-area Tank Farm. The tank is an underground carbon steel waste tank, 85 feet in diameter, and has a working capacity of 1.3 million gallons. While in service, Tank 17 received both sludge and salt, which is unusual for HLW Tanks. Sludge and salt are normally segregated into different tanks. There are only a handful of tanks in the tank farm that contain both sludge and salt.

Most of the waste was removed from Tank 17 in a waste removal campaign between December 1983 and June 1985.[4] During the campaign, slurry pumps were used to agitate the tank, and the waste was pumped from the tank using a telescoping transfer pump. Following bulk waste removal, the tank was spray washed in October 1985 using rotary spray jets. The purpose of the spray washing campaign was to remove residual waste on the tank roof and walls, and to remove more of the residual from the tank floor. After spray washing, the residual sludge in the tank was estimated to be about 2000 gallons, although it was recognized that this estimate was highly uncertain because the tank had at least 3 inches of liquid, equivalent to about 10,000 gallons (The sludge estimate following spray washing in 1985 was later shown to be much too low--see below).

In 1992, 112,000 gallons of water with high levels of tritium contamination were transferred into Tank 17 from K area. This was a one-time transfer of liquid contaminated with reactor moderator following a K-area moderator leak. Calculations indicate that the transferred water contained 5,950 Ci of tritium.[5] As a result of this addition, the concentration of tritium in Tank 17 in 1994 was estimated to be 0.02 Ci/gal, the highest of any HLW tank.[6]

4. Waste Removal in Preparation for Tank Closure

To prepare the tank for closure, the waste first had to be removed. This was done in two steps: supernate removal and sludge removal.

4.1 Supernate Removal

The first step of waste removal was to pump the 279,000 gallons of supernate from Tank 17 to Tank 6. The supernate had to be managed carefully because of its high tritium concentration. For example, if the supernate were simply pumped to an evaporator feed tank, much of the 5,950 Ci of tritium would end up in evaporator overheads and would be released to the river. This could have exceeded release guides.

Therefore, it was decided that the best way to manage the tritium was to store it in tanks in which waste removal is not planned for some time. This method of management gives the tritium an opportunity to decay. Also, because the tritium inventory needs to be managed, it is desirable to send all of the supernate to a single waste tank to minimize the number of tanks that need to be managed.

Tank 6 was chosen as the best tank for storing the waste supernate, based on considerations of tank integrity, available space, and logistics of accomplishing the transfer.[7] Calculations showed that as long as most of the tritium in Tank 17 were transferred to Tank 6 leaving no more than 2 inches of supernate in Tank 17, the residual tritium in tank 17 would pose no risk of exceeding release criteria and could be transferred into the rest of the tank farm with no restrictions.[8] The transfer was accomplished using an electrical sump pump and an above ground flexible transfer line encased in a secondary flexible transfer line (to provide secondary containment and leak detection). Before starting the transfer, three submersible Flygt™ mixers (one 15 HP mixer and two 4 HP mixers) were installed into the tank. The purpose of the mixers was to stir up the supernate so that some sludge would be removed during the transfer. The transfer occurred in early March 1997.

4.2 Sludge Removal

After the supernate was removed from Tank 17, photographs of the tank interior taken on 8 March 1997 showed that the sludge inventory in the tank was greatly in excess of the previously estimated 2,000 gallons. The actual volume was difficult to estimate from the photographs because the top of the sludge was relatively featureless, and virtually all of the tank features that could be used to gauge the depth (such as the lifting plates described below) were completely covered by the sludge. However, the appearance of the sludge, combined with observations made during spray washing, suggested that the inventory might have been as high as 10,000 gallons.

No effort was expended to improve this estimate because there was sufficient information to decide that the sludge needed to be removed. Efforts on Tank 17 immediately focused on removing the sludge.

Sludge removal from Tank 17 was accomplished using a water monitor and an air-operated double-diaphragm pump. The water monitor was an Akron Brass™ water monitor, which is a remotely operated fire hose nozzle intended for fighting fires on tall buildings. The monitor was mounted on a plate designed especially for Tank 17 and installed upside down in the northwest riser of the Tank. From this position, the water monitor could spray any part of the tank with about 150 gallons of water per minute and could be remotely operated from above the tank.

The pump used to pump the sludge from the tank was a Wilden™ air-operated double-diaphragm pump, Model M-8. The pump was installed in the southwest riser of Tank 17. During the course of the spray washing a total of three Wilden™ pumps were installed in the tank because two of the pumps plugged with sludge and could not be unplugged. The last pump to be installed incorporated several extra flushing capabilities that prevented the blockages that incapacitated the first two pumps.

This combination of water monitor and sump pump was found to be effective at removing most of the sludge from the tank. However, as would be expected, the efficiency of the tools declined as the volume of sludge in the tank became smaller.

The high amount of water required to remove small volumes of sludge is probably due to the fact that sludge removal from Tank 17 began when the volume of sludge was only 10,000 gallons, which is less than 1% of the volume of the tank. Calculations done at the Army Corps of Engineers Waterways Experiment Station indicate that it should be possible to remove deep sludge from a waste tank with only 3-5 gallons of water sprayed for each gallon of sludge removed.[9] In deep sludge, the spraying forms a dendridic drainage pattern, similar to the drainage pattern formed by a large river. Such a pattern will efficiently move soil.

However, at low levels in the tank the dendridic pattern breaks down because the channels cut by the flowing water meet the steel bottom of the tank and can cut no deeper into the sludge. Thus, the steepness of the channels decreases, and the amount of water required to remove sludge increases. As the amount of sludge decreases, it must literally be pushed by the water monitor toward the sump pump. Most of the sludge removal from Tank 17 was accomplished in this "pushing" mode.

5. Estimating the Mass of Residual Waste

Estimating the inventory of contaminants in Tank 17 required estimating 1) the mass of residual waste in the tank and 2) the concentration of contaminants in this waste. This section discusses the mass estimates. Section 6 discusses waste concentration estimates and inventories.

Video inspections of Tank 17 after spray washing revealed that most of the tank contained water, perhaps an inch or two deep. Because of the large amount of water sprayed into the tank and removed by the Wilden™ pump (more than 200,000 gallons), any readily soluble components should have been flushed from the tank, and the residual water should not contain significant contaminants. For this reason, the contaminants in the water layer were neglected in computing the tank inventory.

Underneath the liquid were precipitated solids left after waste removal. These solids consisted mostly of brown, silty solids, similar to Purex sludge. Dispersed throughout the brown solids were thin flakes of hard material that appear to be cement-like solids. (See section 5.2.2, "Cement-like Solids.")

The sections that follow describe the method of determining the volumes of precipitated solids in the tank.

5.1 Lifting Plates

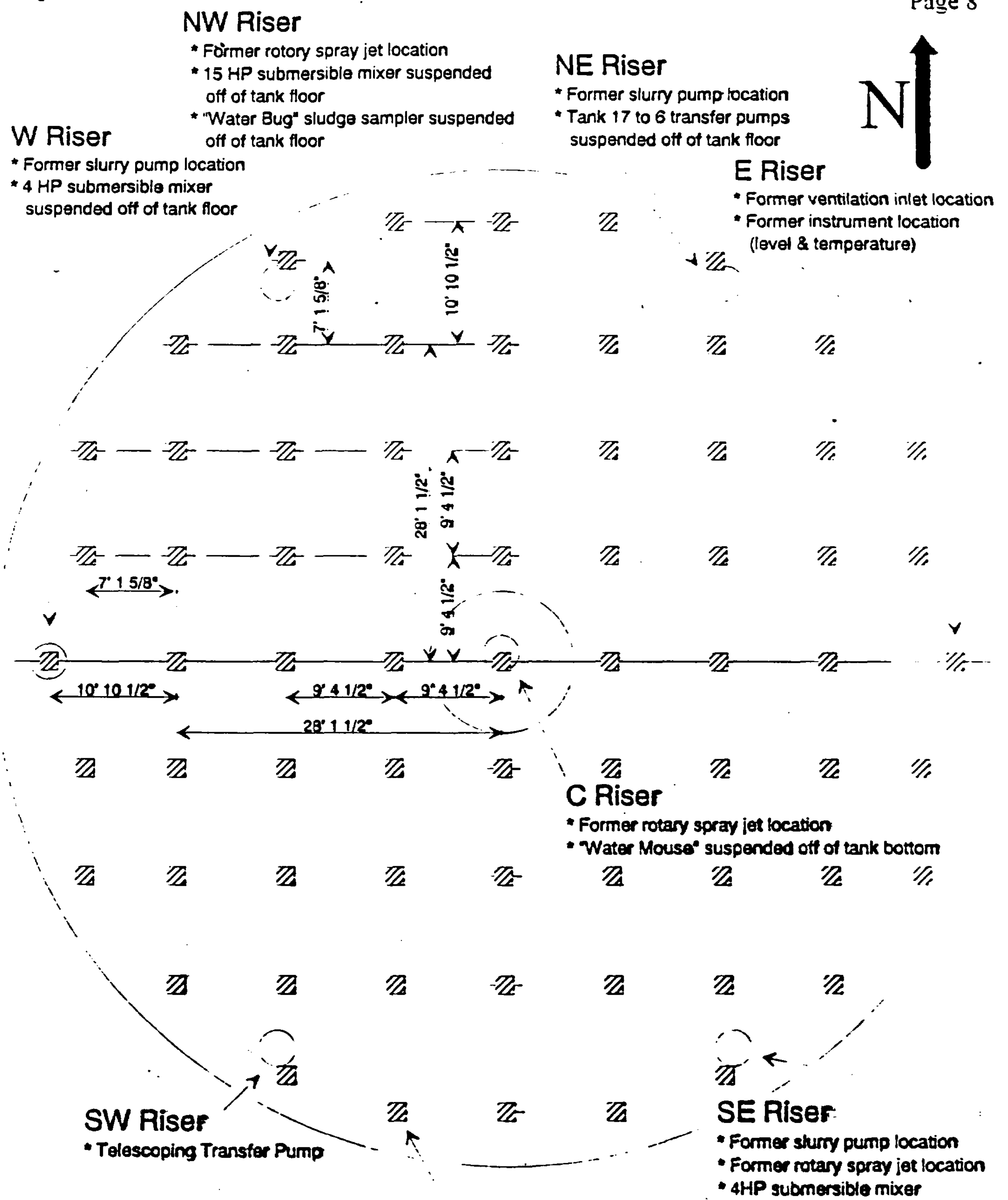
The depth of the sludge over much the floor of Tank 17 was estimated by observing the sludge relative to lifting plates that were placed on the tank floor during construction. The purpose of the lifting plates was to allow the plates forming the floor of the tank to be butt-welded from both sides during construction. The procedure for constructing the tank bottom was as follows:

- The steel plates that formed the tank floor were placed on top of the concrete pad, the top half of all welds was completed, and the lifting plates with lugs were welded into place.
- Using a lifting frame (Print W164197, 2/16/56), the tank floor was lifted off the ground.
- The bottom half of each weld was completed by welders crawling underneath the lifted plates.
- The tank floor was lowered to the concrete pad, and the lifting lugs were ground off.

Although the lifting lugs were removed, the lifting plates were left in place to avoid the possibility of damage to the tank floor, which could have occurred if the lifting plates had been ground off. Thus, the lifting plates now provide convenient "depth gauges" for estimating the depth of solids on parts of the floor where the sludge depth is shallow. Figure 1 shows the arrangement of lifting plates in Tank 17.

Figure 1. Tank 17 Top and Floor

Note: Lifting Plates are not all oriented with the edges aligned north-south east-west



Scale: 7" = 85'
(an 85' diameter tank is 7 inches)

Lifting Plates per W164197

Print W164197 indicates that there are 69 lifting plates on the floor of Tank 17. The print indicates that each lifting plate is square, 12 by 12 inches, 3/8 inches high, and has a 1/4-inch weld bead around its perimeter. The print also instructs the fabricators to make the lifting plates from 1/2-inch plate, which does not agree with the height of 3/8 inch shown for the finished plate. This appears to be an error, but it is possible that the instruction to use a 1/2-inch plate was followed during fabrication, so the plates might actually be 1/2 inch high rather than 3/8 inch high. For the purposes of sludge estimation in Tank 17, it was assumed that the plates are 1/2 inch high because this produces a conservatively high estimate.

The plates that are visible in Tank 17 all appear to be at the locations shown in the print, but the plates are not all oriented with their edges north-south and east-west. Instead, the plates appear to be oriented at somewhat random orientations, indicating no particular care in their orientation when they were welded to the tank floor. The print specifies only the location of the plates, not the orientation, so the placement of the plates appears to satisfy the print. The random orientation of the plates in Tank 17 was surprising because the plates in Tank 20 had been found to be oriented north-south and east-west.[3] In this report we have made no attempt to record the specific orientation of each plate because it is not important in assessing the volume of sludge.

5.2 Estimating Sludge Volume

The depth of solids at each point in the tank was estimated from video inspections of the tank floor.

The estimated solids volume is 2400 gallons, as described in the next section. Two hundred gallons of these solids are estimated to be inert, leaving 2200 gallons of actual sludge.

5.2.1 Solids

The estimated solids volume of the tank was based on a video inspection on 11 July 1997. In this inspection, the depth of sludge over each of the 69 lifting plates was estimated. In spots where the solids depth was equal to or less than 1/2 inch, so the lifting plates were visible, the solids depth was estimated relative to the lifting plates. In spots where the solids were higher than 1/2 inch (so the plates were not visible), the depth was estimated from other known dimensions, such as the Wilden™ pump, the three submersible mixers, and the knowledge that the knuckle plate along the edge of the tank floor has a radius of 12 inches. At the time of the 11 July inspection, most of the sludge was located near the edge of the tank, which contained many objects of known dimensions, so reasonably good estimates could be made of the sludge depth in each spot.

Figure 2 shows the estimated depths at each spot in the tank. It should be noted that the solids have been moved using the water monitor and the "water mouse" (see section 5.2.3, Redistribution with the "Water Mouse") since the time of this inspection. Thus, the solids location at the time of closure will be different from Figure 2, but the volume of solids is the same because no solids have been added to the tank, and the amount removed is negligible.

For the purposes of estimating the volume of solids, it was assumed that the region of the tank closest to each lifting plate was uniformly covered with solids at the same depth as the depth estimated at the plate. The volume of solids in each region was computed by multiplying the region's area by the estimated depth. Of course, the depth in each region was not actually uniform, but this method essentially averages the errors by statistically "sampling" the depth at 69 points distributed in pre-selected locations throughout the tank.

