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# Waste Retrieval Sluicing System Campaign Number 1 Solids Volume Transferred Calculation

J. W. Bailey

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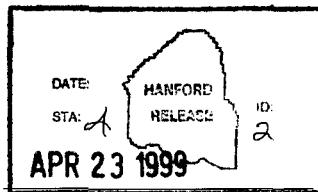
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## **OBJECTIVE / PURPOSE**

This calculation has been prepared to document the volume of sludge removed from tank 241-C-106 during Waste Retrieval Sluicing System (WRSS) Sluicing Campaign #1. This calculation will be updated, if necessary, to incorporate new data.

This calculation supports the declaration of completion of WRSS Campaign #1 and, as such, is also the documentation for completion of Performance Agreement TWR 1.2.1, C-106 Sluicing Performance Expectations. It documents the performance of all the appropriate tank 241-C-106 mass transfer verifications, evaluations, and appropriate adjustments discussed in HNF-SD-WM-PROC-021, Chapter 23, "Process Engineering Calculations for Tank 241-C-106 Sluicing and Retrieval".

## **RESULTS**

The sludge volume removed from tank 241-C-106 is **25.4 inches or 69,850 gallons**, including an uncertainty of **+ 4.0 to - 4.8 inches (+11,000 to - 13,200 gallons)**

The above value is based on the following volume calculations.

1. MASS FLOW METER TRANSFER VOLUME (CORRECTED) = **26.32 inches or 72,380 gallons**.
2. SETTLED & DISSOLVED SOLIDS VOLUME = **25.12 inches or 69,080 gallons**.
  - a. 241-AY-102 Final Settled Solids Volume = 14.22" or 39,100 gallons
  - b. Dissolved Solids Volume = 10.9" or 29,980 gallons.
3. THE ABOVE CALCULATED VOLUME IS BASED ON A WEIGHTED AVERAGE OF THE VOLUMES DETERMINED BY THE MASS FLOW METER AND SETTLED/DISSOLVED VOLUME APPROACHES. THE WEIGHTING IS INVERSELY PROPORTIONAL TO THE UNCERTAINTY RANGES ASSOCIATED WITH EACH OF THESE CALCULATION APPROACHES.
4. THE UNCERTAINTY RANGES ARE DEVELOPED IN THE UNCERTAINTY SECTION OF THIS CALCULATION.

For details of the calculation of each of these values refer to the following sections.

## METHOD OF ANALYSIS

This calculation uses two methods to evaluate the volume of sludge removed from tank 241-C-106. This increases the level of confidence in the sludge volume value determined by this calculation. The two methods used for the calculation are:

1. Corrected mass flow meter data
2. The sum of settled solids and dissolved solids

The mass flow meter data was corrected for errors in the assumed average solids free liquid density for each of the sluicing batches, as required. These corrections are discussed in more detail in the mass flow meter calculation section of this document. The resulting sludge volume value was then compared to the alternate calculation approach value. The settled solids and dissolved solids calculations are discussed in detail in the calculation section of this document. The final calculated value is a weighted average of these two alternative calculation values. The development of the volume uncertainty estimates is discussed in detail in the uncertainty section of this document.

The sludge transferred volumes are reported in both inches (of waste in the tank) and gallons. The inch units were selected for convenient comparison to the Performance Agreement value of two feet while providing improved accuracy. The gallon conversions were provided to allow convenient use in other calculations.

The uses of the input data are discussed in the following paragraphs.

The supernate density data (determined by the densitometer) has several uses. It is used in conjunction with grab sample density values to adjust the mass flow meter system solids free liquid density that is input to the DAS system before the start of the sluicing batch, if necessary. It is also used in conjunction with grab sample density values to determine the volume of solids dissolved by the WRSS sluicing operations.

The densitometer solids levels are used to project the final settled solids volumes in tank 241-AY-102.

The dissolved solids volume is calculated and added to the settled solids volume, above, to produce the alternate calculation of the volume of material removed from tank 241-C-106 to compare to the mass flow meter volume calculation.

Several other sources of data are reviewed to provide indications which support the above calculation inputs or to identify potential problems which require additional evaluation.

It should be noted that the ENRAF<sup>TM</sup> densitometer (ENRAF is a product of ENRAF corporation of the Netherlands) material balance discussed in HNF-SD-WM-PROC-021 could not be performed for the reasons discussed below. Recommendations related to correcting the densitometer data problems to make the instrument density profiles useable for future WRSS process control are provided in the Conclusions and Recommendation section of this calculation.

## INPUT DATA

Several sources of data are used to develop the volume of sludge removed from tank 241-C-106 by WRSS operations. The data sources include the following:

### PRIMARY

1. Mass flow meter (UE-0621) located in the tank 241-AY-102 02A pit

### SECONDARY – VERIFICATION DATA SOURCES

2. Supernate density data from both the ENRAF densitometer (WST-DIT-602A) and post batch grab sample analytical results from preliminary analysis reports
3. Tank 241-AY-102 solids level data from the ENRAF densitometer (WST-DIT-602A)
4. Dissolved solids volume developed from ENRAF densitometer (WST-DIT-602A) data and from post batch grab sample analytical results from preliminary analysis reports

The WRSS Process Control Plan, HNF-SD-WM-PCP-013, Revision 1A, identifies the ENRAF densitometer as the primary solids mass determination instrument during the first sluicing campaign because the solids loading was expected to be below 10%. It indicates that the mass flow meter was to be the primary instrument for subsequent campaigns. Because of problems encountered with the densitometer data, discussed below, and the fact that the slurry solids loading were frequently above the 10% during the first campaign, the mass flow meter has been used as the primary solids transfer instrument for the first campaign.

## CALCULATIONS

The following calculations are broken down into four sections: 1) the mass flow meter transfer volume calculation, 2) the settled solids volume calculation, 3) the dissolved solids volume calculation, and 4) other related process control data.

- I. **MASS FLOW METER TRANSFER VOLUME CALCULATION** - The sludge volume transferred based on the mass flow meter data from each of the sluicing batches is presented below. Corrections to these values, where appropriate, are also included in this section of the calculation.

WRSS Batch	Transferred Volume (Inches)	Input Liquid SpG
Batch 1.1.1	2.89"	(7,958 gal.)
Proc. Test Phase I	0.84"	(2,322 gal.)

Proc. Test Phase II	8.20"	(22,556 gal.)	1.061
Proc. Test Phase III	6.87"	(18,889 gal.)	1.095
Uncorrected Subtotal 18.8"		(51,725 gal.)	

Because the mass flow meter solids transfer volume values are calculated using a solids free liquid specific gravity value which must be estimated in advance, it is appropriate to check this value after each sluicing operation. If it is determined that the input values diverge significantly from analytical and densitometer data, it is appropriate to make adjustments to the mass flow meter solids transfer values.

The estimation of the average carrier fluid specific gravity value for a sluicing batch is a non-trivial task for several reasons.

1. The mixing of the original tank 241-C-106 and tank 241-AY-102 liquid volumes of significantly different specific gravities must be accounted for.
2. The volume of solids that will be dissolved by the sluicing operation must be estimated.
3. The duration and different steps of the sluicing operation must be predicted.

The review of the solids free carrier fluid specific gravity (SpG) inputs for the first four sluicing batches resulted in a decision to adjust the mass flow meter solids transfer values for process test phases II and III. The adjustment calculations are provided below.

The Batch 1.1.1 SpG input value was not adjusted. It can be seen that the input SpG value of 1.054 was significantly higher than the post batch tank 241-AY-102 grab sample SpG value of 1.025. The average tank 241-AY-102 SpG approach to calculating the appropriate carrier fluid density input value isn't applicable to this first sluicing batch. Because the batch was short, the carrier fluid density was most influenced by the bulk fluid density of the waste present in tank 241-C-106 before the start of sluicing operations. The tank 241-C-106 liquid SpG was much higher than that present in tank 241-AY-102. Therefore, it was decided to make no adjustment to the mass flow meter value. It should be noted that any adjustment of the Batch 1.1.1 mass flow meter transfer calculation would have produced a higher calculated volume for this batch.

The phase I process test SpG input was so close to the average of the pre- and post batch values that no adjustment was warranted.

A. Process Test Phase II Mass Flow Meter Adjustment Calculation - The mass flow meter calculates the percent solids being transferred in the slurry line and integrates this value over time to determine the mass of solids transferred. The following equation is used by the mass flow meter to perform this calculation:

$$Co = 100[D_p(D_m - D_f)] / [D_m(D_p - D_f)]$$

Where:       $C_o$       is the slurry percent solids  
                   $D_p$       is the density of the solid particles  
                   $D_m$       is the density of the solid / fluid slurry  
                   $D_f$       is the density of the carrier fluid

All of the values for the variable used in this equation are known for the phase II process test.