Figure 2 shows the volume of sludge (in gallons) that was estimated in each of the 69 regions. The appendix describes the calculation of the area of each region. As mentioned previously, the total volume of solids was estimated to be 2400 gallons.

Previous studies have demonstrated that there are approximately 1.95 pounds of dry sludge solids per gallons of settled sludge.[10] The density of the solids in the bottom of Tank 17 is not known, but it is expected that the density of a thin layer of solids left after waste removal should be less than deep sludge in a waste tank, which is compacted due to compressive settling. Therefore, 1.95 pounds of dry sludge solids per gallon is probably a reasonable upper bound for the solids density in Tank 17. This is equivalent to an estimated 4700 pounds of dry solids in Tank 17.

Figure 2. Type IV Tank Residual Heel Estimate

TANK NO. *17F*

DATE 7/11/97
TIME 0930

		NW12 1.000 in. 34.89 gal	NW13 1.000 in. 46.36 gal	N04 1.000 in. 47.46 gal	NE13 1.000 in. 46.36 gal	NE12 1.000 in. 34.89 gal		
	NW11 1.000 in. 43.14 gal	NW10 0.375 in. 18.05 gal	NW09 0.125 in. 6.88 gal	N03 0.125 in. 6.85 gal	NE09 0.125 in. 6.88 gal	NE10 0.125 in. 6.02 gal	NE11 0.375 in. 16.18 gal	
NW08 1.000 in. 35.06 gal	NW07 0.125 in. 6.47 gal	NW06 0.000 in. 0.00 gal	NW05 0.125 in. 6.83 gal	N02 0.000 in. 0.00 gal	NE05 0.125 in. 6.83 gal	NE06 0.000 in. 0.00 gal	NE07 1.000 in. 51.77 gal	NE08 2.000 in. 70.11 gal
NW04 1.000 in. 52.43 gal	NW03 0.125 in. 5.56 gal	NW02 0.125 in. 6.83 gal	NW01 0.125 in. 6.83 gal	N01 0.125 in. 6.83 gal	NE01 0.000 in. 0.00 gal	NE02 0.125 in. 6.83 gal	NE03 0.375 in. 16.68 gal	NE04 2.000 in. 104.85 gal
W04 0.375 in. 20.58 gal	W03 0.125 in. 8.61 gal	W02 0.000 in. 0.00 gal	W01 0.000 in. 0.00 gal	C01 0.000 in. 0.00 gal	E01 0.125 in. 6.83 gal	E02 0.000 in. 0.00 gal	E03 0.125 in. 8.61 gal	E04 2.000 in. 109.76 gal
SW04 1.000 in. 52.43 gal	SW03 0.125 in. 5.56 gal	SW02 0.125 in. 6.83 gal	SW01 0.125 in. 6.83 gal	S01 0.125 in. 6.83 gal	SE01 0.125 in. 6.83 gal	SE02 0.125 in. 6.83 gal	SE03 0.500 in. 22.24 gal	SE04 3.000 in. 157.28 gal
SW08 1.000 in. 35.06 gal	SW07 0.500 in. 25.89 gal	SW06 0.125 in. 6.83 gal	SW05 0.250 in. 13.66 gal	S02 0.125 in. 6.83 gal	SE05 0.500 in. 27.33 gal	SE06 0.250 in. 13.66 gal	SE07 3.000 in. 155.32 gal	SE08 4.000 in. 140.23 gal
	SW11 1.000 in. 43.14 gal	SW10 1.000 in. 48.12 gal	SW09 1.000 in. 55.03 gal	S03 1.000 in. 54.83 gal	SE09 1.000 in. 55.03 gal	SE10 0.500 in. 24.06 gal	SE11 4.000 in. 172.54 gal	
		SW12 2.000 in. 69.77 gal	SW13 2.000 in. 92.72 gal	S04 2.000 in. 94.93 gal	SE13 2.000 in. 92.72 gal	SE12 2.000 in. 69.77 gal		

Evaluator: T. B. Caldwell

Total Volume: 2,421 gallons

5.2.2 Cement-like Solids

In addition to the brown solids in Tank 17, the tank also contains thin flakes of hard, light gray solids, which appear to be cement. The volume of the cement-like solids in the tank was estimated to be about 200 gallons based on a sample taken in late April and received at SRTC on 1 May 1997. The sample was taken using a "mudsnapper," a spring-loaded clam-shell grab sampler. The sample contained about 31% rock-like material, which was probably cement-like debris from the tank ceiling.[11] The sample was taken from the "rock pile," a pile of solids estimated to contain about 600 gallons of solids. This is the basis for estimating that the volume of the cement-like solids is about 200 gallons.

The most likely explanation of the flakes is that they were created when the roof of the tank was poured. The top of the domed tank is a domed slab of concrete with reinforcing bar. To pour the concrete, a dome-shaped form was erected in place, supported by scaffolding from the floor of the tank. Because of the domed shape, the form was made of many short pieces of wood.

It is likely that cement and cement bleed water seeped through cracks in the form. There would have been many cracks because of the many pieces of straight wood needed to form a curved dome. After the concrete set, the form and scaffold were removed, and, presumably, the floor of the tank was swept to remove any cement flakes. However, some residual chips might have stuck to the roof of the tank when the form was removed. These chips might have broken off and fallen to the floor during tank service, or, perhaps, fell off when the entire tank (including the roof) was sprayed with powerful rotary sprays in October 1985. The exact mechanism by which the chips made their way to the bottom of the tank is uncertain. But, based on the construction history of the tank, the presence of the chips in the tank is not surprising.

The purpose of the sample was to determine the fraction of potentially non-radioactive material in the "rock pile," a large pile of sludge near the southeast riser (See Figure 3). Many people working on the sludge removal from Tank 17 colloquially called this pile the "rock pile" because it contained a high concentration of chips, and video images of it suggested rocks up to an inch in diameter. The chips were also seen in other parts of the tank, although they appeared in highest concentration in the "rock pile." One theory to explain the location of the "rock pile" was that the chips were actually rocks that had been originally distributed throughout the tank and were pushed by the water monitor to the vicinity of the pump, but the pump was unable to suck them up because of their high settling velocity. If these chips had indeed been large rocks, they would have accounted for a large percentage of residual solids in Tank 17, which would have dramatically reduced the estimate of the amount of contaminants in the tank.

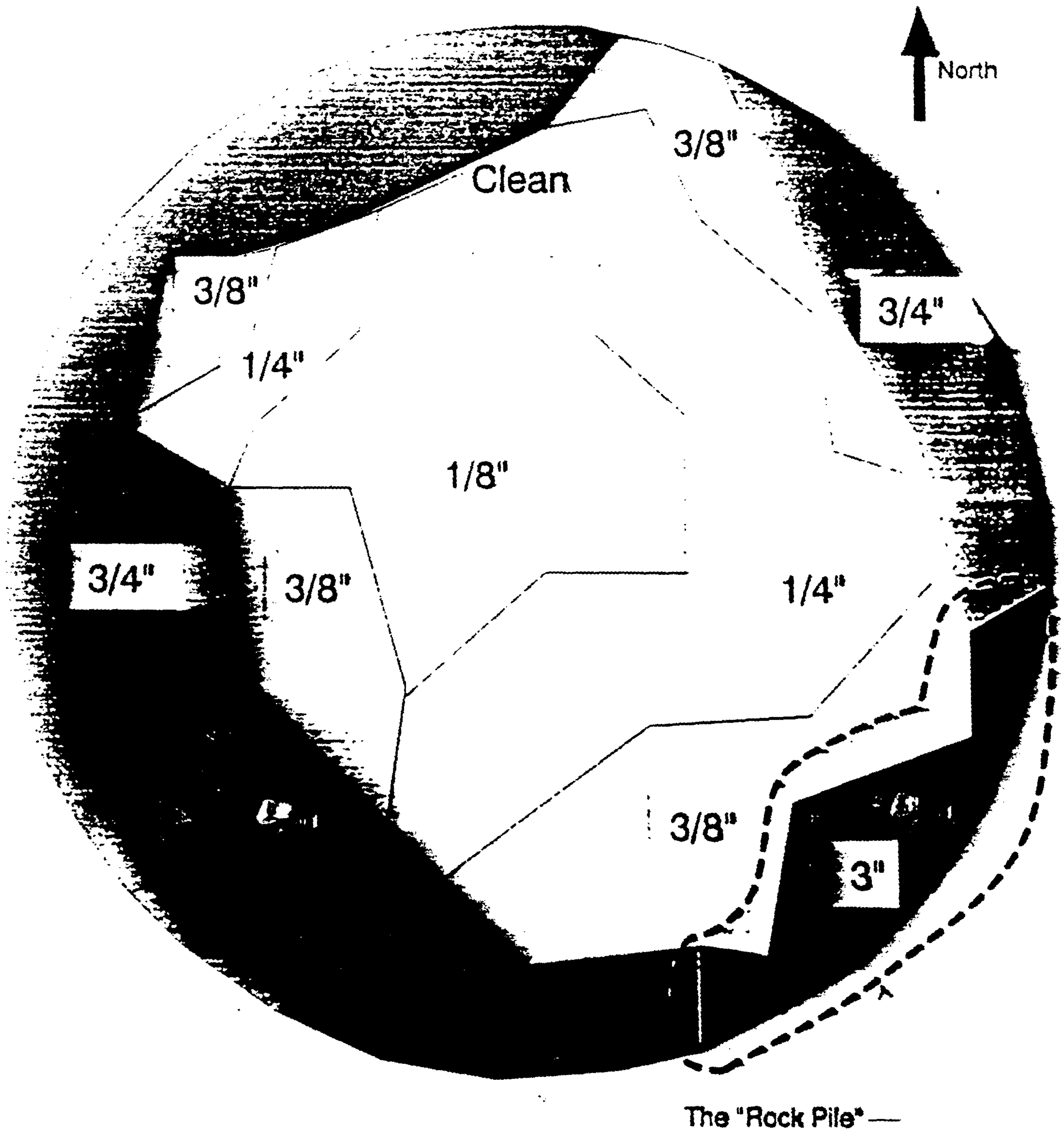
However, the mudsnapper sample showed that the "rock pile" consisted only of 31% of inert chips, less than suggested by the video images. The chips were quite thin, so they appear large when viewed from the side, although their mass is small. Also, significantly, the large pieces that would be visible in video images, which were from 1/2 inch to 1 inch in diameter, comprised only 5% of the weight of the sample. The balance of the chips (26% of the sample) could be observed only by drying the sample and passing it through a sieve.

Two conclusions were reached based on the results of the sample:

- Video observations are unreliable in determining the percentage of inert solids in any region of the tank. The sample was taken from the pile that had the highest proportion of visible solids, yet the visible solids accounted for only 5 wt% of the sample. Most of the inert solids in the sample were not visible.

- It is reasonable to estimate that the "rock pile" contains about 200 gallons of inert solids. Figure 3 shows the extent of the "rock pile" at the time of a video inspection on 21 April 1997. At that time the pile was estimated to have an area of 320 square feet and an average height of 3 inches, for a volume of about 600 gallons. Thirty-one percent of 600 gallons is the basis for saying that there are approximately 200 gallons of inert solids.

Figure 3. Tank 17 Sludge Depth as of 1500, 21 April 1997



5.2.3 Redistribution with the "Water Mouse"

As can be seen in Figure 2, spray washing of the sludge pushed much of the sludge towards the tank wall, leaving large areas near the center of the tank that were relatively clear of sludge. This distribution was undesirable for two reasons:

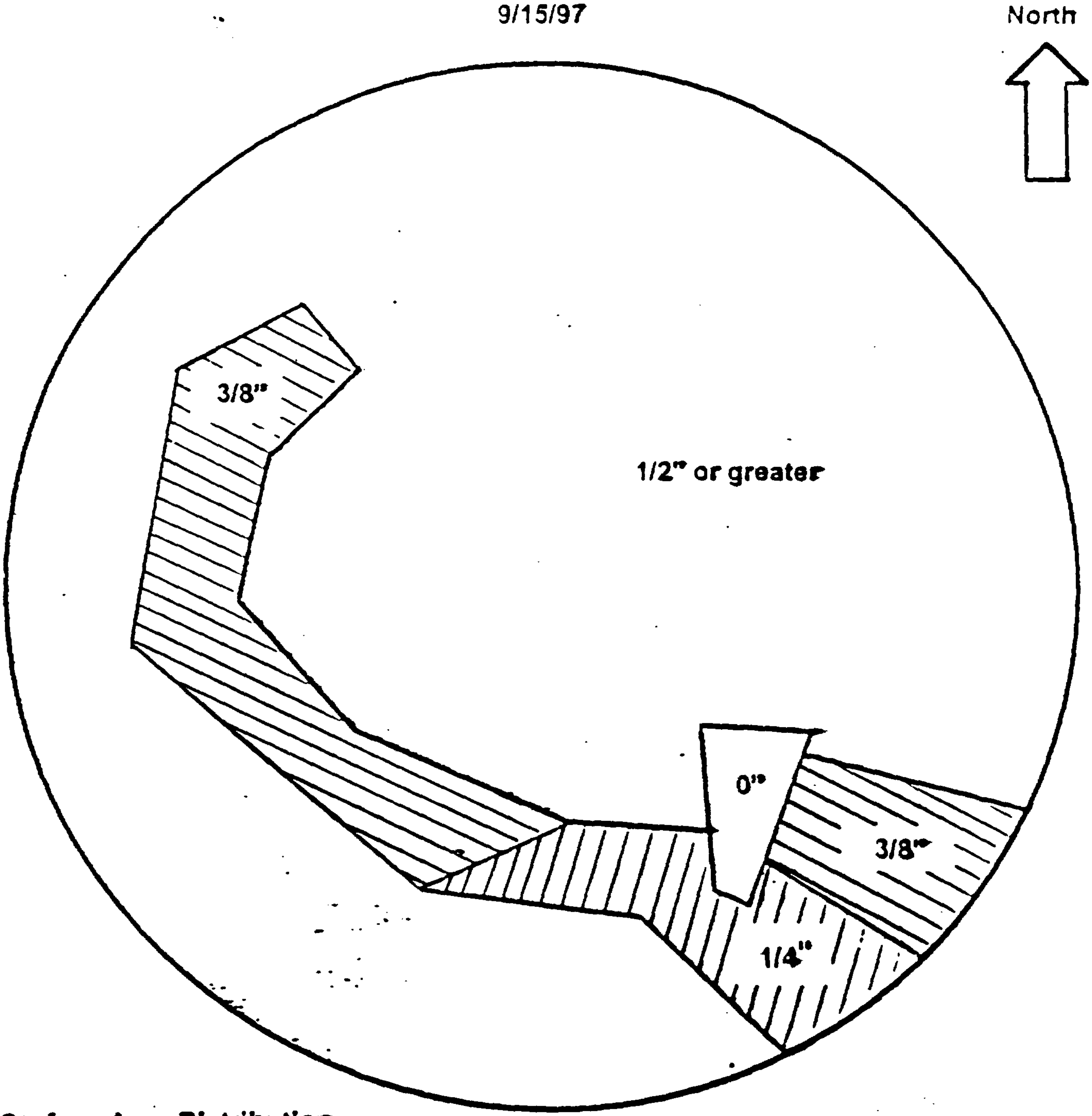
- Piles of sludge near the wall of the tank may not be effectively influenced by the reducing grout. The performance evaluation for Tank 17 was based on the assumption that liquid percolating through the waste layer must have first percolated through the reducing grout. Thus, Tc-99 and plutonium were assumed to be relatively immobile because the water in the vicinity of the waste will be reducing and highly alkaline.[2] However, if large pockets of waste were to remain right up against the tank wall after the tank wall has rusted away, there is the possibility that ordinary groundwater, which is oxidizing and slightly acidic, will percolate into the waste layer, invalidating this assumption.