$C_o = 8.92\%$       (This value is the average from the DAS 10 min frequency percent solids data)

$D_p = 2.61 \text{ SpG}$       (This value is derived from core and grab sample data)

$D_m = 1.12 \text{ SpG}$       (Average slurry density (DI-0621A) from 13:51:40 - 20:24:10)

$D_f = 1.061 \text{ SpG}$       (This is the estimated solids free liquid density value input to the DAS)

A corrected average carrier fluid density is next calculated by averaging the pre- and post process test phase II carrier fluid densities. The post sluicing value is 1.061 SpG which comes from the average of the grab sample liquid analyses. The pre-sludging value is calculated by averaging the lowest densitometer density values taken between 12/18/98 and 3/4/99 and is 1.052 SpG. The post process test phase I grab sample analysis density value of 1.080 was determined to be highly questionable based on subsequent SpG data and was therefore, not used for this calculation. The resulting corrected carrier fluid density for process test phase II is:

$$(1.052 + 1.061) / 2 = 1.057 \text{ SpG}$$

By substituting the corrected average fluid density values into the  $C_o$  calculation equation a corrected average percent solids value for the phase II process test slurry transfer can be calculated.

$$C_o = 100 (2.61 (1.12 - 1.057)) / (1.12 (2.61 - 1.057))$$

$$C_o = 9.45\%$$

The correction factor for adjusting the mass flow meter transfer numbers is then determined by dividing the corrected percent solids value by the original value:

$$\text{Correction Factor} = 9.45 / 8.92 = 1.059$$

Applying this factor to the original transfer volume calculation produces the corrected transfer volume for process test phase II

$$8.20" \times 1.059 = 8.68" \text{ (23,870 gallons)}$$

B. Process Test Phase III Mass Flow Meter Adjustment Calculation - The process test phase III mass flow meter calculation is adjusted using exactly the same technique discussed for the phase II process test. The adjustment calculations are presented below

Again all the values in the mass flow equation are known.

$Co = 3.39\%$  (This value is the average from the DAS 10 second frequency percent solids data)

$Dp = 2.61 \text{ SpG}$  (This value is derived from core and grab sample data)

$Dm = 1.129 \text{ SpG}$  (Average slurry density (DI-0621A) from 11:12:55 - 18:27:55)

$Df = 1.095 \text{ SpG}$  (This is the estimated solids free liquid density value input to the DAS)

A corrected average carrier fluid density is next calculated by averaging the pre- and post process test phase III carrier fluid densities. The post sluicing value is 1.095 SpG which comes from the average of the grab sample liquid analyses. The pre-sludging value comes from the average of the grab sample liquid analyses taken after the phase II test sluicing operations and is 1.061 SpG. The resulting corrected carrier fluid density for process test phase II is:

$$(1.061 + 1.095) / 2 = 1.078 \text{ SpG.}$$

This corrected carrier fluid density is now substituted into the percent solids equation and solved for the adjusted solids percentage for the phase II process test slurry transfer.

$$Co = 100 (2.61 (1.129 - 1.078)) / (1.129 (2.61 - 1.078))$$

$$Co = 7.69\%$$

The correction factor for adjusting the phase III test mass flow meter transfer numbers is then determined by dividing the corrected percent solids value by the original value:

$$\text{Correction Factor} = 7.69 / 3.39 = 2.27$$

Applying this factor to the original transfer volume calculation produces the corrected transfer volume for process test phase III.

$$6.87" \times 2.27 = 15.59" \text{ (42,870 gallons)}$$

The corrected mass flow meter solids transfer volume can now be calculated by substituting the above corrected values into the transfer summary presented at the beginning of this section.

<u>WRSS Batch</u>	<u>Transferred Volume</u> (inches)	<u>Corrected Input Liquid</u> (SpG)
Batch 1.1.1	2.89"	(7,958 gal.)
Proc. Test Phase I	0.84"	(2,322 gal.)
Proc. Test Phase II	8.68"	(23,870 gal.)
Proc. Test Phase III	15.59"	(42,870 gal.)

**Corrected Subtotal 28.00" (77,000 gal.)**

To account for solids recycled to tank 241-C-106 by the sluice stream a 6% correction factor has been established by prior analysis, reference HNF-SD-WM-PCP-013, Revision 1A, section 4.1.4, Tank 241-C-106 Mass Transfer Control. Applying this correction to the above corrected mass flow meter solids transferred volume gives the final mass flow meter solids transfer volume.

Correction for recycled solids - 28.00" X 0.94 = **26.32 inches (72,380 gallons)**

II. **241-AY-102 SETTLED SOLIDS VOLUME CALCULATION** - The settled solids volume calculated below is added to the dissolved solids volume, calculated in Section III, to produce an alternative approach solids volume calculation.

The densitometer solids (sediment) levels have been interpreted to project the final settled solids volume transferred into tank 241-AY-102. The initial solids level data from sluicing batches can not be used directly because settling or compacting of the solids occurs over a several month period after the initial settling.

The purpose of the calculations below is to project the compacted settled solids volume for the solids transferred into tank 241-AY-102. For the purposes of this calculation, compacted solids are defined as solids at the same density or compaction level as the tank 241-C-106 solids before the start of sluicing operations.

Based on the densitometer results experienced to date the solids settling process occurs in four phases. The first is the buildup of solids level to a maximum level occurring in the five to seven days immediately after the sluicing operation. The second phase is fast settling for a one to eight day period, after the maximum value is achieved. The third phase is medium rate settling for a period of six to seven days following the fast settling rate period. The fourth and final phase is slow settling for two to three months following the medium rate settling period.

The data used in the calculations below is contained in Attachment 1 to this calculation.

A. Settling Baseline - To support calculating the final volume of settled solids, the densitometer data from WRSS operations between November 15, 1998 and March 4, 1999 is used to establish a baseline for the settling response of the transferred waste. The baseline evaluation period

includes solids transferred by WRSS Batch 1.1.1 and process test phase I sluicing. This baseline is modified, as required, based on the actual settling results from the subsequent batches.

	<u>Densitometer Reading</u>	<u>Date</u>
• Pre-Batch Solids Level	9.11"	(11/15/98)
• Maximum Post Batch 1.1.1 Solids Level	12.90"	(11/23/98)
• Post Medium Settling Rate Solids Level	12.20"	(12/1/98)
• Final Settled Solids Level	11.93"	(3/4/99)
• Pre-Process Test Phase I Solids Level	12.11"	(12/7/98)
• Post-Process Test Phase I Solids Level	12.28"	(12/19/98)

Based on the above densitometer solids level data, the following solids level baseline is calculated:

	<u>Base Value</u>
1. Solids Level Increase (12.90 – 9.11)	3.79"
2. Medium Settling Period Level Decrease (12.90-12.2)	0.70"
3. Process Test Correction (12.28 – 12.11)	0.17"
4. Long-Term Settling Level Decrease (12.90 – 11.93)	0.97"
5. Long-Term Settling Decrease – Corrected ( 97+17)	1.14"

The Batch 1.1.1 and process test phase I final settled solids volume calculation follows:

$$3.79" - 0.97" = \underline{\underline{2.82"}}$$

B. Process Test Phase II Solids Volume Transferred Calculation - The densitometer reading associated with the phase II testing operations follow:

• Pre-Process Test Phase II Solids Level	11.93" (3/4/99)
• Max. Post Process Test Phase II Solids Level	20.16" (3/15/99)
• Post Medium Rate Settling Solids Level	18.05" (3/25/99)

The medium rate settling solids level decrease, 2.11" (calculated from the above data), is a larger percentage decrease than would be calculated based on the baseline values from A, above. For this reason an alternative method of calculating the final settled solids volume had to be developed. The alternative approach assumes that the ratio of the medium rate settling volume reduction and the final settled solids volume reduction will be the same as the ratio determined for these values from the baseline period. It also assumes that the 18.05" densitometer reading, taken just before the start of process test phase III sluicing, equates to the end of the medium settling rate period. The latter assumption is supported by a comparison of the duration of the fast and medium settling rate periods from the baseline evaluation.

The process test phase II final settled solids volume calculation follows:

1. Initial Solids Level Increase (20.16" – 11.93") =	8.23"
2. Medium Rate Settling Solids Lev. Decrease (20.16-18.05) =	2.11"

3. Final Settled Solids Level (2.11" X (1.14"/0.70"))	3.44"
4. Solids Volume Transferred (8.23" - 3.44") =	<u>4.79"</u>

C. Process Test Phase III Solids Volume Transferred Calculation - The densitometer reading associated with the phase III testing operations follows:

- Pre-Process Test Phase III Solids Level 18.05" (3/25/99)
- Max. Post Process Test Phase III Solids Level 29.40" (4/5/99)

The solids volume transferred by process test phase III is calculated assuming the ratio of the maximum solids level change and the final solids level volume transferred established by the above phase II transfer calculation are applicable to this transfer. The solids volume transferred calculation follows:

1. Process Test Phase III Solids Level Increase (29.4" - 18.05") = 11.35"
2. Solids Volume Transferred (11.35"X(4.79/8.23) = 6.61"

D. Total Solids Volume Transferred During Campaign #1 Calculation - The calculation of the total campaign #1 solids transfer sums the values from the A., B. & C. calculations above.

$$2.82" + 4.79" + 6.61" = 14.22"$$

III. DISSOLVED SOLIDS VOLUME CALCULATION - The dissolved solids volume calculated below is added to the settled solids volume, calculated in Section II, to produce an alternative approach solids volume calculation.

The volume of solids dissolved by WRSS sluicing operations is calculated by determining the change in solids-free liquid density between that which would be expected with no solids dissolution and the actual solids-free liquid density determined from grab sample analysis.

The bulk liquid density expected for the WRSS system for different solids volume transfers has been calculated by Mr. K. G. Carothers using an EXCEL™ (EXCEL is a product of Microsoft Corporation) spreadsheet, "WRSS Sample Data". This spreadsheet calculates both the liquid density and chemical composition that would be expected if the tank 241-AY-102 liquid, the tank 241-C-106 liquid, and interstitial liquid are combined with no solids dissolution. The spreadsheet SpG value for a two foot solids transfer to tank 241-AY-102 is 1.050.

The post process test phase III grab sample analytical result SpG average is 1.095 giving a density change due to solids dissolution of 0.045 or 0.045 g/cc. Applying the conversion from g/cc to lb./gallon (8.32) gives a 0.3744 lb./gallon density change.

The tank 241-AY-102 liquid level (4/6/99) is 170.7" minus the settled solids volume of approximately 28" (from the rounded off April 6, 1999 densitometer sediment level determination). This gives a liquid volume of 142.7". Added to this is half the interstitial liquid contained in the

solids settled in tank 241-AY-102 since WRSS sluicing operations began. Only one half the volume is used to account for the fact that the actual interstitial liquid varies in dissolved solids content depending on which sluicing batch deposited the solids. Because the last two sluicing batches were significantly larger than the first two this approximation should provide a conservative volume of interstitial liquid at the above change in liquid density value. See calculations below:

$$0.78 \text{ (vol.\% interstitial liq.)} [28'' \text{ (solids lev.)} - 9.11'' \text{ (orig. solids lev.)}] / 2 = 7.4''$$

Combining the two liquid volumes  $(142.7'' + 7.4'') = 150.1''$

Converting this to gallons  $(150.1'' \times 2750 \text{ gal./in.}) = 412,775 \text{ gallons}$

Multiplying by the density change gives  $(412,775 \times 0.3744) = 154,540 \text{ lb.}$

Dividing by the pound solids per inch of sludge value, 14,200 lb./in (derived from data in the PCP, HNF-SD-WM-PCP-013) for tank 241-C-106 solids gives the equivalent tank 241-C-106 sludge volume currently dissolved in the tank 241-AY-102 supernate  $(154,540 \text{ lb.} / 14,200 \text{ lb./in.}) = 10.9 \text{ inches}$

**IV. FINAL SOLIDS VOLUME TRANSFERRED DETERMINATION** - One method of combining the two calculated values to produce a final solids volume transferred calculation value is to perform a weighted average. The two calculated values have been weighted using an inverse proportionality relationship of the uncertainties applicable to each of the values calculated in the Calculation Uncertainty Estimates section, below. It was felt that this would produce an average with a lower uncertainty.

- A. The transferred volume from the mass flow meter is 26.31 inches or 72,350 gallons. The uncertainty for this value is  $\pm 10.2$  inches.
- B. The transferred volume from the settled and dissolved solids calculation is  $(10.9'' + 14.22'') = 25.12$  inches or 69,080 gallons. The uncertainty for this value is  $+ 4.0$  to  $- 4.8$  inches.

The maximum uncertainty ranges for the two values are  $(10.2'' + 10.2'') = 20.4''$  and  $(4.0'' + 4.8'') = 8.8''$ , respectively. The two weighting factors for the A and B value uncertainty are:

- A.  $100\%(20.4/(20.4 + 8.8)) = 69.9\%$
- B.  $100\%(8.8/(20.4 + 8.8)) = 30.1\%$ .

Applying the A weighting factor to the B volume calculation -  $0.699(25.12'') = 17.5$  inches  
Applying the B weighting factor to the A volume calculation -  $0.301(26.32'') = 7.9$  inches

The inversely proportionally weighted average value of the final solids volume transferred calculation value is  $17.5'' + 7.9'' = 25.4 \text{ inches}$ .

V. **OTHER RELATED PROCESS CONTROL DATA** - This section is broken down into a section discussing other process control data which support the above solids volume calculated values and a sub-section on process control data which is inconclusive or anomalous.

A. Other Supporting Process Control Data - Additional support for the 25.4 inch solids volume transfer comes from several instruments including: 1) the tank 241-C-106 thermocouples, 2) the tank 241-AY-102 MIT thermocouples, and 3) the tank 241-AY-102 MIT validation probe temperature profile.

1. The tank 241-C-106 riser R-14 thermocouple number three - This thermocouple should have been exposed to the tank supernate after process test phase II. Transfer of one foot of waste from the tank should have reduced the solids level in the center portion of the tank by 15.95 inches due to the five foot "No Sluice Zone" around the perimeter of the tank. The original average solids level was 67". Removing 15.95" would leave 51.05". TC-3 on the R-14 tree is located at the 52" liquid level and should, therefore, have been exposed to tank supernate.

This thermocouple did show an immediate temperature response to the tank liquid temperature, see Figure 1. It subsequently showed a temperature rise to a temperature approximately half way between its pre-batch temperature and the temperature of the tank liquid. This temperature then began showing a downward trend which would have reached the tank liquid temperature in roughly two months – approximately the same settling period noted in tank 241-AY-102 using the ENRAF densitometer. This response is interpreted as showing that the solids in the tank had been fluffed just as in tank 241-AY-102 covering TC-3 with very little settled material which prevented, or at least significantly reduced, convective cooling. The subsequent compaction of these fluffed solids in conjunction with the general cooling of the tank due to removal of nearly 16 inches of insulating sludge produced the observed downward temperature trend. The upward TC-3 temperature trend experienced beginning on March 18, 1999 was the result of the transfer line flush which added cool liquid to the tank. This reduced the evaporative cooling until the cool fluid could be heated to the original tank liquid temperature.

2. The tank 241-AY-102 MIT thermocouples - The fixed MIT thermocouples show data very similar to the MIT validation probe, discussed below. They are, therefore, considered to support a mass transfer at least as high as that calculated above.
3. The tank 241-AY-102 MIT validation probe temperature profile – Figure 2 compares the ENRAF densitometer solids levels to those inferred from the MIT validation probe measurements. Since the start of sluicing operations, the MIT data shows the interface of the conductive / non-conductive zones in tank 241-AY-102 to be approximately ten inches above the solids level measured by the densitometer.

This difference in level may come from several sources or groups of sources as discussed below. However, the MIT data would definitely not support a transferred solids volume less than that calculated by the settled solids methodology.

Possible explanations for the different levels determined by the densitometer and MIT validation probe include:

- a. The densitometer potential wire dragging causing lower readings.
- b. The different physical properties being measured by the two instruments, ie., a pre-set change in measured density (densitometer) and the point at which enough solids have accumulated in the waste to cause it to no longer allow convective fluid flow.
- c. A reference level error in the MIT instrument.

The MIT data differences will be investigated further after the densitometer wire dragging problem is resolved, if the measurement differences at that time warrant further investigation.

B. Inconclusive Process Control Data - Process control data which is considered inconclusive or anomalous is the ENRAF densitometer density profiles.

The data from the ENRAF densitometer density profiles has been evaluated and is not providing meaningful data. This density profile data source is therefore considered inconclusive.

Most of the density profiles from the densitometer show the lowest measured density at a level well below the liquid surface (most frequently at 84"). This is technically impossible – having a more dense fluid on top of a less dense fluid. This anomalous data is believed to be the result of the densitometer plummet support wire dragging on the inside surface of the four inch riser during part of the plummet travel. This is projected to occur because the four inch riser is not completely plumb.

In addition, during periods when no solids transfers are occurring, the density profiles show a change in the total quantity of solids present in the tank, ie., the data is inconsistent.

The sediment level data from the densitometer is being used. The uncertainties associated with using the sediment levels are evaluated below.

## **CALCULATION UNCERTAINTY ESTIMATES**

There are numerous sources of uncertainty inherent in calculating the volume of waste solids removed from tank 241-C-106. A comprehensive assessment of the uncertainty is not possible at this time. A

FIGURE 1

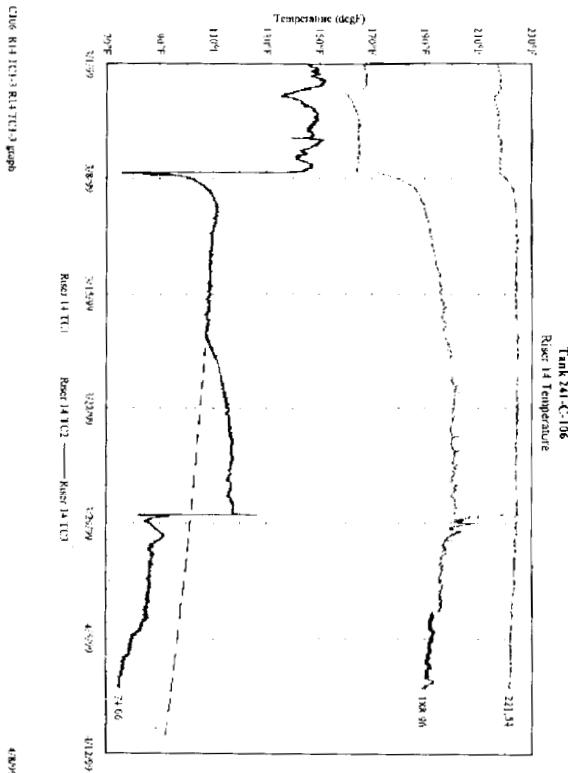
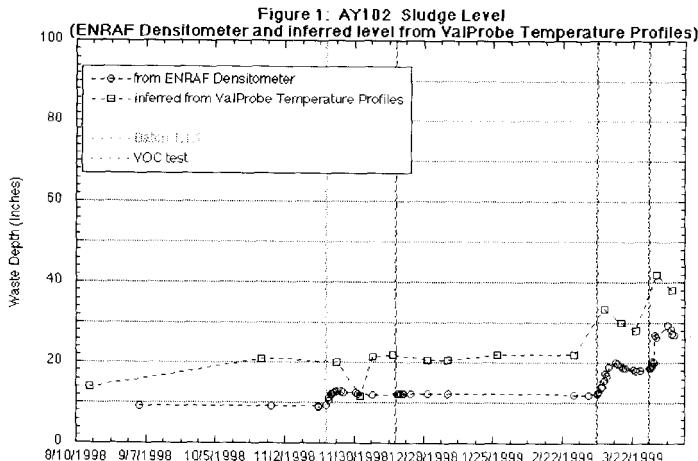


FIGURE 2



rough approximation of the impact of these uncertainties on the accuracy of the calculated solids volume is included in this section of the calculation.