- The concentration of contaminants in the reducing grout was computed by taking the total contaminant concentration and dividing by the entire mass of reducing grout (See section 6.3.2, "Class C Calculation"). However, if large areas of the tank were to remain clean during closure, it seems inappropriate to take credit for the mass of reducing grout covering these clean areas. For example, if all of the sludge were in one pile covering 10% of the area of the tank, one could argue that it would be reasonable to take credit for only the weight of the reducing grout in that 10% of the tank in computing the contaminant concentration.

For these two reasons, the decision was made to redistribute the sludge away from the tank wall and attempt to cover more of the surface of the floor of the tank, so the extent of the clean areas would be reduced.

The redistribution was accomplished using a high pressure cleaning device called the hydrolazer. The heart of the hydrolazer was a hollow steel cleaning head, roughly rectangular in shape, about 12 inches wide, 13 inches long, and 6 inches tall. High pressure water entered the head through a flexible hose. The hydrolazer had two forward nozzles and ten aft nozzles, so it tended to move forward when water was spraying through it, with the hose trailing like a tail. The head was steered by two cables, one on each side, which were actuated using winches located at the center riser of the tank. By alternately pulling on the cables and letting them out, the hydrolazer could be driven toward the wall of the tank, pulled back toward the center riser, and steered toward the right or left. The installation of the hydrolazer in Tank 17 was dubbed the "Water Mouse" because of the way the device scurried around the tank when manipulated with the two cables.

Figure 4 TANK 17 SLUDGE DISTRIBUTION MAP
AFTER "WATER MOUSE" OPERATION
WATER REMOVAL - LIQUID DEPTH <3/8"
9/15/97



Surface Area Distribution

* 1/2" or greater = 80%
* 3/8" = 13%
* 1/4" = 5%
* 0" = 2%

The Water Mouse was successful at redistributing the sludge in Tank 17. After the Water Mouse operation, a video inspection on 15 September 1997 (See Figure 4) showed that 80% of the tank was covered with sludge greater than 1/2 inch. The exact depth of the sludge at various spots in this region was difficult to estimate because the lifting plates was covered, the sludge was relatively featureless, and there were few objects in this region of the tank that could be used for judging depth.

In the portions of the tank where the lifting plates could be observed, about 13% of the tank had sludge about 3/8 inch, 5% about 1/4 inch, and only 2% of the tank floor appeared to be bare, rusty metal. The piles of sludge that had been near the tank wall, some of which had been higher than 4 inches, were moved toward the interior of the tank. Also, much of the floor of the tank appeared to be covered with fine solids that had settled in a rippled pattern, like miniature sand dunes. It appears likely that some of these solids will be moved by the reducing grout and encapsulated into the grout.

The configuration after Water Mouse operation (Figure 4) was much more desirable than the configuration found in the inspection on 11 July 1997 (Figure 2) at the completion of spray washing. Based on the video inspection of 15 September 1997, the decision was made to close the tank.

6. Waste Composition and Inventory

6.1 Process Knowledge Estimates

Estimates of the composition of residual sludge in Tank 17 were derived from the Waste Characterization System (WCS).[12]

The inventories and compositions of major sludge constituents in WCS are based on tank fill histories. WCS sludge inventories are based on sludge transfers from the canyons to the tank farms and between tanks. WCS contains the following information about each sludge transfer:

- Date
- Source - canyon or tank
- Destination - tank
- Process - PUREX or H Modified (HM)
- Stream - High Heat Waste (HHW), Low Heat Waste (LHW), or Mixed
- Volume
- Major chemical compound weights - $Fe(OH)_3$, $NaAlO_2$, $Ni(OH)_2$, and MnO_2

- Major actinide weights - Th-232, U-233, U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242

6.1.1 Chemical Contaminants

For each transfer, WCS keeps track of which tank received the waste and how much of each compound was in the transfer. For major chemical compounds (the four listed above) the information comes directly from canyon records. These four compounds account for about 80% of the weight of SRS sludge. The minor compounds are estimated by multiplying the weight of Fe(OH)3 by the flowsheet ratio of that constituent to Fe(OH)3. WCS computes the inventory of chemical contaminants that were received in each waste tank by simply summing up the quantity of chemicals in each transfer.

To determine the concentration of each compound, the inventory of that compound is divided by the calculated total mass of sludge in the waste tank. These concentrations were then multiplied by the estimated mass of sludge in Tank 17 (about 4700 pounds) to derive an estimate of the total chemical inventory in the tank, which is reported in Table 2.

6.1.2 Radionuclides

The radionuclide inventory was estimated only for the sludge because the primary salt radionuclide, Cs-137, would have been preferentially washed out during the spray washing in 1985 and during spray washing in 1997.

WCS computes the inventory of fission and activation products (H-3 through Eu-155 in Table 1) using concentrations based on yield distributions in SRS reactor assemblies, solubility data, and other information (for example, the knowledge that a large amount of tritium was added to Tank 17). The concentrations predicted by WCS were used to estimate the inventory in Tank 17, with the exception of Tc-99, which is discussed in the section below.

WCS computes the inventory of sludge actinides (U-232 through Cm-245 in Table 1) using a combination of techniques used for chemicals and fission and activation products. The mass of major actinides in each transfer are known from canyon accountability records or process records. The concentration of minor actinides was estimated from yield distributions in SRS reactor assemblies.

Similar to the treatment for chemical constituents, the concentration of each radionuclide in Tank 17 was computed by dividing the estimated inventory of that radionuclide fed to the tank by the estimated total mass of sludge fed to the tank. Each of these concentrations was them multiplied by the estimated mass of sludge remaining in Tank 17 to derive the inventories that are reported in Table 1.

6.1.3 Tc-99

The predicted tank inventory reported in Table 1 for Tc-99 is based on an adjusted concentration that is 13.5 times the concentration reported by WCS. This is the only nuclide for which the process knowledge concentration has been adjusted. The value for this radionuclide was adjusted for two reasons:

- The performance evaluation predicts that the dose at the seepline will be predominantly due to Tc-99. Therefore, it is important to estimate this radionuclide conservatively.
- Sample results indicate that the concentration of Tc-99 in the residual sludge in Tanks 17 and 20 is elevated relative to the concentration predicted by WCS for the bulk sludge in these tanks. In particular, the ratio of Tc-99 to iron (iron is an indicator for sludge) was extremely high in the white deposits in Tank 20, which were found to contain a high concentration of cryolite.[3] The presence of highly enriched Tc-99 in these deposits suggests that the Tc-99 might have precipitated in the cryolite, so that the residual deposits have a higher amount of Tc-99 than the bulk sludge. The Tc-99 in Tank 17 is also enriched relative to WCS predictions, although not to the same extent as Tank 20.

The adjustment factor of 13.5 was chosen in September 1996 based on sample results from Tank 20. At that time the Tc-99 concentration predicted for Tank 20 by process knowledge was 6.95 E-05 Ci/kg, whereas the measured concentration in the Tank 20 sludge is 0.94 microCi/gm, which is equivalent to 9.4 E-04 Ci/kg.[13] Since that time, the process knowledge estimate has changed slightly due to refinements in the method of calculation. WCS currently predicts that the sludge in Tank 20 should have a concentration of 6.3 E-05 Ci of Tc-99 per kg. Thus, the appropriate adjustment factor to be used in the performance evaluation should have been 15 (9.2 E-04 divided by 6.3 E-05), about 11% higher. However, the error introduced by using the old adjustment factor is small relative to other conservative assumptions, so there are no plans to revise the Tank 20 performance evaluation.

Samples in Tank 17 show a Tc-99 enrichment factor of 3.4, much less than the enrichment factor of 13.5 in Tank 20. WCS currently predicts the sludge concentration in Tank 17 to be 1.36 E-04 Ci/kg of Tc-99, compared to a sample result of 0.46 microCi/gm (4.6 E-04 Ci/kg).

Because there was only one sample taken from Tank 17, the adjustment factor of 13.5 found in Tank 20 was also applied to the WCS inventory estimate in Tank 17. As more experience is obtained in characterizing residuals, it may be possible to reduce the adjustment factor. For example, cryolite should be relatively easily removed by spray washing, so it is possible that the Tc-99 was removed from Tank 17 during spray washing. However, since samples were not taken after spray washing, there would not be a strong basis for defending an estimate in which the Tc-99 concentration was not adjusted upward. For example, it is possible that Tc-99 may also be enriched by compounds other than cryolite that are less easily removed by the spray washing.

6.2 Samples

Two samples were taken of Tank 17 sludge in January 1997, in addition to a supernate dip sample. The three samples were analyzed at SRTC.[14]

The measured supernate composition of the dip sample compared favorably with previous measurements of the Tank 17 supernate. The supernate sample results also showed that most of the contaminants were in the sludge. For example, the Tc-99 concentration in the supernate was 7.4 E-04 µCi/mL, almost three orders of magnitude lower than the concentration in the sludge, 4.6 E-01 µCi/mL. Because the supernate concentrations would have been reduced even more during spray washing, which occurred later, the inventory of contaminants in the supernate is negligible and was neglected in assessing the inventories of contaminants in the tank.

The sludge samples were taken using a "water bug" device, which was designed to collect a sludge sample even through the tank still had 279,000 gallons of supernate at this time. The "water bug" device consisted of a floating pump with a weighted length of flexible tubing. The pump sucked liquid through the tubing, effectively "dredging" solids from the bottom of the tank, and exhausted part of its discharge into a filtered receptacle, which caught the solids. The other part of the discharge of the pump was directed sideways into the liquid, which caused the "water bug" to move around the tank. In effect, the device moved around the tank like a motor boat, dredging up and collecting sludge solids.

One advantage of this technique of sample collection is that the sample is a composite of sludge over a wide area of the tank. The disadvantage of the technique is that the only the top of the sludge is sampled. However, Tank 17 should have been well mixed by the campaigns of waste removal with slurry pumps followed by spray washing with powerful rotary sprays. The fact that the sample results are similar to process knowledge supports this assumption.

6.3 Estimated Inventories

The estimated inventories of contaminants in Tank 17 are reported in Tables 1 and 2.

Table 1
Radionuclide Inventories in Tank 17 Solids

Nuclide	Concentration from WCS (10/31/96) (Ci/kg)	Tank Inventory Based on 2400 gallons (Ci)	"Water Bug" Samples (microCi/gm)	"Water Bug" Samples Inventory Based on 2,400 gal (Ci)	Conservative Estimate (Highest of WCS and samples) (Ci)	Class C Upper Limit	Class C Units	Tank 17 Concentration in Class C units	Factor Relative to Class C limit	Factor With 72 Inches of Grout
H-3	0.000E+00	0.00E+00	11.4	24.25	24.25	None	NA			
C-14	1.611E-06	3.42E-03			3.4E-3	8.000E+00	Ci/m^3	0.00038	4.71E-05	4.43E-07
Ni-59	9.478E-05	2.01E-01			2.0E-01	2.200E+02	Ci/m^3	0.0228	0.0001	9.48E-07
Co-60	1.189E-03	2.52E+00	0.393	0.836	2.5E+00	None	NA			
Se-79	7.839E-06	1.66E-02			1.7E-02	None	NA			
Sr-90	4.287E-01	9.10E+02	60.2	128	9.1E+02	7.000E+03	Ci/m^3	100	0.014	0.000135
Y-90	4.287E-01	9.10E+02			9.1E+02	None	NA			
Tc-99	1.360E-04	3.90E+00	0.462	0.983	3.9E+00	3.000E+00	Ci/m^3	0.43	0.143	0.0013
Ru-106	1.031E-06	2.19E-03			2.2E-03	None	NA			
Rh-106	1.031E-06	2.19E-03			2.2E-03	None	NA			
Sb-125	7.395E-04	1.57E+00			1.6E+00	None	NA			
Sn-126	1.456E-05	3.09E-02			3.1E-02	None	NA			
I-129	6.453E-10	1.37E-06			1.4E-06	8.000E-02	Ci/m^3	1.51E-07	1.89E-06	1.78E-08
Cs-134	3.313E-06	7.03E-03			7.0E-03	None	NA			
Cs-135	8.976E-08	1.91E-04			1.9E-04	None	NA			
Cs-137	2.961E-02	6.29E+01	9.57	20.36	6.3E+01	4.600E+03	Ci/m^3	6.920	0.0015	1.42E-05
Ce-144	6.208E-08	1.32E-04			1.3E-04	None	NA			
Pr-144	6.208E-08	1.32E-04			1.3E-04	None	NA			
Pm-147	1.250E-02	2.65E+01			2.7E+01	None	NA			
Eu-154	2.013E-03	4.27E+00	0.0763	0.162	4.3E+00	None	NA			
Eu-155		0.00E+00	0.0413	0.0879	8.8E-02	None	NA			
U-232	2.408E-08	5.11E-05			5.1E-05	100	nCi/gm	0.024	0.00024	3.31E-07
U-235	1.549E-07	3.29E-04	0.00013	0.0003	3.3E-04	100	nCi/gm	0.155	0.00155	2.13E-06
U-238	9.624E-06	2.04E-02	0.003	0.007	2.0E-02	100	nCi/gm	9.60	0.096	0.000132
Np-237	0.000E+00	0.00E+00	0.007	0.015	0.015	100	nCi/gm	7.12	0.071	9.81E-05
Pu-238	0.000E+00	0.00E+00	33.4	71.05	71.05	100	nCi/gm	33400	334	0.46
Pu-239	5.637E-03	1.20E+01	7.58	16.13	16.13	100	nCi/gm	7584	76	0.10
Pu-240	1.488E-03	3.16E+00	1.72	3.66	3.66	100	nCi/gm	1723	17.24	0.024
Pu-241	9.837E-03	2.09E+01	152	323	3.2E+02	3500	nCi/gm	152000	43	0.060
Pu-242	2.145E-06	4.55E-03	0.0027	0.0058	5.8E-03	100	nCi/gm	2.74	0.027	3.78E-05
Am-241	2.021E-02	4.29E+01	4.49	9.55	4.3E+01	100	nCi/gm	20166	202	0.278
Cm-244	3.735E-07	7.93E-04			7.9E-04	100	nCi/gm	0.37	0.0037	5.14E-06
Cm-245	2.244E-13	4.76E-10			4.8E-10	100	nCi/gm	2.24E-07	2.247E-09	3.09E-12
Total alpha emitting nuclides with half lives greater than 5 years (Ci)					130					
						Sum of Class C Factors			673	0.9283