Based on the calculations contained in the following section, the ranges of uncertainty in the three parts of the solids volume calculations are.

Mass Flow Meter -  $\pm 10.2$  inches (28,050 gal.)

Verifying Process Control Information Uncertainties

Settled Solids Volume -  $\pm 0.16''$  to  $-0.99''$

(+ 440 to - 2,720 gal.)

Dissolved Solids Volume -  $\pm 3.8$  inches (10,450 gallons)

Total -  $\pm 4.0$  to  $-4.8$  inches  
(+11,000 to - 13,200 gallons)

Because the final volume transferred calculation should be no more uncertain than the least uncertain of the two input calculations, the final volume transferred calculation uncertainty is **+ 4.0 to - 4.8 inches (+11,000 to - 13,200 gallons)**

- I. Mass Flow Meter Data Uncertainty - Instrument accuracy for the mass flow meter has been determined by testing of an identical mass flow meter in a test loop. The testing, conducted by PNNL, determined the uncertainty range to be  $\pm$  40 to 50% when the slurry solids loading was below 10% and  $\pm$  20 to 40% when the slurry solids loading was above 10%, reference HNF-SD-W320-DB-001, "Design Basis Document Project W-320 Tank 241-C-106 Sluicing", Appendix. Data from the first sluicing campaign indicates that the mass flow meter solids volume values are more accurate than that determined by PNNL.

The slurry solids loading experience during the first campaign ranged between approximately 0% and 14%. The  $\pm$  40% value from the PNNL testing was selected because the actual sluicing solids loading ranged around the 10% value which is the dividing point for the PNNL uncertainty range estimates. The 40% value was a limit for the each of the two ranges and was therefore selected. It should provide an appropriate approximation of the accuracy of the mass flow data for the WRSS sluicing operations conducted to date.

Applying the 40% uncertainty to the 25.4 inches (69,850 gal.) mass flow meter transferred volume gives an uncertainty of  **$\pm$  10.2 inches (28,050 gal.)**

- II. Settled Solids Volume Calculation Uncertainty - The instrumentation supporting the settled solids volume is the ENRAF densitometer. The densitometer sediment level measurement accuracy is  $\pm$  2 mm (0.08"). This uncertainty equates to 220 gallons in tank 241-AY-102. However, the main sources of positive uncertainty in the settled solids volume calculation is the assumptions made in projecting the solids settling behavior based on prior settling measurement data. The instrument error is neglected in the negative uncertain because it is insignificant compared to the assumption induced error. The positive uncertainty associated with the error from the postulated densitometer plummet support wire dragging, discussed below, is the same order of magnitude as the instrument error and these two sources are summed to give the positive uncertainty  $(0.08" + 0.08") = 0.16"$ .

Based on the calculations below, the settled solids volume uncertainty is **+ 0.16" to - 0.99" (+ 440 to - 2,720 gal.)**

- A. Settled Solids Volume Negative Uncertainty - The main potential cause of settled solids volume negative uncertainty is the assumption that the slow settling period is complete after three months. This assumption was used in developing the Batch 1.1.1 and process test phase I baseline. If this assumption is in error, the subsequent settled solids volume calculations would be higher than the actual final settled solids volumes. The following calculations are used to assess the potential negative error in the settled solids volume.

To assess the maximum potential impact of this assumption being incorrect, the settling time to final compaction is doubled to six months. Doubling the settling period is considered to bound

the potential range of the settling period because densitometer sediment level data from immediately before process test phase II no longer showed a downward trend. The values used in the following calculations come from Sections II.A through II.D, above.

Assuming the slow settling rate remained unchanged during the extended period (a conservative assumption), the 0.27" (0.97" - 0.70") settling would increase to 0.54". Applying this compaction to the waste volume transferred by Batch 1.1.1 and process test phase I gives a transferred volume of 2.55" (2.82" - 0.27" additional settling). If this value is then used in developing the projections of the final settled solid volumes transferred in process test phases II and III, the calculated settled solids volume for these batches are:

$$\text{Process Test Phase II} - (8.23" - 2.11" - (2.11" \times (0.54"/0.70")) = 4.49"$$

$$\text{Process Test Phase III} - (11.35" \times (4.49"/8.23" )) = 6.19"$$

The total compacted, settled solids volume would be the sum of these three figures, (2.55" + 4.49" + 6.19") = 13.23".

Comparing this volume to the previously calculated value, 14.22" gives a negative uncertainty of (14.22 - 13.23) = 0.99".

B. Settled Solids Volume Positive Uncertainty - The main potential cause of settled solids volume negative uncertainty is the postulated ENRAF densitometer error caused by dragging of the plummet support wire on either a slightly non-plumb installation riser or on an internal component of the densitometer assembly.

The wire dragging problem has been postulated to explain the observed densitometer profile measurements which generally show a minimum fluid density at an elevation at or near 85 inches with densities increasing in both directions from there. Increasing density in the upward direction is a physically impossible condition in a low viscosity liquid.

To assess the potential impact of the wire dragging phenomenon on the settled solids volume calculation, one must understand how the densitometer sediment levels are determined. A solids free liquid density is input to the densitometer. The densitometer is then lowered until a small pre-set increase in density is detected. The level at which this density increase is detected is recorded as the tank solids level (identified as sediment level in the densitometer activity log).

If a density higher than the solids free liquid density is input to the densitometer, the plummet will penetrate further into the lightly settled solids before detecting the pre-set density increase, thereby, recording a solids level lower than that actually present in the tank.

The solids free liquid density value was initially taken as the densitometer measured density at a point approximately two feet below the liquid surface. Because of the

inverted density profile measured in the upper portion of the liquid, postulated to be caused by the dragging of the densitometer plummet wire, the two foot level density was not the lowest density measured in the liquid. Even the lowest density measured in the liquid may in fact not be the solids free liquid density, but rather a partially clarified liquid density.

To approximate the potential error caused by the using the densitometer measured density two feet below the liquid surface, the difference between this measurement and the lowest density measured and the standard deviation for the error value is calculate. Two standard deviations are then assumed to provide reasonable confidence that the error has been bounded. The effect of this bounding error value on the measured solids level is then calculated to establish the positive uncertainty in the solids level value.

From the calculation in Appendix A, the standard deviation between the density measured at two feet and the minimum liquid density is  $S = 0.00379$ . Two standard deviations would give a density (Specific Gravity [SpG]) error of 0.00758.

Next we determine the densitometer solids level measurement error associated with this error in the solids free liquid SpG error. This is accomplished by comparing this SpG change to densitometer data from two sediment level determinations performed consecutively using two different solids free liquid SpG inputs. The densitometer sediment level runs that were performed between April 5, 1999 through April 7, 1999 produced the data below.

<u>Date</u>	<u>Sediment Level (In.)</u>	<u>SpG Used</u>	<u>Delta Level</u> (Inches)	<u>Delta SpG</u>
4/5	29.45	1.08484	5.02"	0.3957
4/5	24.38	1.48057		
4/6	28.29	1.08588	3.59"	0.3178
4/6	24.70	1.40372		
4/7	27.36	1.08564	2.71"	0.3229
4/7	24.65	1.40885		

Dividing the level changes by the SpG changes to produce the normalized correction factor gives: 12.69, 11.30, and 8.39. Averaging these values to produce an average correction factor gives 10.79.

Assuming the ratio of the difference in solids levels versus the differences in input SpGs would hold for the two standard deviations change in SpG gives a reduction in solids level of **0.082 inches (225 gallons)**.

III. Dissolved Solids Volume Calculation Uncertainty - The dissolved solids volume uncertainty is a function of the accuracy of the density values used in its development. This uncertainty is estimated

by evaluating the density measurement deviations and the impact these would have on the dissolved solids calculation.

The density measurement uncertainty is assessed by comparing the ranges of values for solids free liquids densities from sets of grab samples. From this we can determine the deviations from the average value. The associated standard deviation is then calculated. To bound the potential error in the calculated dissolved solids volume an error band of two standard deviations is then assumed. This error band is next used to calculate the dissolved solids volume at the two extremes of the possible density values. The resulting maximum and minimum dissolved solids values are then used to determine the uncertainty range for the calculated dissolved solids volume.

The grab sample SpG analytical results from the phase II and phase III process test are used to calculate the standard deviation for grab sample SpG data. The subject SpG data is provided below:

Process Test Phase II SpG Data

1.063, 1.063, 1.066, 1.061,  
1.064, 1.053, 1.038, 1.069,  
1.066, 1.058, 1.070, 1.055

Average SpG = 1.061

Process Test Phase III SpG Data

1.095, 1.092, 1.088, 1.090

Average SpG = 1.095

Calculating the standard deviation in the same way shown in Appendix A

$$S = \left[ \left( (1.063 - 1.061)^2 + (1.063 - 1.061)^2 + (1.066 - 1.061)^2 + (1.061 - 1.061)^2 + (1.064 - 1.061)^2 + (1.053 - 1.061)^2 + (1.038 - 1.061)^2 + (1.069 - 1.061)^2 + (1.066 - 1.061)^2 + (1.058 - 1.061)^2 + (1.070 - 1.061)^2 + (1.055 - 1.061)^2 + (1.095 - 1.095)^2 + (1.092 - 1.095)^2 + (1.088 - 1.095)^2 + (1.090 - 1.095)^2 \right) / (16 - 1) \right]^{1/2}$$

$$S = \left[ (0.000004 + 0.000004 + 0.000025 + 0 + 0.000009 + 0.000064 + 0.000529 + 0.000064 + 0.000025 + 0.000009 + 0.000081 + 0.000036 + 0 + 0.000009 + 0.000049 + 0.000025) / 15 \right]^{1/2}$$

$$S = (0.000933/15)^{1/2} = \mathbf{0.00789}$$

Two standard deviations (**0.0158**) are used to bound the maximum uncertainty. If this SpG error is then add and subtracted from the value for the change in SpG used to calculate the dissolved solids volume and the calculation carried out with the modified SpG values, the resulting calculated dissolved solids volumes are 14.7" and 7.1", respectively. This equates to a dissolved solids volume uncertainty of **± 3.8" (10,450 gal.)**.