Table 2
Chemical Inventories in Tank 17 Solids

	Inventory from WCS Adjusted to 2400 gal (kg)	Average of Water Bug Samples (wt%)	Estimated Inventory from samples (kg)	Conservative Estimate (Highest of WCS and Samples) (kg)
Silver	7.2	<2.0E-02	<0.4	7.2
Aluminum	123.7	3.9E+00	83.2	123.7
Barium	4.2	<3.89E-03	<0.08	4.2212
Fluoride	3.8	5.0E-02	1.1	3.8
Chromium	5.1	3.1E-02	0.7	5.1
Copper	3.6	<8.7E-03	<0.2	3.6
Iron	583.7	2.4E+01	510.5	583.7
Mercury	1.5	7.5E-03	0.2	1.5
Nitrate plus Nitrite	39.2	5.3E+00	106.4	106.4
Manganese	27.3	2.4E+00	51.9	51.9
Nickel	0.0	3.0E-02	0.6	0.9
Lead	6.0	<5.23E-02	<1.1	6.0
Uranium	60.9			60.9
Zinc	7.2	3.1E-02	0.7	7.2
Sodium		9.5E+00	202.9	202.9
Silicon		1.8E+00	37.4	37.4
Boron		<2.06E-02	<0.44	<0.44
Calcium		8.7E-01	18.5	18.5
Lithium		<8.28E-03	<0.18	<0.18
Magnesium		1.6E+00	33.4	33.4
Molybdenum		<3.19E-03	<0.068	<0.068
Titanium		<5.0E-03	<0.1	0.8
Zirconium		<8.6E-03	<0.2	0.0
Cadmium		9.2E-01	19.5	19.5
Phosphate		<2.45E-02	<0.5211	<0.5211
Chloride		7.0E-02	1.5	1.5
Sulfate		1.0E-01	2.1	2.1
Oxalate		9.5E-01	20.2	20.2

6.3.1 Radionuclide Inventories

Table 1 shows the radionuclide contaminants. Columns 2 and 3 show the inventories predicted from process knowledge, as discussed previously. Column 4 shows the average concentrations from the "water bug" sampler. Column 5 shows the inventory predicted from sample results.

The inventories of Cs-137 and Pu-239 were below the predictions.

Technetium-99 was lower than predicted, although as discussed previously, the process knowledge prediction was adjusted upward by a factor of 13.5 based on experience in Tank 20. If it were not for this adjustment, the sample result would have been 3.4 times the predicted value. As a result of the adjustment, the sample result is 4 times less than the predicted value.

Plutonium-238 and Np-237 were notably higher than predictions. Seventy-one curies of Pu-238 were found in Tank 17, although none were predicted. Production records do not indicate that any Pu-238 went to Tank 17, which contains Purex Low-Heat Waste. It had long been recognized that some small amount of Pu-238 and other plutonium isotopes would be present in Purex Low-Heat Waste, but the amount was expected to be small enough to be neglected. The sample results from Tank 17 (and also from Tank 20[3]) shows that this assumption is not correct, because Pu-238 is, in fact, the alpha radionuclide that is present in highest concentration relative to its Class C limit. Pu-241 is present in higher concentration, but its Class C limit is 35 times higher, so its concentration relative to its limit is lower.

For the performance evaluation, Pu-238 is not a concern because it is relatively immobile in the environment and has a half-life of only 86 years. Therefore, virtually no Pu-238 will travel through the environment and outcrop at the seepline. However, the Pu-238 is a concern because of its Class C implications (see next section). Plans are to revise the assumptions in the WCS to specify that some fraction of the Pu-238 and the other plutonium isotopes go to Low-Heat Waste.

The last nuclide that occurred higher than its predicted concentration was Np-237. Similar to Pu-238, Np-237 was thought to be present in low enough concentrations that it could be neglected. The inventory estimate of Np-237 in Tank 17 is low. However, of the nuclides of concern in Tank 17, Np-237 is unique in that it has a high ingestion dose conversion factor, a long half-life, and travels relatively easily through the environment (Most nuclides with high dose conversion factors, such as Pu-239, are relatively immobile). Therefore, it is important to estimate Np-237 conservatively.

For the purposes of Tank 17, Np-237 can be neglected. However, as a result of the discovery of Np-237 in Tank 20 and 17, plans are to revise the WCS to account for Np-237 in Low-Heat Waste. It appears likely that Np-237 will be a significant dose contributor to the performance evaluation for some tanks.

6.3.2 Class C Calculation

The rightmost five columns of Table 1 include a Class C calculation for the waste in Tank 17. The column entitled "Class C Upper Limit" shows the Class C limit for each radionuclide, from Nuclear Regulatory Commission regulation 10 CFR 61.55, effective 1991. The units for the value in the column are shown in the next column, entitled "Class C Units." The next column, "Tank 17 Concentration in Class Units," shows the computed concentration of the Tank 17 sludge converted to the appropriate units.

In the column "Factor relative to Class C Limit" the computed concentration in Tank 17 is divided by the limit to obtain a Class C factor for each radionuclide. To be within the Class C designation the sum of all of these factors must be less than or equal to 1. As can be seen from the sum at the bottom of the column, the sludge in Tank 17 is currently 673 times the upper limit for the Class C waste.

The last column, "Factor with 72 Inches Grout," shows the factors if one takes credit for the mass of 72 inches of grout covering the entire tank floor in computing the radionuclide concentration. The grout is assumed to have a specific gravity of 1.6, which is equivalent to light CLSM. Plans are to pour 72 inches of reducing grout in Tank 17, which has a specific gravity of 2.4, so this calculation incorporates a safety factor of 50%. As can be seen from the summation at the bottom of the column, 72 inches of grout is sufficient to bring the sum of the Class C factors to less than 1.000. Thus, if one takes credit for the mass of 72 inches or more of grout covering the entire tank floor, the concentration of the waste plus grout in Tank 17 will be less than the upper limit for Class C waste.

6.3.3 Chemical Inventories

Table 2 shows the chemical contaminants. Column 2 shows the inventories predicted by WCS. Also shown are the concentrations measured in the tank, and the estimated inventories based on the samples.

6.4 Other Contaminants

The risers in Tank 17 contain lead, which acted as radiation shielding when the tank stored HLW. Plans are to leave these risers in place when the tank is closed. The estimated mass of lead is approximated 500 pounds per riser. There are six risers on the tank, for an estimated total of 3000 pounds of lead.

In addition to the contaminants in Tanks 17-20, there will be contamination in other equipment in the area, such as the 1F Evaporator, the 1F Concentration Transfer System, ventilation systems, and transfer piping. The inventory of contaminants in these locations is expected to be small relative to the amount of contamination in the tanks.

To account for contamination outside of the tank, we recommend that an inventory of contaminants equal to 20% of the waste inside the tank be added to the performance evaluation for each waste tank (i.e. performance modeling of the Tank 17-20 area should add 20% of the inventory in these four tanks). Based on engineering judgment, this 20% should bound the contamination in these locations. As closure modules are prepared for these locations, the modules will show that the contamination left behind is smaller than this estimate, or the estimate will be revised and the performance evaluation repeated.

7. Acronym List

CST	Concentration Storage and Transfer
CSTE	Concentration Storage and Transfer Engineering
CTS	Concentrate Transfer System
HHW	High Heat Waste
HLW	High-Level Waste
LHW	Low Heat Waste
SRS	Savannah River Site
SRTC-IWT	Savannah River Technology Center, Interim Waste Technology section
WCS	Waste Characterization System

8. References

1 "Industrial Wastewater Closure Plan for F- and H-Area High-Level Waste Tanks," Rev. 1, 10 July 1996

2 "Industrial Wastewater Closure Module for the High-Level Waste Tank 17 System," Revision 2, 26 August 1997

3 P. D. d'Entremont and J. R. Hester, "Characterization of Tank 20 Residual Waste," WSRC-TR-96-0267, 17 March 1997

4 W. S. Cavin and A. T. Crumm, "Waste Transfers and Miscellaneous Additions," WSRC-TR-93-425, Rev. 1, 21 January 1994

5 G. K. Georgeton, "Updated Tritium and Chemistry Calculations for Tank 17 Following K-Area Water Addition," WER-WMT-920142, 13 February 1997

6 M. E. Jamison et. al., "HLW Supernate Radionuclide Characterization," WSRC-TR-94-0290, Rev. 2, 22 August 1994

7 L. S. Livingston, Evaluation of Receipt Tanks for Long-Term Storage of Tank 17F Tritiated Water," WSRC-TR-96-0349, Rev. 0, 10 March 1997

8 P. D. d'Entremont, "Residual Tritium in Tank 17," HLW-HLE-97-0069, 6 March 1997

9 L. M. Smith, "Assessment of Soil Erosion Methods for Sludge Recovery, Savannah River Site," Technical Report GL-97-XX, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS

10 L. F. Landon and T. T. Thompson, "Technical Data Summary for the Defense Waste Processing Facility, Stage 2," DPSTD-80-39-2, December 1980

11 M. S. Hay, "Observations on the Mudsnapper Sample of the Tank 17F 'Rock Pile'," SRT-LWP-97-059, 7 May 1997

12 J. R. Hester, "High Level Waste Characterization System," WSRC-TR-96-0264, December 1996

13 P. D. d'Entremont and D. T. Bignell, "Options for Meeting Class C Criteria During HLW Tank Closure," WSRC-TR-96-0327, 16 October 1996

14 M. S. Hay, "Characterization of Tank 17F Samples in Support of Tank Closure," WSRC-RP-97-066, 28 January 1997

APPENDIX

SLUDGE HEEL VOLUME ESTIMATION METHOD FOR TANK 17

I. INTRODUCTION

The volume of sludge within a Type IV waste tank can be estimated by visually judging the depth of the sludge in the tank and integrating smaller increments of known volumes based on these depths. This technique is a tool for estimating sludge volumes of less than 3000 gallons with sludge depths not exceeding ¾". The sludge depth is determined by locating tank internal landmarks and judging the sludge depth using a remote video camera that is zoomed and focused on the landmark. The landmark accounts for a fraction of the total surface area of the tank bottom. The volume for that area fraction can be estimated by multiplying the area times the sludge depth. Total sludge volume is then calculated by summing all of the volume fractions.

Tank 17 sludge heel volume was estimated in July 1997 using this method and was found to be approximately 2400 gallons.

II. LANDMARK DESCRIPTION AND FRACTION DEVELOPMENT

One half inch (½") thick plates welded to the tank serve as the landmarks. The plates are twelve inches square (12 in^2) and are placed periodically along the tank bottom. The plates were used during tank construction. Lifting rods were welded to these plates and the rods were then attached to a lifting frame. They were adjusted using turnbuckles. This allowed the tank bottom steel sheets to be welded first on the concrete foundation mat and then lifted to allow for welding of the bottom seams. The bottom was then lowered on the mat for tank wall fabrication. The lifting rods were eventually cut from the lifting plates leaving only a remnant of the rod.

A study of plant drawing W164197 Rev 0, shows that plates to be ½ inch thick attached with a ¼ inch filet weld bead. The following is a schematic of the plate.

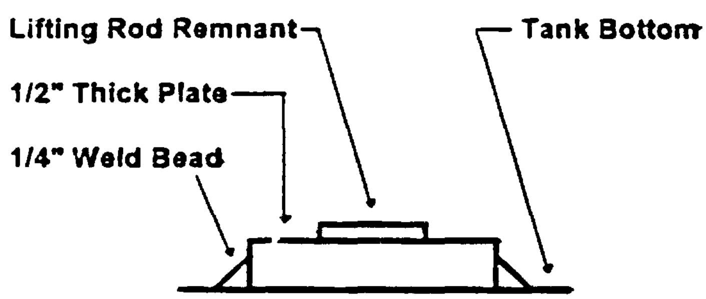


Figure A1. Lifting Plate Elevation View (Not to Scale)

A tank radius of less than the full radius of 42.5 feet is used. Since the tank bottom transitions to the tank wall with a curved 12-inch radius knuckle, a thin layer of sludge will not reach the outer edge of the tank. Assuming a sludge depth of 2", the calculated sludge radius will not exceed 42.0528 feet. Therefore, the total area is 5555.712 ft^2.

There are sixty-nine (69) lifting plates in the Type IV tanks. They are placed in a symmetrical pattern in accordance with the design drawing (W164197). Some of the plates are placed closer together than others and the contributing area fractions for the plates are therefore different. Refer to the attached computation for the development of the area fractions. In summary, the area fraction for each plate is constructed by drawing a boundary that is half of the distance to the adjacent plates. The area fractions end up looking like pieces to a jigsaw puzzle. The areas are calculated using geometry and trigonometry. The area fractions are added up and normalized to the total area of 5555.712 ft^2. Normalization is performed to lessen the additive errors introduced during fraction area development. Each piece is assigned a type and an ID number. For example, the center plate is type "A" and given the ID of "C01". Its normalized area is 87.6624 ft^2. Refer to Table A2 for a listing of the area fraction types and Table B3 for a listing of each plate ID.

III. SLUDGE VOLUME ESTIMATION

A video camera with pan-tilt-zoom capability is placed in one of the risers. Sufficient lighting is provided to allow a clear view of each lifting plate. Each plate is viewed and assessed for sludge depth. The criteria for estimation is given in Table A1.