## **CONCLUSIONS**

This calculation fully meets its intended objective and purpose. The uncertainties associated with the solids transfer values have been estimated.

## **RECOMMENDATIONS**

1. An evaluation of the total volume of waste remaining in tank 241-C-106 should be accomplished during Campaign #2. The evaluation would pump tank 241-C-106 to as close to zero liquid content as possible while monitoring the level rise in tank 241-AY-102

This technique allows a more accurate calculation of the volume of solids remaining in tank 241-C-106. The remaining uncertainty is the volume of liquid puddles remaining in tank 241-C-106 after pumping to minimum liquid level. The in-tank imaging system will have to be fully functional to support this evaluation.

2. Additional evaluation of the ENRAF densitometer is needed to correct the postulated wire dragging problem if possible to make the density profile data useful. Evaluations simulated correcting the wire dragging problem appeared to indicate that if the problem were corrected, the data would correlate fairly well with other process control information.

## **REFERENCES**

1. Carothers, K. G., 1999, EXCEL spread sheet, "WRSS Sample Data", Richland, Washington
2. LMHC 1999a, "Tank Waste Remediation System Process Engineering Instruction Manual", HNF-SD-WM-PROC-021, Lockheed Martin Hanford Corporation for Fluor Daniel Hanford, Inc., Richland Washington
3. LMHC 1999b, "Tank 241-C-106 Waste Retrieval Sluicing System Process Control Plan", HNF-SD-WM-PCP-013, Revision 1B, Lockheed Martin Hanford Corporation for Fluor Daniel Hanford, Inc., Richland Washington
4. McGraw-Hill Book Company, 1973, Chemical Engineer's Handbook – Fifth Edition, N.Y., N.Y
5. NHC 1998, "Design Basis Document Project W-320 Tank 241-C-106 Sluicing", HNF-SD-W320-DB-001, Revision 2, Numatec Hanford Company for Fluor Daniel Hanford, Inc., Richland Washington

## APPENDIX A

### SOLIDS FREE LIQUID DENSITY ERROR STANDARD DEVIATION CALCULATION

Prepared By J. W. Bailey, April 13, 1999

The data from the densitometer profiles taken between November 18, 1998 and March 18, 1999 are used to establish the standard deviation for the purposes of assessing the Campaign #1 settled solids volume uncertainty. This profile time frame was selected because it includes virtually all the measurements used in calculating the settled solids volume. A few profiles taken after the process test phase III operations have been excluded due to changes in the location of the value used for the solids free liquid density. These changes make these latter profiles non-representative. The densitometer profile data used to develop the standard deviation follows at the end of this calculation.

The formula for the standard deviation follows:

$$S^2 = \sum_{i=1}^n (X_i - \bar{X})^2 / (n-1)$$

where  $X_1, X_2, \dots, X_n$  are the observations, reference Chemical Engineer's Handbook – Fifth Edition.

The two foot level versus minimum density differences ( $D_1$  through  $D_n$ ) calculated in each of the 34 profiles at the end of this calculation are listed below:

0.01156, 0.01098, 0.01115, 0.01133, 0.01066, 0.01022, 0.01001, 0.01004, 0.01018, 0.01123, 0.01128, 0.00571, 0.01146, 0.01055, 0.00550, 0.00618, 0.00668, 0.00000, 0.00051, 0.00867, 0.00014, 0.00341, 0.00016, 0.00012, 0.00526, 0.00473, 0.00468, 0.00539, 0.00544, 0.00680, 0.00565, 0.00556, 0.00517, 0.00555

Averaging these values give a  $D_{avg}$  of 0.00682.

The calculation of the standard deviation follows:

$$S = \sqrt{[((0.00682 - 0.01156)^2 + (0.00682 - 0.01098)^2 + (0.00682 - 0.01115)^2 + (0.00682 - 0.01133)^2 + (0.00682 - 0.01066)^2 + (0.00682 - 0.01022)^2 + (0.00682 - 0.01001)^2 + (0.00682 - 0.01004)^2 + (0.00682 - 0.01018)^2 + (0.00682 - 0.01123)^2 + (0.00682 - 0.01128)^2 + (0.00682 - 0.00571)^2 + (0.00682 - 0.01146)^2 + (0.00682 - 0.01055)^2 + (0.00682 - 0.00550)^2 + (0.00682 - 0.00618)^2 + (0.00682 - 0.00668)^2 + (0.00682 - 0.00000)^2 + (0.00682 - 0.00051)^2 + (0.00682 - 0.00867)^2 + (0.00682 - 0.00014)^2 + (0.00682 - 0.00341)^2 + (0.00682 - 0.00016)^2 + (0.00682 - 0.00012)^2 + (0.00682 - 0.00526)^2 + (0.00682 - 0.00473)^2 + (0.00682 - 0.00468)^2 + (0.00682 - 0.00682)^2)}$$

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$$0.00539)^2 + (0.00682 - 0.00544)^2 + (0.00682 - 0.00680)^2 + (0.00682 - 0.00565)^2 + (0.00682 - 0.00556)^2 + (0.00682 - 0.00517)^2 + (0.00682 - 0.00555)^2) / (34 - 1)]^2$$

$$S = [(0.0000225 + 0.0000173 + 0.0000187 + 0.0000203 + 0.0000147 + 0.0000116 + 0.0000102 + 0.0000104 + 0.0000113 + 0.0000194 + 0.0000199 + 0.0000012 + 0.0000215 + 0.0000139 + 0.0000017 + 0.0000004 + 0.0000002 + 0.0000465 + 0.0000398 + 0.0000034 + 0.0000446 + 0.0000116 + 0.0000444 + 0.0000449 + 0.0000024 + 0.0000044 + 0.0000046 + 0.0000020 + 0.0000019 + 0.0000000 + 0.0000014 + 0.0000016 + 0.0000027 + 0.0000016) / 33]^2$$

$$S = (.0004728/33)^2 = \mathbf{0.00379}$$

**TANK 241-AY-102 DENSITOMETER PROFILE ACTIVITY LOG DATA AND 2 FOOT VS. MIN. DENSITY DIFFERENCE**

Density Profile Start:	Date	Time	Start Level	Start SpG
			11-18-1998	22:15:59
11-18-1998	21:38:23		155.95	1.05129
11-18-1998	21:41:24		143.95	1.05137
11-18-1998	21:44:25		131.95	1.05048 = 2 FT LEVEL
11-18-1998	21:47:26		119.95	1.04683
11-18-1998	21:50:27		107.95	1.04607
11-18-1998	21:55:19		95.98	1.04431
11-18-1998	21:58:20		83.95	1.03892 = MINIMUM DENSITY
11-18-1998	22:01:21		71.95	1.04048
11-18-1998	22:04:22		59.95	1.04247
11-18-1998	22:07:23		47.95	1.04331
11-18-1998	22:10:24		35.95	1.0443
11-18-1998	22:13:25		23.95	1.04695

$$2 \text{ FT LEVEL DENSITY} - \text{MINIMUM} = 0.01156$$

Density Profile Start:	Date	Time	Start Level	Start SpG
			11-19-1998	11:44:08
11-19-1998	11:09:41		155.95	1.07014
11-19-1998	11:12:42		143.95	1.06992
11-19-1998	11:15:43		131.95	1.06869 = 2 FT LEVEL
11-19-1998	11:18:44		119.95	1.06582
11-19-1998	11:21:45		107.95	1.06449
11-19-1998	11:25:24		95.97	1.06225
11-19-1998	11:28:25		83.95	1.05771 = MINIMUM DENSITY
11-19-1998	11:31:26		71.95	1.05933
11-19-1998	11:34:27		59.95	1.06144
11-19-1998	11:37:28		47.95	1.06208
11-19-1998	11:40:29		35.95	1.06302

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11-19-1998 11:43:30 23.95 1.06484

2 FT LEVEL DENSITY - MINIMUM = 0.01098

Density Profile Start:		11-19-1998	13:28:56
Date	Time	Level	SpG
11-19-1998	12:55:06	155.95	1.07045
11-19-1998	12:58:07	143.95	1.06975
11-19-1998	13:01:08	131.95	1.06782 = 2 FT LEVEL
11-19-1998	13:04:09	119.95	1.06513
11-19-1998	13:07:10	107.95	1.06396
11-19-1998	13:10:29	95.95	1.06176
11-19-1998	13:13:30	83.95	1.05667 = MINIMUM DENSITY
11-19-1998	13:16:31	71.95	1.05866
11-19-1998	13:19:32	59.95	1.06079
11-19-1998	13:22:33	47.95	1.06123
11-19-1998	13:25:34	35.95	1.06171
11-19-1998	13:28:35	23.95	1.06427