Table A1. Sludge Depth Criteria

Depth (Inches)	Method
0	Able to see entire weld bead. No visible sludge around the plate with a clean or mostly clean tank floor.
1/8	A "dusting" of sludge is evident. The weld bead is mostly visible, but there is sufficient sludge surrounding the plate cover portions of the weld bead.
1/4	Weld bead is mostly covered but portions of the bead are still visible.
3/8	The weld bead is completely covered but the edge of the lifting plate is clearly visible
1/2	The square shape of the lifting plate is clearly visible but the sludge appears to be the same depth as the top of the lifting plate.
3/4	Only the remnant of the lifting rod is visible. The shape of the plate may be discerned through the sludge.

If a plate cannot be seen in its intended location, then sludge depth must be estimated by using bottom debris or equipment as a reference point. If no such artifacts are present, then the estimator must make a best guess. After the depths are estimated, they are converted to feet and then multiplied by the normalized area fraction. Summing the volume fractions will yield the total sludge volume in cubic feet which are then converted to the nearest whole gallon.

A detailed inspection was performed on July 11, 1997 at 0930 using this technique. Refer to Table A3 and the *Type IV Tank Residual Heel Estimate Worksheet* for the results of this inspection. It was estimated that approximately 2400 gallons of sludge residue was still left in the tank.

IV. ERROR DISCUSSION

If all of the plates can be seen, and if the sludge residue is relatively level (i.e. no abrupt peaks and valleys), it can be assumed that the sludge can be estimated to within ±1/8" which corresponds to ±433 gallons. This is the smallest resolution that can ascertained by video inspection. The error increases substantially when there are abrupt changes in sludge depths or when some or all of the plates are not visible. Other errors are introduced by the distortion in the tank bottom. Stresses formed during welding of the tank bottom, caused the tank to buckle in some areas so the tank is not entirely flat. The degree of flatness is difficult to determine from video inspection.

Table A2. Area Fraction Types

Sludge Radius	42.0528	feet
Total Area	5555.71	ft^2

Piece Type	Qty	Calculated Area Each	Calculated Total Area	Normalized Total Area	Normalized Area Ea.
A	25	87.8906	2197.2650	2191.5601	87.6624
B	2	110.8398	221.6796	221.1040	110.5520
C	4	77.3925	309.5700	308.7662	77.1916
D	4	71.5194	286.0776	285.3348	71.3337
E	4	83.2657	333.0628	332.1980	83.0495
F	4	88.5090	354.0360	353.1168	88.2792
G	2	88.1821	176.3642	175.9063	87.9531
H	2	76.3332	152.6664	152.2700	76.1350
I	4	74.5602	298.2408	297.4665	74.3666
J	4	56.1070	224.4280	223.8453	55.9613
K	4	69.3719	277.4876	276.7671	69.1918
L	4	56.3807	225.5228	224.9373	56.2343
M	4	84.3123	337.2492	336.3736	84.0934
N	2	88.2620	176.5240	176.0657	88.0328
TOTALS→	*69*		*5570.1740*	*5555.7117*	*1110.0367*

Table A3. Tank 17 Sludge Heel Volume Estimate - July 11, 1997 @ 0930

Piece ID No.	Piece Type	Area Ea.	Depth (in.)	Gallons
C01	A	87.6624	0.000	0.00
N01	A	87.6624	0.125	6.83
N02	A	87.6624	0.000	0.00
N03	G	87.9531	0.125	6.85
N04	H	76.1350	1.000	47.46
S01	A	87.6624	0.125	6.83
S02	A	87.6624	0.125	6.83
S03	G	87.9531	1.000	54.83
S04	H	76.1350	2.000	94.93
E01	A	87.6624	0.125	6.83
E02	A	87.6624	0.000	0.00
E03	B	110.5520	0.125	8.61
E04	N	88.0328	2.000	109.76
W01	A	87.6624	0.000	0.00
W02	A	87.6624	0.000	0.00
W03	B	110.5520	0.125	8.61
W04	N	88.0328	0.375	20.58
NE01	A	87.6624	0.000	0.00
NE02	A	87.6624	0.125	6.83
NE03	D	71.3337	0.375	16.68

Table A3. Tank 17 Sludge Heel Volume Estimate - July 11, 1997 @ 0930

Piece ID No.	Piece Type	Area Ea.	Depth (in.)	Gallons
NE04	M	84.0934	2.000	104.85
NE05	A	87.6624	0.125	6.83
NE06	A	87.6624	0.000	0.00
NE07	E	83.0495	1.000	51.77
NE08	L	56.2343	2.000	70.11
NE09	F	88.2792	0.125	6.88
NE10	C	77.1916	0.125	6.02
NE11	K	69.1918	0.375	16.18
NE12	J	55.9613	1.000	34.89
NE13	I	74.3666	1.000	46.36
NW01	A	87.6624	0.125	6.83
NW02	A	87.6624	0.125	6.83
NW03	D	71.3337	0.125	5.56
NW04	M	84.0934	1.000	52.43
NW05	A	87.6624	0.125	6.83
NW06	A	87.6624	0.000	0.00
NW07	E	83.0495	0.125	6.47
NW08	L	56.2343	1.000	35.06
NW09	F	88.2792	0.125	6.88
NW10	C	77.1916	0.375	18.05
NW11	K	69.1918	1.000	43.14
NW12	J	55.9613	1.000	34.89
NW13	I	74.3666	1.000	46.36
SE01	A	87.6624	0.125	6.83
SE02	A	87.6624	0.125	6.83
SE03	D	71.3337	0.500	22.24
SE04	M	84.0934	3.000	157.28
SE05	A	87.6624	0.500	27.33
SE06	A	87.6624	0.250	13.66
SE07	E	83.0495	3.000	155.32
SE08	L	56.2343	4.000	140.23
SE09	F	88.2792	1.000	55.03
SE10	C	77.1916	0.500	24.06
SE11	K	69.1918	4.000	172.54
SE12	J	55.9613	2.000	69.77
SE13	I	74.3666	2.000	92.72
SW01	A	87.6624	0.125	6.83
SW02	A	87.6624	0.125	6.83
SW03	D	71.3337	0.125	5.56
SW04	M	84.0934	1.000	52.43
SW05	A	87.6624	0.250	13.66
SW06	A	87.6624	0.125	6.83
SW07	E	83.0495	0.500	25.89
SW08	L	56.2343	1.000	35.06
SW09	F	88.2792	1.000	55.03
SW10	C	77.1916	1.000	48.12

Table A3. Tank 17 Sludge Heel Volume Estimate - July 11, 1997 @ 0930

Piece ID No.	Piece Type	Area Ea.	Depth (in.)	Gallons
SW11	K	69.1918	1.000	43.14
SW12	J	55.9613	2.000	69.77
SW13	I	74.3666	2.000	92.72
		5555.71		**2421** gallons
		TOTAL AREA (ft^2)		TOTAL VOLUME

TYPE IV TANK RESIDUAL HEEL ESTIMATE WORKSHEET

TANK NO. *17F*

DATE 7/11/97
TIME 0930

		NW12 1.000 in. 34.89 gal	NW13 1.000 in. 46.36 gal	N04 1.000 in. 47.46 gal	NE13 1.000 in. 46.36 gal	NE12 1.000 in. 34.89 gal		
	NW11 1.000 in. 43.14 gal	NW10 0.375 in. 18.05 gal	NW09 0.125 in. 6.88 gal	N03 0.125 in. 6.85 gal	NE09 0.125 in. 6.88 gal	NE10 0.125 in. 6.02 gal	NE11 0.375 in. 16.18 gal	
NW08 1.000 in. 35.06 gal	NW07 0.125 in. 6.47 gal	NW06 0.000 in. 0.00 gal	NW05 0.125 in. 6.83 gal	N02 0.000 in. 0.00 gal	NE05 0.125 in. 6.83 gal	NE06 0.000 in. 0.00 gal	NE07 1.000 in. 51.77 gal	NE08 2.000 in. 70.11 gal
NW04 1.000 in. 52.43 gal	NW03 0.125 in. 5.56 gal	NW02 0.125 in. 6.83 gal	NW01 0.125 in. 6.83 gal	N01 0.125 in. 6.83 gal	NE01 0.000 in. 0.00 gal	NE02 0.125 in. 6.83 gal	NE03 0.375 in. 16.68 gal	NE04 2.000 in. 104.85 gal
W04 0.375 in. 20.58 gal	W03 0.125 in. 8.61 gal	W02 0.000 in. 0.00 gal	W01 0.000 in. 0.00 gal	C01 0.000 in. 0.00 gal	E01 0.125 in. 6.83 gal	E02 0.000 in. 0.00 gal	E03 0.125 in. 8.61 gal	E04 2.000 in. 109.76 gal
SW04 1.000 in. 52.43 gal	SW03 0.125 in. 5.56 gal	SW02 0.125 in. 6.83 gal	SW01 0.125 in. 6.83 gal	S01 0.125 in. 6.83 gal	SE01 0.125 in. 6.83 gal	SE02 0.125 in. 6.83 gal	SE03 0.500 in. 22.24 gal	SE04 3.000 in. 157.28 gal
SW08 1.000 in. 35.06 gal	SW07 0.500 in. 25.89 gal	SW06 0.125 in. 6.83 gal	SW05 0.250 in. 13.68 gal	S02 0.125 in. 6.83 gal	SE05 0.500 in. 27.33 gal	SE06 0.250 in. 13.66 gal	SE07 3.000 in. 155.32 gal	SE08 4.000 in. 140.23 gal
	SW11 1.000 in. 43.14 gal	SW10 1.000 in. 48.12 gal	SW09 1.000 in. 55.03 gal	S03 1.000 in. 54.83 gal	SE09 1.000 in. 55.03 gal	SE10 0.500 in. 24.06 gal	SE11 4.000 in. 172.54 gal	
		SW12 2.000 in. 69.77 gal	SW13 2.000 in. 92.72 gal	S04 2.000 in. 94.93 gal	SE13 2.000 in. 92.72 gal	SE12 2.000 in. 69.77 gal		

Evaluator: T. B. Caldwell

Total Volume: 2,421 gallons

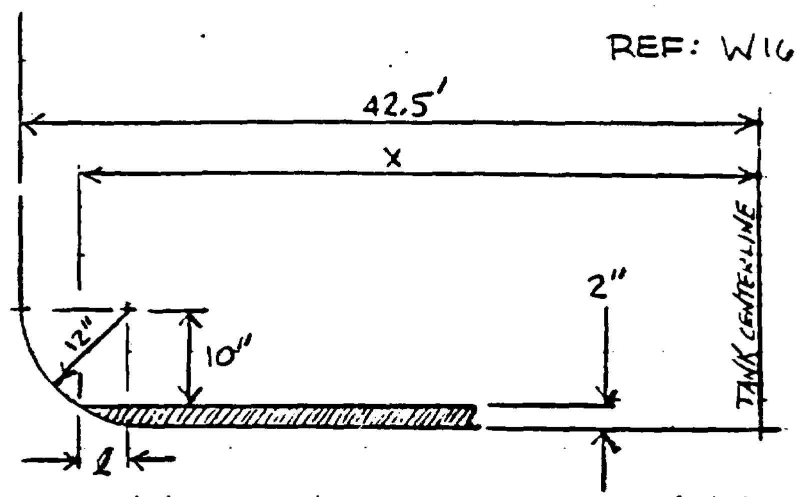
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: [signature]

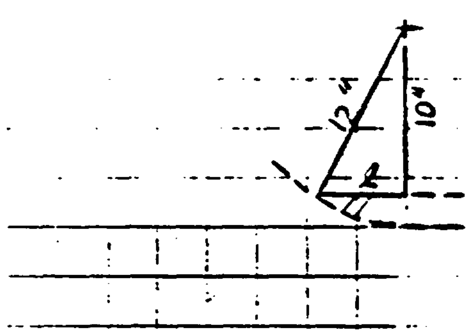
DETERMINE SLUDGE CIRCLE DIAMETER ASSUMING 2" DEPTH

REF: W163941



ELEVATION VIEW
(NOT TO SCALE)

SOLVE FOR "X":



IN THE FORM $a^2 + b^2 = c^2$
$\therefore\ b = \sqrt{c^2 - a^2}$

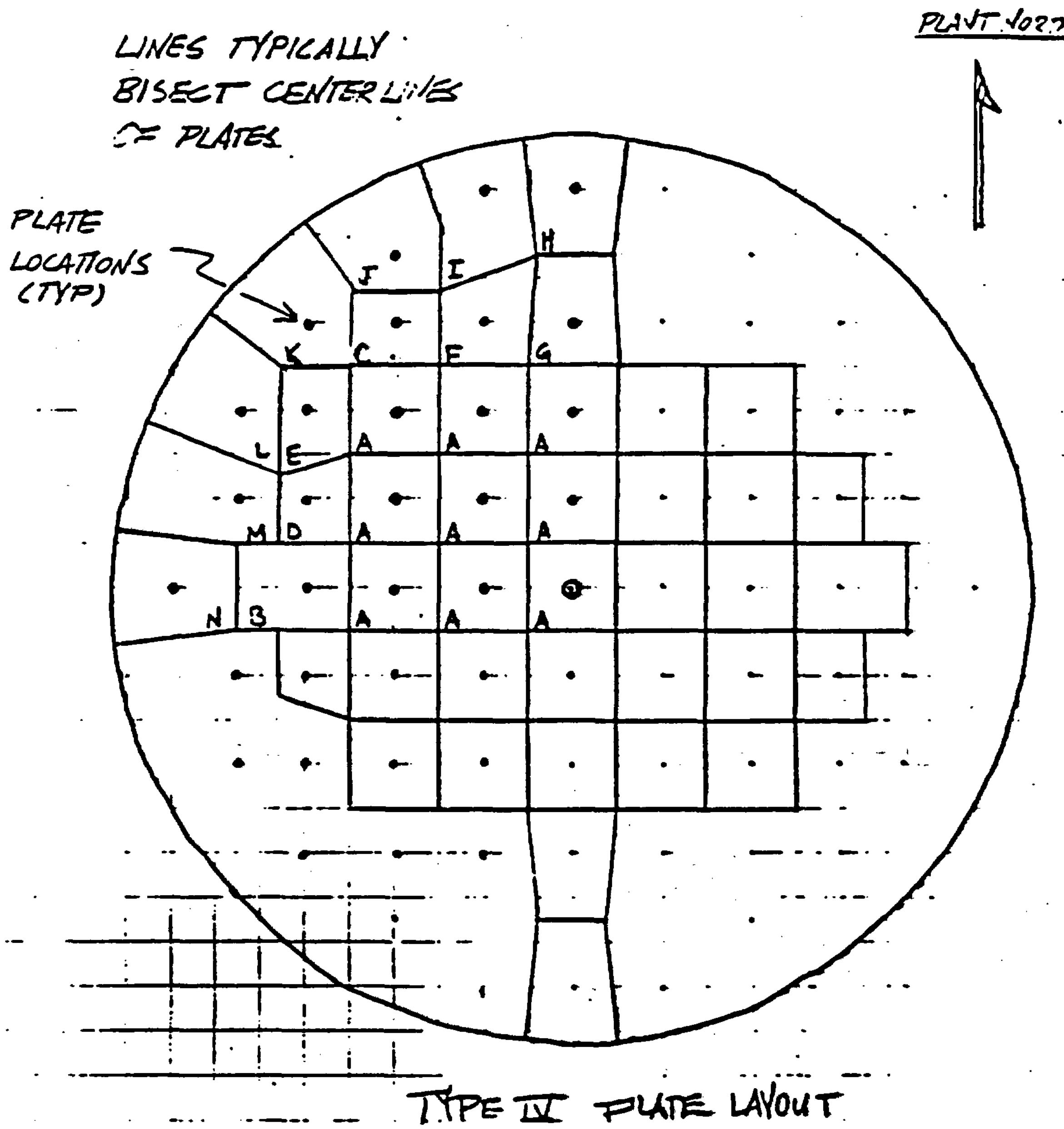
$\ell = \sqrt{12^2 - 10^2} = \sqrt{44}$
$\ell = 6.6332'' = 0.5528'$

$x = 42.5 - (1 - 0.5528) = \boxed{42.0528'}$

COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont



TYPE IV PLATE LAYOUT
(REF W164197)

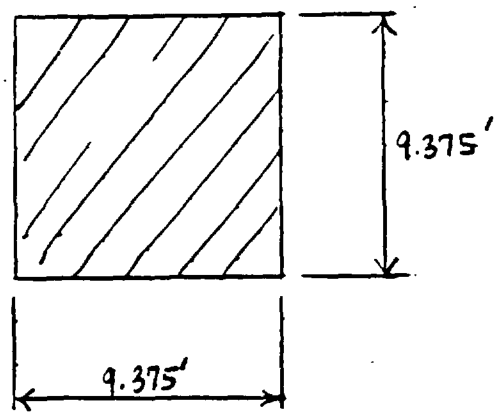
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont

PIECE "A" (QTY = 25)

$A = 87.8906\ FT^2$
$TOT\ A = 2197.2650\ FT^2$

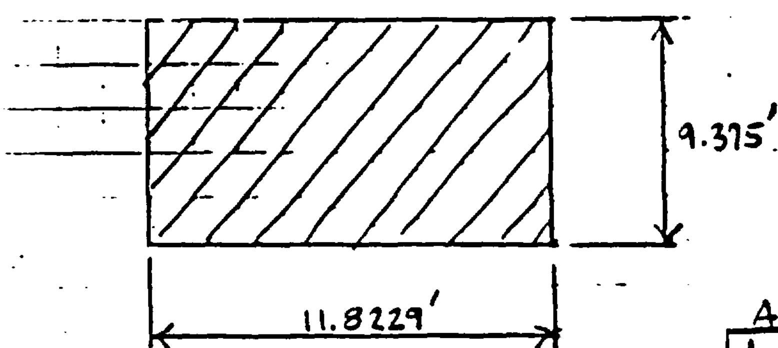


$A = (9.375)^2 = 87.8906\ FT^2$

TOTAL AREA BY "A"
$2197.266\ FT^2$

PIECE "B" (QTY = 2)

$A = 110.8398\ FT^2$
$TOT\ A = 221.6796\ FT^2$



$A = (9.375)(11.8229)$
$A = 110.8398\ FT^2$

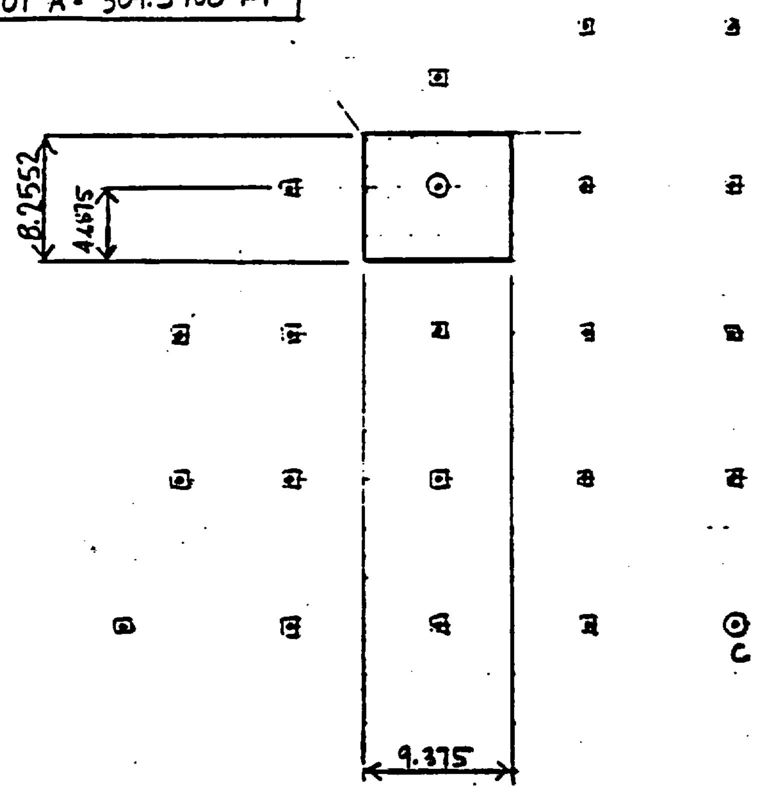
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont

PIECE "C" (QTY = 4)

A = 77.3925 FT²
TOT A = 309.5700 FT²



$A = (8.2552)(9.3750)$

$A = 77.3925 \text{ FT}^2$

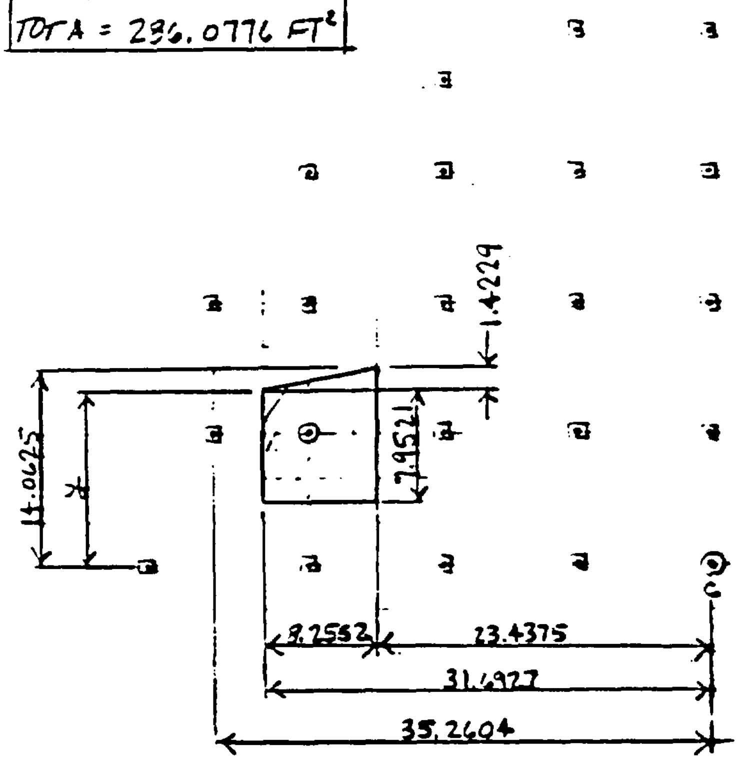
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: [signature]

PIECE "D" (QTY = 4)

A = 71.5194 FT²
TOT A = 286.0776 FT²



SOLVE FOR y

$y/31.6927 = 14.0625/35.2604$

$y = 12.6396$

AREA OF RECTANGLE

$A_R = (8.2552)(7.1521)$
$A_R = 65.6462\ FT^2$

AREA OF TRIANGLE

$A_T = (\frac{1}{2})(8.2552)(1.4229)$
$A_T = 5.8732\ FT^2$

$A = 5.8732 + 65.6462$
$A = 71.5194\ FT^2$

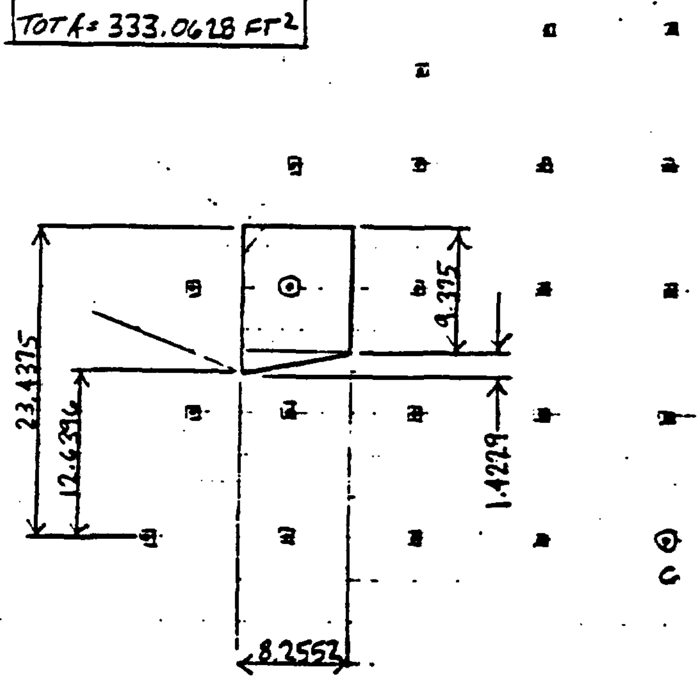
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: [signature]

PIECE "E" (QTY = 4)

A = 83.2657 FT²
TOT A = 333.0628 FT²



AREA OF RECTANGLE

$A_R = (8.2552)(9.375)$
$A_R = 77.3925$ FT²

AREA OF TRIANGLE

$A_T = \frac{1}{2}(8.2552)(1.4229)$
$A_T = 5.8732$ FT²

A = 83.2657 FT²

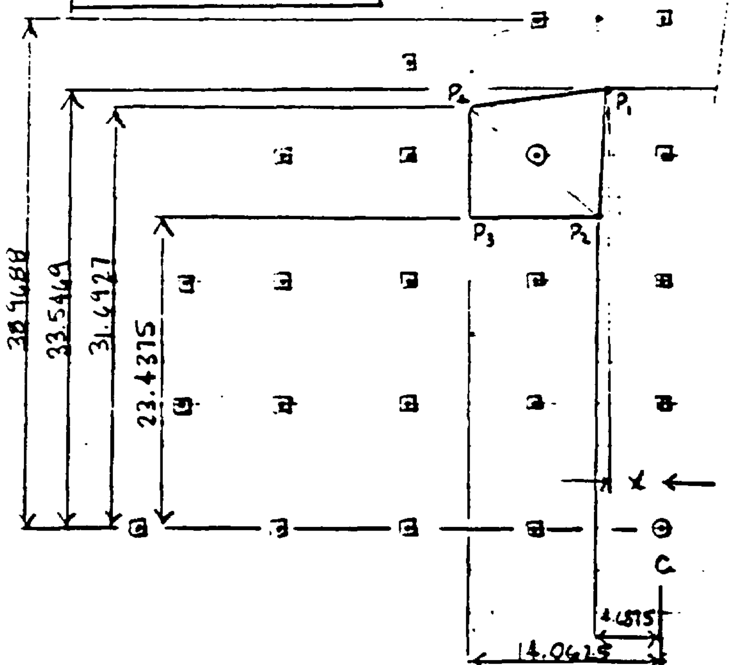
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont

PIECE "F" (QTY = 4)

A = 38.5090 FT²
TOT A = 354.0360 FT²



$x / 33.5469 = 4.6875 / 38.9688$

$x = 4.0353$

AREA OF RIGHT TRIANGLE

$A = \frac{1}{2}(9.3750)(8.2552)$

$A_1 = 38.6962$

AREA OF LARGE TRIANGLE

$s = (12.4916 + 10.1972 + 10.1304)\frac{1}{2}$

$s = 16.4096$

$A_2 = \sqrt{16.4096(16.4096-12.4916)(16.4096-10.1972)(16.4096-10.1972)} = 49.8128$

$A = 49.8128 + 38.6962 = 88.5090$ FT²

COORDINATES

P_1 (4.0353, 33.5469)
P_2 (4.6875, 23.4375)
P_3 (14.0625, 23.4375)
P_4 (14.0625, 31.6927)

$\overline{P_1P_2}$:

$\sqrt{(4.0353-4.6875)^2+(33.5469-23.4375)^2}$
$= 10.1304$

$\overline{P_2P_3}$

$14.0625 - 4.6875$
$= 9.375$

$\overline{P_3P_4}$

$31.6927 - 23.4375$
$= 8.2552$

$\overline{P_4P_1}$

$\sqrt{(4.0353-14.0625)^2+(33.5469-31.6927)^2}$
$= 10.1972$

$\overline{P_2P_4}$

$\sqrt{(14.0625-4.6875)^2+(31.6927-23.4375)^2}$
$= 12.4916$

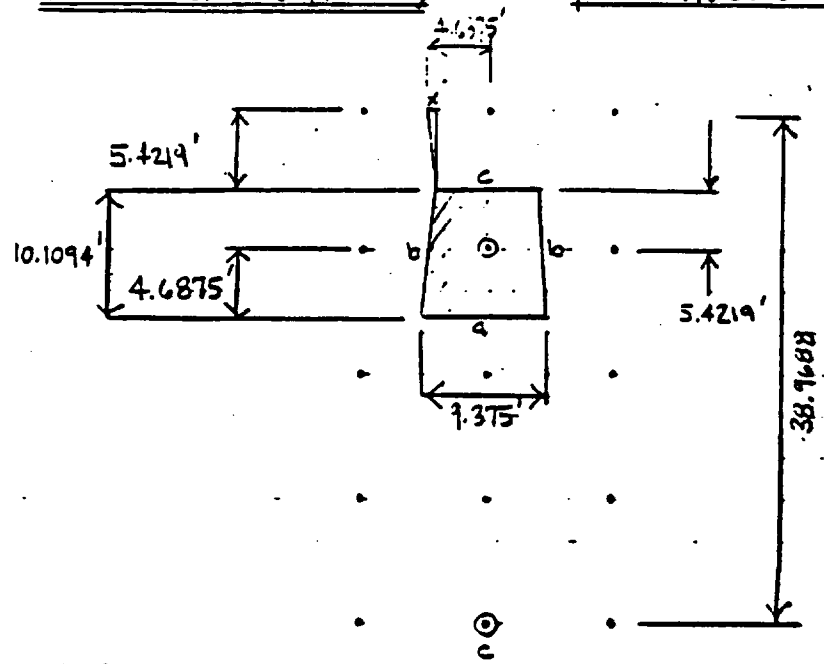
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. Sintenart [signature]