2 FT LEVEL DENSITY - MINIMUM = 0.01115

Density Profile Start:		11-19-1998	20:13:02
Date	Time	Level	SpG
11-19-1998	19:39:18	155.95	1.06769
11-19-1998	19:42:19	143.95	1.06599
11-19-1998	19:45:20	131.95	1.06449 = 2 FT LEVEL
11-19-1998	19:48:21	119.95	1.06202
11-19-1998	19:51:22	107.95	1.05999
11-19-1998	19:54:33	95.95	1.05922
11-19-1998	19:57:34	83.95	1.05316 = MINIMUM DENSITY
11-19-1998	20:00:35	71.95	1.0549
11-19-1998	20:03:36	59.95	1.05707
11-19-1998	20:06:37	47.95	1.05853
11-19-1998	20:09:38	35.95	1.05862
11-19-1998	20:12:39	23.95	1.06053

2 FT LEVEL DENSITY - MINIMUM = 0.01133

Density Profile Start:		11-19-1998	20:54:45
Date	Time	Level	SpG
11-19-1998	20:20:58	155.95	1.06615
11-19-1998	20:23:59	143.95	1.06534
11-19-1998	20:27:00	131.95	1.06355 = 2 FT LEVEL
11-19-1998	20:30:01	119.95	1.06102
11-19-1998	20:33:02	107.95	1.06021
11-19-1998	20:36:09	95.95	1.05925

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11-19-1998	20:39:10	83.95	1.05289 = MINUMUM DENSITY
11-19-1998	20:42:11	71.95	1.05423
11-19-1998	20:45:12	59.95	1.05713
11-19-1998	20:48:13	47.95	1.05789
11-19-1998	20:51:14	35.95	1.05793
11-19-1998	20:54:15	23.95	1.06014

2 FT LEVEL DENSITY - MINIMUM = 0.01066

Density Profile Start:		11-21-1998	00:40:57
Date	Time	Level	SpG
11-21-1998	00:06:23	155.95	1.06527
11-21-1998	00:09:24	143.95	1.06397
11-21-1998	00:12:25	131.95	1.06266 = 2 FT LEVEL
11-21-1998	00:15:26	119.95	1.05987
11-21-1998	00:18:27	107.95	1.05867
11-21-1998	00:22:28	95.95	1.05722
11-21-1998	00:25:29	83.95	1.05244 = MINUMUM DENSITY
11-21-1998	00:28:30	71.95	1.05373
11-21-1998	00:31:31	59.95	1.05589
11-21-1998	00:34:32	47.95	1.05658
11-21-1998	00:37:33	35.95	1.05756
11-21-1998	00:40:34	23.95	1.05992

2 FT LEVEL DENSITY - MINIMUM = 0.01022

Density Profile Start:		11-21-1998	01:28:53
Date	Time	Level	SpG
11-21-1998	00:55:07	155.95	1.0647
11-21-1998	00:58:08	143.95	1.06397
11-21-1998	01:01:09	131.95	1.06237 = 2 FT LEVEL
11-21-1998	01:04:10	119.95	1.05966
11-21-1998	01:07:11	107.95	1.05838
11-21-1998	01:10:17	95.95	1.05665
11-21-1998	01:13:18	83.95	1.05236 = MINUMUM DENSITY
11-21-1998	01:16:19	71.95	1.05354
11-21-1998	01:19:20	59.95	1.05637
11-21-1998	01:22:21	47.95	1.05664
11-21-1998	01:25:22	35.95	1.05744
11-21-1998	01:28:23	23.95	1.05982

2 FT LEVEL DENSITY - MINIMUM = 0.01001

Density Profile Start:		12-01-1998	10:32:49
Date	Time	Level	SpG
12-01-1998	10:32:49	155.95	1.0647
12-01-1998	10:35:50	143.95	1.06397
12-01-1998	10:38:51	131.95	1.06237 = 2 FT LEVEL
12-01-1998	10:41:52	119.95	1.05966
12-01-1998	10:44:53	107.95	1.05838
12-01-1998	10:47:54	95.95	1.05665
12-01-1998	10:50:55	83.95	1.05236 = MINUMUM DENSITY
12-01-1998	10:53:56	71.95	1.05354
12-01-1998	10:56:57	59.95	1.05637
12-01-1998	10:59:58	47.95	1.05664
12-01-1998	11:02:59	35.95	1.05744
12-01-1998	11:05:00	23.95	1.05982

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12-01-1998	09:59:26	155.95	1.05956
12-01-1998	10:02:27	143.95	1.05916
12-01-1998	10:05:28	131.95	1.05768 = 2 FT LEVEL
12-01-1998	10:08:29	119.95	1.05906
12-01-1998	10:11:30	107.95	1.05378
12-01-1998	10:14:34	95.95	1.05249
12-01-1998	10:17:35	83.95	1.04764 = MINIMUM DENSITY
12-01-1998	10:20:36	71.95	1.04872
12-01-1998	10:23:37	59.95	1.05016
12-01-1998	10:26:38	47.95	1.05197
12-01-1998	10:29:39	35.95	1.05173
12-01-1998	10:32:40	23.95	1.05444

2 FT LEVEL DENSITY - MINIMUM = 0.01004

Density Profile Start:		12-07-1998	14:20:03
Date	Time	Level	SpG
12-07-1998	13:46:15	155.95	1.05675
12-07-1998	13:49:16	143.95	1.05725
12-07-1998	13:52:17	131.95	1.05617 = 2 FT LEVEL
12-07-1998	13:55:18	119.95	1.05297
12-07-1998	13:58:19	107.95	1.05189
12-07-1998	14:01:23	95.95	1.05
12-07-1998	14:04:24	83.95	1.04599 = MINIMUM DENSITY
12-07-1998	14:07:25	71.95	1.04668
12-07-1998	14:10:26	59.95	1.04791
12-07-1998	14:13:27	47.95	1.0489
12-07-1998	14:16:28	35.95	1.04914
12-07-1998	14:19:29	23.95	1.05186

2 FT LEVEL DENSITY - MINIMUM = 0.01018

Density Profile Start:		12-17-1998	12:12:05
Date	Time	Level	SpG
12-17-1998	11:38:20	155.95	1.07896
12-17-1998	11:41:21	143.95	1.07897
12-17-1998	11:44:22	131.95	1.07851 = 2 FT LEVEL
12-17-1998	11:47:23	119.95	1.0757
12-17-1998	11:50:24	107.95	1.07518
12-17-1998	11:53:28	95.95	1.07263
12-17-1998	11:56:29	83.95	1.06728 = MINIMUM DENSITY
12-17-1998	11:59:30	71.95	1.06843
12-17-1998	12:02:31	59.95	1.06959
12-17-1998	12:05:32	47.95	1.07067
12-17-1998	12:08:33	35.95	1.0713
12-17-1998	12:11:34	23.95	1.07415

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2 FT LEVEL DENSITY - MINIMUM = 0.01123

Density Profile Start:		12-17-1998	12:52:55
Date	Time	Level	SpG
12-17-1998	12:18:57	155.95	1.079
12-17-1998	12:21:58	143.95	1.0796
12-17-1998	12:24:59	131.95	1.07841 = 2 FT LEVEL
12-17-1998	12:28:00	119.95	1.0754
12-17-1998	12:31:01	107.95	1.07481
12-17-1998	12:34:05	95.95	1.07156
12-17-1998	12:37:06	83.95	1.06713 = MINIMUM DENSITY
12-17-1998	12:40:07	71.95	1.06816
12-17-1998	12:43:08	59.95	1.06955
12-17-1998	12:46:09	47.95	1.07018
12-17-1998	12:49:10	35.95	1.07109
12-17-1998	12:52:11	23.95	1.07376

2 FT LEVEL DENSITY - MINIMUM = 0.01128

Density Profile Start:		12-17-1998	19:50:08
Date	Time	Level	SpG
12-17-1998	19:15:58	155.95	1.05936
12-17-1998	19:18:59	143.95	1.05917
12-17-1998	19:22:00	131.95	1.05833 = 2 FT LEVEL
12-17-1998	19:25:01	119.95	1.05646
12-17-1998	19:28:02	107.95	1.05505
12-17-1998	19:31:06	95.95	1.05262 = MINIMUM DENSITY
12-17-1998	19:34:07	83.95	1.05812
12-17-1998	19:37:08	71.95	1.05825
12-17-1998	19:40:09	59.95	1.0609
12-17-1998	19:43:10	47.95	1.06198
12-17-1998	19:46:11	35.95	1.06339
12-17-1998	19:49:12	23.95	1.06453

2 FT LEVEL DENSITY - MINIMUM = 0.00571

Density Profile Start:		12-18-1998	14:39:54
Date	Time	Level	SpG
12-18-1998	14:06:04	155.95	1.07283
12-18-1998	14:09:05	143.95	1.07276
12-18-1998	14:12:06	131.95	1.07224 = 2 FT LEVEL
12-18-1998	14:15:07	119.95	1.06963
12-18-1998	14:18:08	107.95	1.06804
12-18-1998	14:21:12	95.95	1.06577

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12-18-1998	14:24:13	83.95	1.06078 = MINIMUM DENSITY
12-18-1998	14:27:14	71.95	1.06194
12-18-1998	14:30:15	59.95	1.06327
12-18-1998	14:33:16	47.95	1.06403
12-18-1998	14:36:17	35.95	1.06498
12-18-1998	14:39:18	23.95	1.06773

2 FT LEVEL DENSITY - MINIMUM = 0.01146

Density Profile Start:	Date	Time	Level	SpG
12-18-1998	14:45:33	155.95	1.07233	
12-18-1998	14:48:34	143.95	1.07198	
12-18-1998	14:51:35	131.95	1.07098 = 2 FT LEVEL	
12-18-1998	14:54:36	119.95	1.06873	
12-18-1998	14:57:37	107.95	1.06737	
12-18-1998	15:00:41	95.95	1.06533	
12-18-1998	15:03:42	83.95	1.06043 = MINIMUM DENSITY	
12-18-1998	15:06:43	71.95	1.0618	
12-18-1998	15:09:44	59.95	1.0631	
12-18-1998	15:12:45	47.95	1.06409	
12-18-1998	15:15:46	35.95	1.06481	
12-18-1998	15:18:47	23.95	1.06766	

2 FT LEVEL DENSITY - MINIMUM = 0.01055

Density Profile Start:	Date	Time	Level	SpG
12-18-1998	19:08:29	155.95	1.05235	
12-18-1998	19:11:30	143.95	1.05268	
12-18-1998	19:14:31	131.95	1.05194 = 2 FT LEVEL	
12-18-1998	19:17:32	119.95	1.04972	
12-18-1998	19:20:33	107.95	1.0477	
12-18-1998	19:23:37	95.95	1.04644 = MINIMUM DENSITY	
12-18-1998	19:26:38	83.95	1.05153	
12-18-1998	19:29:39	71.95	1.05202	
12-18-1998	19:32:40	59.95	1.05428	
12-18-1998	19:35:41	47.95	1.05583	
12-18-1998	19:38:42	35.95	1.05651	
12-18-1998	19:41:43	23.95	1.05828	

2 FT LEVEL DENSITY - MINIMUM = 0.00550

Density Profile Start:	Date	Time	Level	SpG
12-18-1998	19:48:36	155.95	1.05303	

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12-18-1998	19:51:37	143.95	1.05282
12-18-1998	19:54:38	131.95	1.05122 = 2 FT LEVEL
12-18-1998	19:57:39	119.95	1.04902
12-18-1998	20:00:40	107.95	1.04719
12-18-1998	20:03:44	95.95	1.04504 = MINIMUM DENSITY
12-18-1998	20:06:45	83.95	1.05113
12-18-1998	20:09:46	71.95	1.05152
12-18-1998	20:12:47	59.95	1.05458
12-18-1998	20:15:48	47.95	1.05491
12-18-1998	20:18:49	35.95	1.05696
12-18-1998	20:21:50	23.95	1.05792

2 FT LEVEL DENSITY - MINIMUM = 0.00618

Density Profile Start:		12-19-1998	14:50:42
Date	Time	Level	SpG
12-19-1998	14:16:24	155.95	1.06441
12-19-1998	14:19:25	143.95	1.06456
12-19-1998	14:22:26	131.95	1.06225 = 2 FT LEVEL
12-19-1998	14:25:27	119.95	1.05902
12-19-1998	14:28:28	107.95	1.05791
12-19-1998	14:31:32	95.95	1.05557 = MINIMUM DENSITY
12-19-1998	14:34:33	83.95	1.06062
12-19-1998	14:37:34	71.95	1.06099
12-19-1998	14:40:35	59.95	1.06404
12-19-1998	14:43:36	47.95	1.06559
12-19-1998	14:46:37	35.95	1.06672
12-19-1998	14:49:38	23.95	1.06865

2 FT LEVEL DENSITY - MINIMUM = 0.00668

Density Profile Start:		12-19-1998	21:12:44
Date	Time	Level	SpG
12-19-1998	20:38:56	160.16	1.0607
12-19-1998	20:41:57	147.95	1.06269
12-19-1998	20:44:58	135.95	1.06001 = MINIMUM DENSITY / 2 FT LEVEL
12-19-1998	20:47:59	123.95	1.06148
12-19-1998	20:51:00	111.95	1.06214
12-19-1998	20:54:01	99.95	1.0654
12-19-1998	20:57:02	87.95	1.06751
12-19-1998	21:00:03	75.95	1.06891
12-19-1998	21:03:04	63.95	1.06896
12-19-1998	21:06:05	51.95	1.06767
12-19-1998	21:09:06	39.95	1.06617

2 FT LEVEL DENSITY - MINIMUM = 0.00000

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Density Profile Start:		12-19-1998	22:56:03
Date	Time	Level	SpG
12-19-1998	22:22:24	159.95	1.05995 = MINIMUM DENSITY
12-19-1998	22:25:25	147.95	1.06209
12-19-1998	22:28:26	135.95	1.06046 = 2 FT LEVEL
12-19-1998	22:31:27	123.95	1.06138
12-19-1998	22:34:28	111.95	1.06115
12-19-1998	22:37:29	99.95	1.06526
12-19-1998	22:40:30	87.95	1.06802
12-19-1998	22:43:31	75.95	1.06842
12-19-1998	22:46:32	63.95	1.0687
12-19-1998	22:49:33	51.95	1.06758
12-19-1998	22:52:34	39.95	1.06602
12-19-1998	22:55:38	27.95	1.06251

2 FT LEVEL DENSITY - MINIMUM = 0.00051

Density Profile Start:		03-04-1999	13:19:07
Date	Time	Level	SpG
03-04-1999	12:45:01	155.95	1.0723
03-04-1999	12:48:02	143.95	1.07215
03-04-1999	12:51:03	131.95	1.07116 = 2 FT LEVEL
03-04-1999	12:54:04	119.95	1.06879
03-04-1999	12:57:05	107.95	1.0688
03-04-1999	13:00:09	95.95	1.06768
03-04-1999	13:03:10	83.95	1.06249 = MINIMUM DENSITY
03-04-1999	13:06:11	71.95	1.06363
03-04-1999	13:09:12	59.95	1.06465
03-04-1999	13:12:13	47.95	1.06459
03-04-1999	13:15:14	35.95	1.06557

2 FT LEVEL DENSITY - MINIMUM = 0.00867

Density Profile Start:		03-08-1999	02:19:52
Date	Time	Level	SpG
03-08-1999	01:46:23	155.95	1.08458
03-08-1999	01:49:24	143.95	1.08343
03-08-1999	01:52:25	131.95	1.08255 = 2 FT LEVEL
03-08-1999	01:55:26	119.95	1.08021
03-08-1999	01:58:27	107.95	1.08071
03-08-1999	02:01:31	95.95	1.08659
03-08-1999	02:04:32	83.95	1.08241 = MINIMUM DENSITY
03-08-1999	02:07:33	71.95	1.08599
03-08-1999	02:10:34	59.95	1.08989
03-08-1999	02:13:35	47.95	1.09292
03-08-1999	02:16:36	35.95	1.09495

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03-08-1999 02:19:37 23.95 1.10413

2 FT LEVEL DENSITY - MINIMUM = 0.00014

Density Profile Start:		03-08-1999	03:40:50
Date	Time	Level	SpG
03-08-1999	03:07:26	155.95	1.08148
03-08-1999	03:10:27	143.95	1.08199
03-08-1999	03:13:28	131.95	1.08075 = 2 FT LEVEL
03-08-1999	03:16:29	119.95	1.07894
03-08-1999	03:19:30	107.95	1.07849
03-08-1999	03:22:34	95.95	1.07734 = MINIMUM DENSITY
03-08-1999	03:25:35	83.95	1.08266
03-08-1999	03:28:36	71.95	1.09549
03-08-1999	03:31:37	59.95	1.09968
03-08-1999	03:34:38	47.95	1.10277
03-08-1999	03:37:39	35.95	1.10537
03-08-1999	03:40:40	23.95	1.11381

2 FT LEVEL DENSITY - MINIMUM = 0.00341

Density Profile Start:		03-08-1999	18:54:10
Date	Time	Level	SpG
03-08-1999	18:22:58	146.47	1.08631
03-08-1999	18:25:59	134.47	1.08484 = MINIMUM DENSITY
03-08-1999	18:29:00	122.47	1.085 = 2 FT LEVEL
03-08-1999	18:32:01	110.47	1.08624
03-08-1999	18:35:02	98.47	1.0862
03-08-1999	18:38:03	86.47	1.0883
03-08-1999	18:41:04	74.47	1.08532
03-08-1999	18:44:05	62.47	1.08536
03-08-1999	18:47:06	50.47	1.08575
03-08-1999	18:50:07	38.47	1.0846

2 FT LEVEL DENSITY - MINIMUM = 0.00016

Density Profile Start:		03-08-1999	19:31:31
Date	Time	Level	SpG
03-08-1999	19:00:37	146.47	1.08522
03-08-1999	19:03:38	134.47	1.08395 = MINIMUM DENSITY
03-08-1999	19:06:39	122.47	1.08407 = 2 FT LEVEL
03-08-1999	19:09:40	110.47	1.08596
03-08-1999	19:12:41	98.47	1.08672
03-08-1999	19:15:42	86.47	1.08846
03-08-1999	19:18:43	74.47	1.08511
03-08-1999	19:21:44	62.47	1.08486

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03-08-1999	19:24:45	50.47	1.08563
03-08-1999	19:27:46	38.47	1.08463
03-08-1999	19:30:47	26.47	1.15461

2 FT LEVEL DENSITY - MINIMUM = 0.00012

Density Profile Start:	03-09-1999	10:44:27	
Date	Time	Level	SpG
03-09-1999	10:11:07	155.95	.96979
03-09-1999	10:14:08	143.95	.96939
03-09-1999	10:17:09	131.95	.96686 = 2 FT LEVEL
03-09-1999	10:20:10	119.95	.9666
03-09-1999	10:23:11	107.95	.96597
03-09-1999	10:26:15	95.95	.96346 = MINIMUM DENSITY
03-09-1999	10:29:16	83.95	.97083
03-09-1999	10:32:17	71.95	.97135
03-09-1999	10:35:18	59.95	.97344
03-09-1999	10:38:19	47.95	.97399
03-09-1999	10:41:20	35.95	.97434
03-09-1999	10:44:21	23.95	1.05722