PIECE "G" (QTY=2)

A = 88.1821 FT²
TOT A = 176.3642 FT²



a = 9.375
b = 10.1304

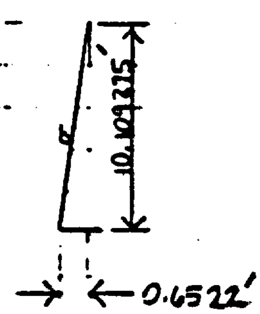
$$A = \frac{8.0706 + 9.375}{2}(10.1094)$$

A = 88.1821 FT²

$$x = 4.6875\left(5.4219/38.9688\right) = 0.6522'$$

$$c = 9.375 - 2(0.6522) = 8.0706'$$

check 'b' dimension



$$b = \sqrt{10.109375^2 + 0.6522^2}$$

$$b = 10.13039 \sim 10.1304 \checkmark$$

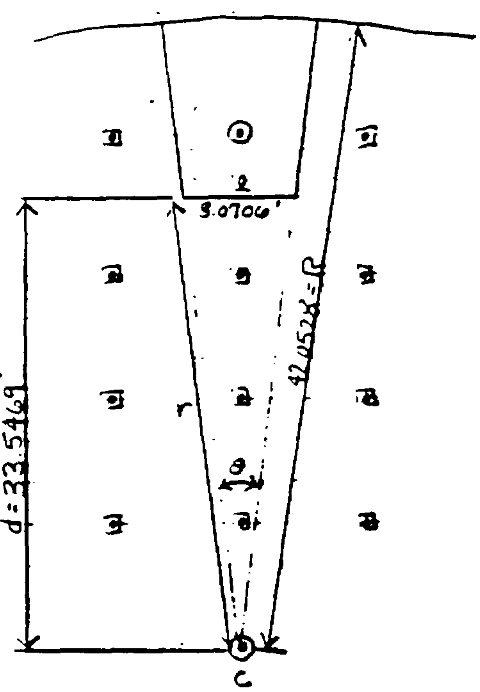
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. [signature]

PIECE "H" (QTY = 2)

$A = 76.3332\ FT^2$
TOT. A = $152.6664\ FT^2$



$$\ell = 2\sqrt{r^2 - d^2}$$

$$\left(\frac{\ell}{2}\right)^2 = r^2 - d^2$$

$$r = \sqrt{(\ell/2)^2 + d^2}$$

$$r = \sqrt{(3.0706/2)^2 + 33.5469^2}$$

$$r = 33.7837\ FT$$

$$\sin\frac{\theta}{2} = \frac{\ell}{2r}$$

$$\sin\theta/2 = 3.0706/2(33.7387)$$

$$\theta/2 = 6.8591°$$

$$\theta = 13.7181°$$

AREA OF SECTOR

$$A = \pi R^2 (\theta/360)$$

$$A = \pi (42.0528)^2 (13.7181/360)$$

$$A = 211.7050\ FT^2$$

AREA OF TRIANGLE

$$A = \frac{1}{2} d\ell = \frac{1}{2}(33.5469)(8.0706) = 135.3718\ FT^2$$

AREA OF PIECE

$$A = 211.7050 - 135.3718 = \boxed{76.3332\ FT^2}$$

TOTAL AREA
$152.6664\ FT^2$

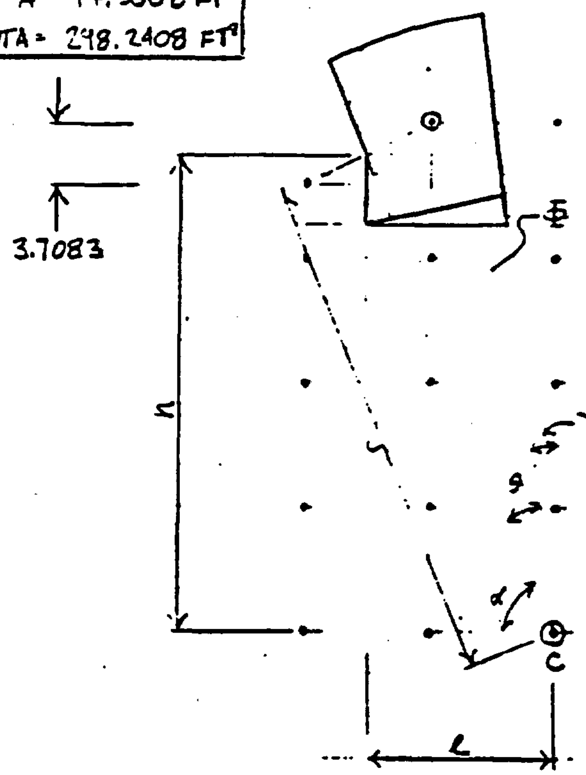
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont

PIECE "I" (QTY = 4)

A = 74.5602 FT²
TOTA = 298.2408 FT²



DETERMINE θ

$h = 37.1146'$
$\ell = 14.0625'$

$\tan\alpha = 37.1146 / 14.0625$

$\alpha = 69.2486°$

$\gamma = 6.8591°$

$\theta = 90 - (69.2486 + 6.8591)$

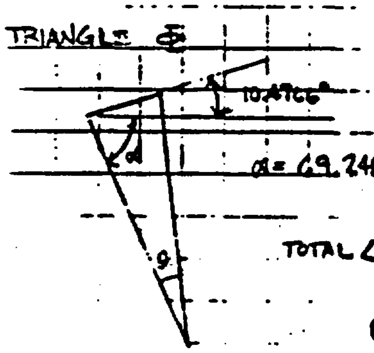
$\theta = 13.8923°$

AREA OF SECTOR

$A = \pi R^2 (\theta/360)$

$A = 214.3934\ FT^2$

TRIANGLE ⊕



TOTAL ∠ = 10.4766 + 69.2486 = 79.7252°

θ = 13.8923°

COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont

PIECE 'I' & 'F' COMMON LINE CHECK

$y = mx + b$

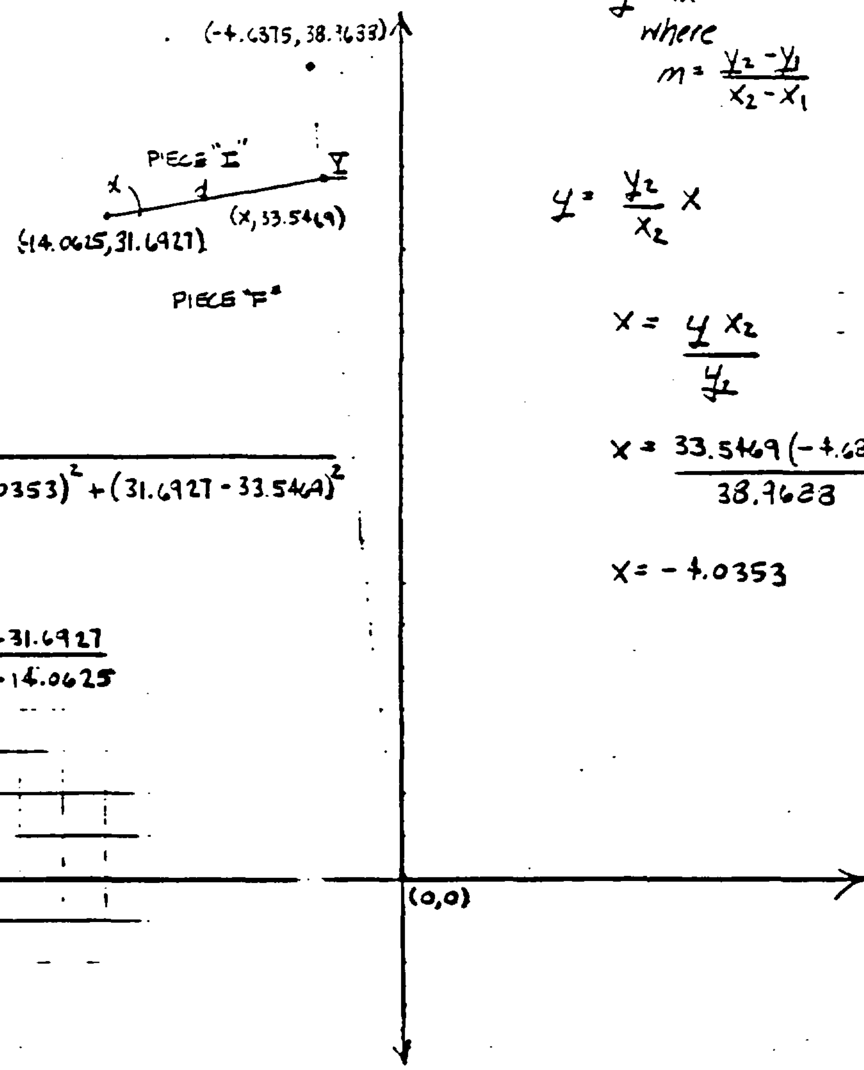
$y = mx$
where $y_1 = 0$
$m = \frac{y_2 - y_1}{x_2 - x_1}$ $x_1 = 0$

$y = \frac{y_2}{x_2} x$

$x = \frac{y\, x_2}{y_2}$

$x = \frac{33.5469(-4.6375)}{38.9633}$

$x = -4.0353$



$d = \sqrt{(-14.0625 + 4.0353)^2 + (31.6927 - 33.5469)^2}$

$d = 10.1972$

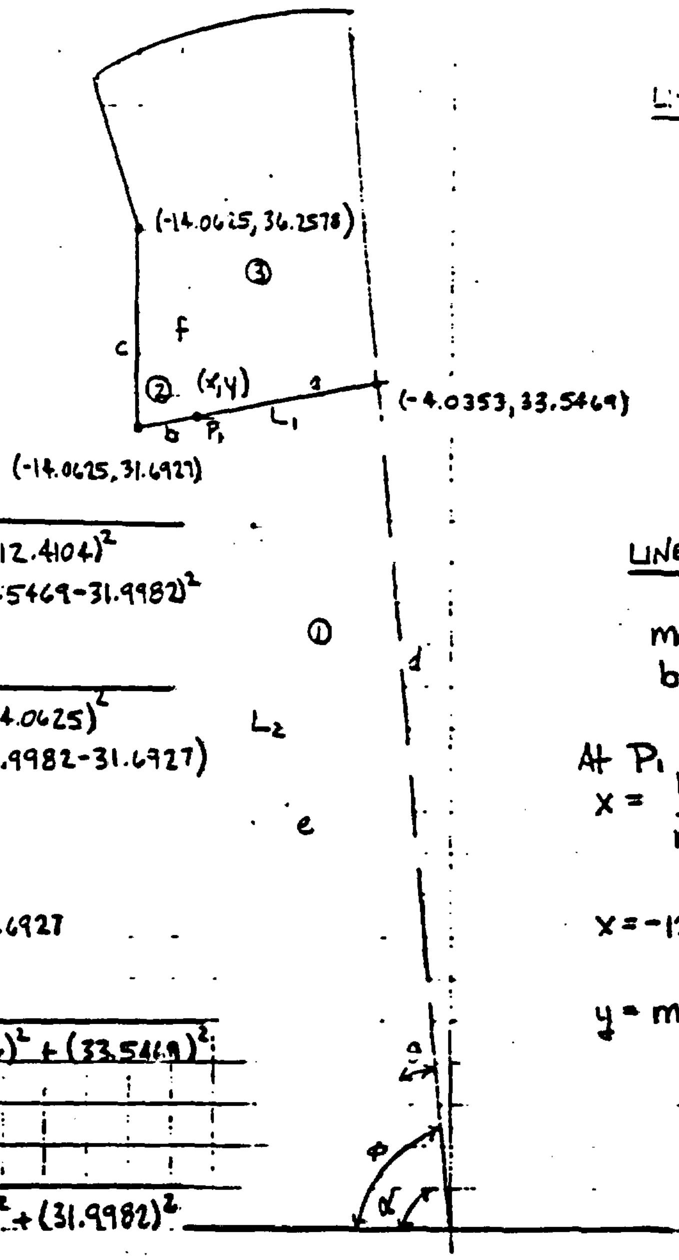
$\tan \alpha = \frac{33.5469 - 31.6927}{-4.0353 + 14.0625}$

$\alpha = 10.4766°$

COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont



$\alpha = 69.2436$

LINE L_1:

$m_1 = \dfrac{(33.5469 - 31.6927)}{(-4.0353 + 14.0625)}$

$m_1 = 0.184917$

$b_1 = y - mx$

$b_1 = 33.5469 - 0.184917(-4.0353)$

$b_1 = 34.2931$

LINE L_2:

$m_2 = -2.57833$

$b_2 = 0$

At P_1

$x = \dfrac{b_2 - b_1}{m_1 - m_2} = \dfrac{0 - 34.2931}{0.184917 + 2.57833}$

$x = -12.4104$ ←

$y = m_2 x + b_2$

$y = -2.57833(-12.4104)$

$y = 31.9982$ ←

$a = \sqrt{(-4.0353 + 12.4104)^2 + (33.5469 - 31.9982)^2}$

$a = 8.5171$

$b = \sqrt{(-12.4104 + 14.0625)^2 + (31.9982 - 31.6927)}$

$b = 1.6801$

$c = 36.2578 - 31.6927$

$c = 4.5651$

$d = \sqrt{(-4.0353)^2 + (33.5469)^2}$

$d = 33.7887$

$e = \sqrt{(-12.404)^2 + (31.9982)^2}$

$e = 34.3206$

$f = \sqrt{(-14.0625 + 12.4104)^2 + (36.2578 - 31.9982)^2}$

$f = 4.5688$

TRIANGLE ①

$S = (34.3206 + 33.7887 + 8.5171)\frac{1}{2}$

$S = 38.3132$

$A = \sqrt{38.3132(38.3132 - 34.3206)(38.3132 - 33.7887)(38.3132 - 8.5171)}$

$A = 143.6042$

COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont

TRIANGLE ②

$S = (4.5638 + 4.5651 + 1.6301)\frac{1}{2}$

$S = 5.4070$

$A = \sqrt{5.4070(5.4070 - 4.5683)(5.4070 - 4.5651)(5.4070 - 1.6301)}$

$A = 3.7710$

AREA ③ = AREA OF SEGMENT + AREA OF TRIANGLE ② − AREA OF TRIANGLE ①

AREA ③ = 214.3934 + 3.7710 − 143.6042

A = 74.5602 FT

TOTAL AREA
298.2408

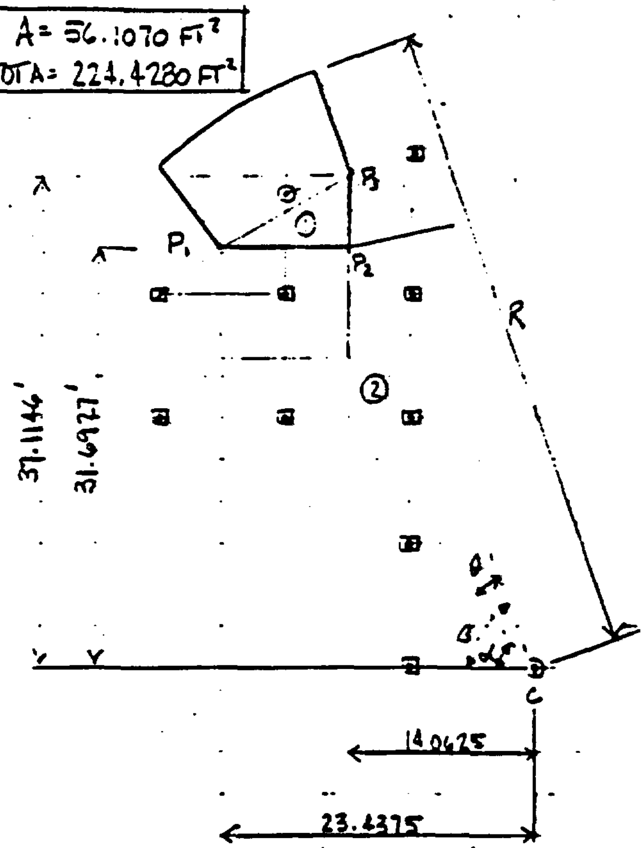
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'[signature]

PIECE "J" (QTY = 4)

A = 56.1070 FT²
TOTA = 224.4280 FT²



$R = 42.0528'$

$\tan \beta = 37.1146 / 14.0625$

$\beta = 69.2486°$

$\tan \alpha = 31.6927 / 23.4375$

$\alpha = 53.5162°$

$\theta = 15.7324°$

AREA OF SECTOR

$A = \pi R^2 (\theta/360)$

$A = \pi (42.0528)^2 (15.7324/360)$

$A = 242.7908$

AREA OF SMALL TRIANGLE

$A = \frac{1}{2}bh = \frac{1}{2}(23.4375-14.0625)(37.1146-31.6927)$

$A = 25.4152$

LENGTH BETWEEN P2 & P1

$d_1 = \sqrt{(37.1146-31.6927)^2 + (14.0625-23.4375)^2}$

$d_1 = 10.8299$

LENGTH BETWEEN P1 & C

$d_2 = \sqrt{31.6927^2 + 23.4375^2} = 39.4176$

LENGTH BETWEEN P2 & C

$d_3 = \sqrt{37.1146^2 + 14.0625^2}$

$d_3 = 39.6894$

COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: Paul D. d'Entremont [signature]

AREA OF LARGE TRIANGLE

$$S = \frac{d_1 + d_2 + d_3}{2} = \frac{10.3299 + 39.4176 + 39.6394}{2} = 44.9635$$

$$A = \sqrt{44.9635(44.9635 - 10.3299)(44.9635 - 39.4176)(44.9635 - 39.6894)}$$

$$A = 212.0990 \text{ FT}^2$$

AREA OF PIECE "I" = AREA OF SECTOR + AREA OF SMALL TRIANGLE − AREA OF LARGE TRIANGLE

$$A = 242.7908 + 25.4152 - 212.0990$$

$$A = 56.1070 \text{ FT}^2$$

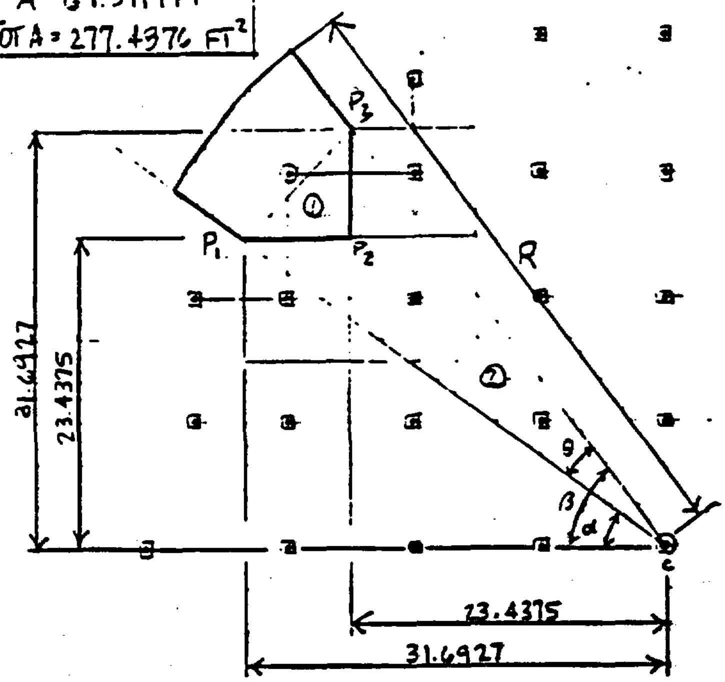
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: [signature]

PIECE "K" (QTY = 4)

$A = 69.3719\ FT^2$
$TOT\ A = 277.4876\ FT^2$



$R = 42.0528$

$\tan \beta = 31.6927 / 23.4375$
$\beta = 53.5162°$

$\tan \alpha = 23.4375 / 31.6927$
$\alpha = 36.4838°$

$\theta = \beta - \alpha = 53.5162 - 36.4838$
$\theta = 17.0324°$

AREA OF SECTOR:
$A = \pi R^2 (\theta/360)$
$A = \pi (42.0528)^2 (17.0324/360)$
$A = 262.8531\ FT^2$

AREA OF SMALL TRIANGLE:
$A = \frac{1}{2} bh$
$A = \frac{1}{2}(31.6927 - 23.4375)(31.6927 - 23.4375)$

$A = 34.0742\ FT^2$

AREA OF PIECE

$A = 262.8531 - 227.5554 + 34.0742$
$A = 69.3719\ FT^2$

$\overline{P_1C}$ BY SYMMETRY $= \overline{P_2C}$ ∴

$\overline{P_2C} = \overline{P_1C} = \sqrt{31.6927^2 + 23.4375^2} = 39.4176$

$\overline{P_3P_1} = \sqrt{2(31.6927 - 23.4375)^2} = 11.6746$

$s = (2(39.4176) + 11.6746)\frac{1}{2} = 45.2549$

AREA OF LARGE TRIANGLE:

$A = \sqrt{45.2549(45.2549 - 39.4176)^2(45.2549 - 11.6746)}$
$A = 227.5554\ FT$

COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by:
Reviewed by: Paul D. d'Entremont

PIECE "L" (QTY = 4)

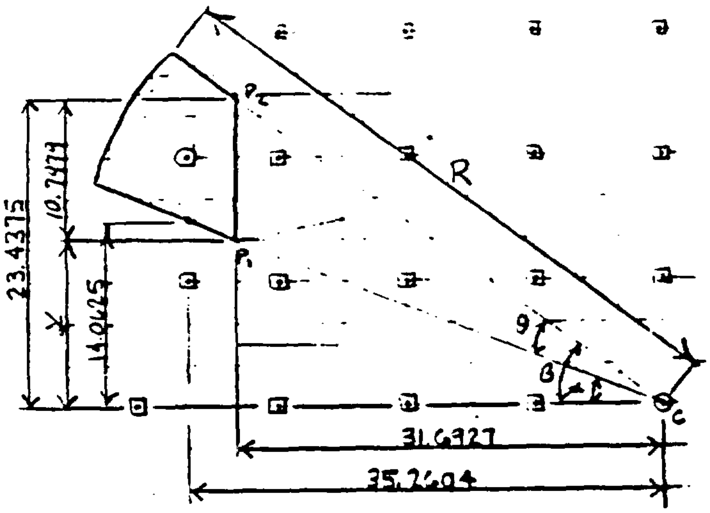
$R = 42.0528$

$A = 56.3807\ FT^2$
$TOT\ A = 225.5229\ FT^2$

$\tan\alpha = 14.0625/35.2604$
$\alpha = 21.7430°$

$\tan\beta = 23.4375/31.6927$
$\beta = 36.4838°$

$\theta = 36.4833 - 21.7430$
$\theta = 14.7403°$



AREA OF SECTOR:

$A = \pi R^2 (\theta/360)$
$A = \pi (42.0528)^2 (14.7403/360)$
$A = 227.4879\ FT^2$

$\overline{P_1C} = \sqrt{(12.6396)^2 + (31.6927)^2}$
$\overline{P_1C} = 34.1202$

$\overline{P_2C} = \sqrt{(23.4375)^2 + (31.6927)^2}$
$\overline{P_2C} = 39.4176$

SOLVE FOR y

$\frac{y}{31.6927} = \frac{14.0625}{35.2604}$

$y = 12.6396$

$S = \frac{34.1202 + 39.4176 + 10.7979}{2}$

$S = 42.16785$

AREA OF TRIANGLE

$A = \sqrt{42.16785(42.16785-34.1202)(42.16785-39.4176)(42.16785-10.7979)}$
$A = 171.1072\ FT^2$

$A = 227.4879 - 171.1072$
$A = 56.3807$

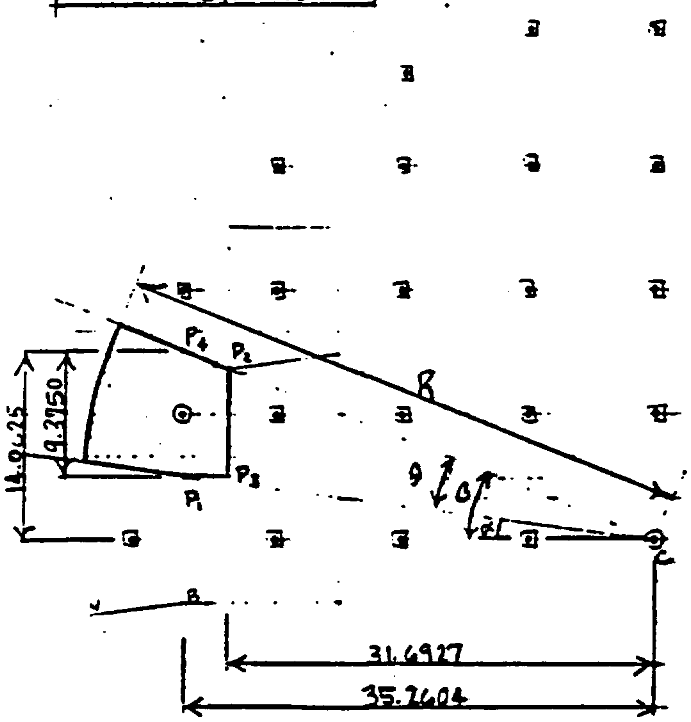
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: [signature]

PIECE "M" (QTY = 4)   R = 42.0528

A = 84.3123 FT²
TOT A = 337.2492 FT²



$\tan \alpha = \frac{(9.375/2)}{35.2604}$
$\alpha = 7.5725°$

$\tan \beta = \frac{14.0625}{35.2604}$
$\beta = 21.7430°$

$\theta = \beta - \alpha = 21.7430 - 7.5725$
$\theta = 14.1705°$

AREA OF SECTOR:
$A = \pi R^2 (\theta/360)$
$A = \pi (42.0528)^2 (14.1705/360)$
$A = 218.6867\ FT^2$

$\overline{P_2P_2}$:
$(12.6396 - 9.375/2) = 7.9521$

$\overline{P_1P_3}$:
$(35.2604 - 31.6927) = 3.5677$

$\overline{P_1P_2}$
$\sqrt{(7.9521)^2 + (3.5677)^2} = 8.7158$

FIND COORD. FOR P_2
$y/31.6927 = 14.0625/35.2604$
$y = 12.6396$

$\overline{P_1C}$:
$\sqrt{(9.375/2)^2 + (35.2604)^2} = 35.5706$

$\overline{P_2C}$:
$\sqrt{(12.6396)^2 + (31.6927)^2} = 34.1202$

AREA OF SMALL TRIANGLE
$A = \frac{1}{2}bh = \frac{1}{2}(3.5677)(7.9521) = 14.1854\ FT^2$

AREA OF LARGE TRIANGLE
$s = \frac{1}{2}(35.5706 + 34.1202 + 8.7158)$
$s = 39.2033$

$A = \sqrt{39.2033(39.2033-35.5706)(39.2033-34.1202)(39.2033-8.7158)} = 148.5598\ FT^2$

AREA = 218.6867 - 148.5598 + 14.1854 = 84.3123 FT²

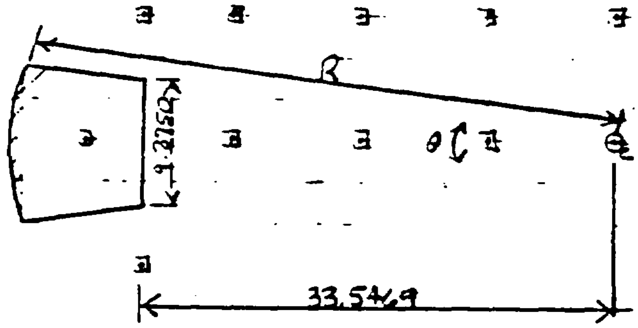
COMPUTATION SHEET

Tank Closure Program
Type IV Tank Sludge Volume Estimation Method

Computation by: [signature]
Reviewed by: [signature]

PIECE "N" (QTY = 2)   R = 42.0528

A = 88.2620 FT²
TOT A = 176.5240 FT²



$\tan \frac{\theta}{2} = (9.375/2)/33.5469$

$\frac{\theta}{2} = 7.9544°$

$\theta = 15.9088°$

AREA OF SECTOR

$A = \pi R^2 (\theta/360)$

$A = \pi(42.0528)^2(15.9088/360)$

$A = 245.5131\ FT^2$

AREA OF TRIANGLE

$A_T = \frac{1}{2}bh = \frac{1}{2}(9.375)(33.5469)$

$A_T = 157.2511\ FT^2$

$A = 245.5131 - 157.2511$

$A = 88.2620\ FT^2$