NOT INCLUDED IN CALCULATION DUE TO BELOW 1.0 VALUES

Density Profile Start:	03-09-1999	14:24:10	
Date	Time	Level	SpG
03-09-1999	13:50:46	155.95	1.07307
03-09-1999	13:53:47	143.95	1.07279
03-09-1999	13:56:48	131.95	1.0708 = 2 FT LEVEL
03-09-1999	13:59:49	119.95	1.06766
03-09-1999	14:02:50	107.95	1.06764
03-09-1999	14:05:54	95.95	1.06554 = MINIMUM DENSITY
03-09-1999	14:08:55	83.95	1.0707
03-09-1999	14:11:56	71.95	1.07175
03-09-1999	14:14:57	59.95	1.07428
03-09-1999	14:17:58	47.95	1.0752
03-09-1999	14:20:59	35.95	1.0762
03-09-1999	14:24:00	23.95	1.15992

2 FT LEVEL DENSITY - MINIMUM = 0.00526

Density Profile Start:	03-09-1999	17:59:02	
Date	Time	Level	SpG
03-09-1999	17:25:38	155.95	1.07236
03-09-1999	17:28:39	143.95	1.07099
03-09-1999	17:31:40	131.95	1.0685 = 2 FT LEVEL
03-09-1999	17:34:41	119.95	1.0676

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03-09-1999	17:37:42	107.95	1.06625
03-09-1999	17:40:46	95.95	1.06377 = MINIMUM DENSITY
03-09-1999	17:43:47	83.95	1.07095
03-09-1999	17:46:48	71.95	1.07131
03-09-1999	17:49:49	59.95	1.07341
03-09-1999	17:52:50	47.95	1.07433
03-09-1999	17:55:51	35.95	1.07496
03-09-1999	17:58:52	23.95	1.16089

2 FT LEVEL DENSITY - MINIMUM = 0.00473

Density Profile Start:		03-09-1999	19:23:22
Date	Time	Level	SpG
03-09-1999	18:49:40	155.95	1.08304
03-09-1999	18:52:41	143.95	1.0825
03-09-1999	18:55:42	131.95	1.08085 = 2 FT LEVEL
03-09-1999	18:58:43	119.95	1.0783
03-09-1999	19:01:44	107.95	1.07709
03-09-1999	19:04:48	95.95	1.07617 = MINIMUM DENSITY
03-09-1999	19:07:49	83.95	1.08146
03-09-1999	19:10:50	71.95	1.08271
03-09-1999	19:13:51	59.95	1.08482
03-09-1999	19:16:52	47.95	1.08685
03-09-1999	19:19:53	35.95	1.08683
03-09-1999	19:22:54	23.95	1.17554

2 FT LEVEL DENSITY - MINIMUM = 0.00468

Density Profile Start:		03-10-1999	10:14:44
Date	Time	Level	SpG
03-10-1999	09:41:16	155.95	1.07903
03-10-1999	09:44:17	143.95	1.07884
03-10-1999	09:47:18	131.95	1.07662 = 2 FT LEVEL
03-10-1999	09:50:19	119.95	1.07477
03-10-1999	09:53:20	107.95	1.07413
03-10-1999	09:56:24	95.95	1.07123 = MINIMUM DENSITY
03-10-1999	09:59:25	83.95	1.07696
03-10-1999	10:02:26	71.95	1.07878
03-10-1999	10:05:27	59.95	1.08076
03-10-1999	10:08:28	47.95	1.08307
03-10-1999	10:11:29	35.95	1.08279
03-10-1999	10:14:30	23.95	1.17494

2 FT LEVEL DENSITY - MINIMUM = 0.00539

Density Profile Start:		03-10-1999	10:54:14
Date	Time	Level	SpG

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03-10-1999	10:20:52	155.95	1.07871
03-10-1999	10:23:53	143.95	1.07864
03-10-1999	10:26:54	131.95	1.07705 = 2 FT LEVEL
03-10-1999	10:29:55	119.95	1.07499
03-10-1999	10:32:56	107.95	1.07463
03-10-1999	10:36:00	95.95	1.07161 = MINIMUM DENSITY
03-10-1999	10:39:01	83.95	1.07736
03-10-1999	10:42:02	71.95	1.07837
03-10-1999	10:45:03	59.95	1.08091
03-10-1999	10:48:04	47.95	1.08256
03-10-1999	10:51:05	35.95	1.08318
03-10-1999	10:54:06	23.95	1.1736

2 FT LEVEL DENSITY - MINIMUM = 0.00544

Density Profile Start:		03-10-1999	18:22:53
Date	Time	Level	SpG
03-10-1999	17:49:28	155.95	1.06848
03-10-1999	17:52:29	143.95	1.06799
03-10-1999	17:55:30	131.95	1.06587 = 2 FT LEVEL
03-10-1999	17:58:31	119.95	1.0633
03-10-1999	18:01:32	107.95	1.06197
03-10-1999	18:04:36	95.95	1.05907 = MINIMUM DENSITY
03-10-1999	18:07:37	83.95	1.06536
03-10-1999	18:10:38	71.95	1.06666
03-10-1999	18:13:39	59.95	1.06906
03-10-1999	18:16:40	47.95	1.07053
03-10-1999	18:19:41	35.95	1.07183
03-10-1999	18:22:42	23.95	1.16098

2 FT LEVEL DENSITY - MINIMUM = 0.00680

Density Profile Start:		03-10-1999	19:11:44
Date	Time	Level	SpG
03-10-1999	18:38:22	155.95	1.06769
03-10-1999	18:41:23	143.95	1.0672
03-10-1999	18:44:24	131.95	1.06517 = 2 FT LEVEL
03-10-1999	18:47:25	119.95	1.06319
03-10-1999	18:50:26	107.95	1.06191
03-10-1999	18:53:30	95.95	1.05952 = MINIMUM DENSITY
03-10-1999	18:56:31	83.95	1.06506
03-10-1999	18:59:32	71.95	1.06667
03-10-1999	19:02:33	59.95	1.06884
03-10-1999	19:05:34	47.95	1.07023
03-10-1999	19:08:35	35.95	1.07166
03-10-1999	19:11:36	23.95	1.15958

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2 FT LEVEL DENSITY - MINIMUM = 0.00565

Density Profile Start:	Date	Time	Level	SpG
03-11-1999	03-11-1999	10:01:44	155.95	1.06403
03-11-1999	03-11-1999	10:04:45	143.95	1.06441
03-11-1999	03-11-1999	10:07:46	131.95	1.06243 = 2 FT LEVEL
03-11-1999	03-11-1999	10:10:47	119.95	1.06059
03-11-1999	03-11-1999	10:13:48	107.95	1.05926
03-11-1999	03-11-1999	10:16:52	95.95	1.05687 = MINIMUM DENSITY
03-11-1999	03-11-1999	10:19:53	83.95	1.06258
03-11-1999	03-11-1999	10:22:54	71.95	1.06314
03-11-1999	03-11-1999	10:25:55	59.95	1.06562
03-11-1999	03-11-1999	10:28:56	47.95	1.06681
03-11-1999	03-11-1999	10:31:57	35.95	1.06758
03-11-1999	03-11-1999	10:34:58	23.95	1.14553

2 FT LEVEL DENSITY - MINIMUM = 0.00556

Density Profile Start:	Date	Time	Level	SpG
03-11-1999	03-11-1999	10:41:29	155.95	1.06365
03-11-1999	03-11-1999	10:44:30	143.95	1.06347
03-11-1999	03-11-1999	10:47:31	131.95	1.06247 = 2 FT LEVEL
03-11-1999	03-11-1999	10:50:32	119.95	1.06008
03-11-1999	03-11-1999	10:53:33	107.95	1.05919
03-11-1999	03-11-1999	10:56:37	95.95	1.0573 = MINIMUM DENSITY
03-11-1999	03-11-1999	10:59:38	83.95	1.0623
03-11-1999	03-11-1999	11:02:39	71.95	1.06339
03-11-1999	03-11-1999	11:05:40	59.95	1.06562
03-11-1999	03-11-1999	11:08:41	47.95	1.06687
03-11-1999	03-11-1999	11:11:42	35.95	1.06778
03-11-1999	03-11-1999	11:14:43	23.95	1.14569

2 FT LEVEL DENSITY - MINIMUM = 0.00517

Density Profile Start:	Date	Time	Level	SpG
03-18-1999	03-18-1999	13:37:52	155.95	1.07689
03-18-1999	03-18-1999	13:40:53	143.95	1.07602
03-18-1999	03-18-1999	13:43:54	131.95	1.07463 = 2 FT LEVEL
03-18-1999	03-18-1999	13:46:55	119.95	1.07227
03-18-1999	03-18-1999	13:49:56	107.95	1.07059
03-18-1999	03-18-1999	13:53:00	95.95	1.06908 = MINIMUM DENSITY
03-18-1999	03-18-1999	13:56:01	83.95	1.07314
03-18-1999	03-18-1999	13:59:02	71.95	1.07423

**APPENDIX A**

03-18-1999	14:02:03	59.95	1.07642
03-18-1999	14:05:04	47.95	1.07768
03-18-1999	14:08:05	35.95	1.07912

**2 FT LEVEL DENSITY - MINIMUM = 0.00555**

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