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Evaluation of Historical Dry Well Surveillance Logs

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Abstract: Several dry well surveillance logs from 1975 through 1995
for the SX Tank Farm have been examined to identify potential subsurface
zones of radioactive contaminant migration. Several dynamic conditions
of the gamma-ray emitting radioactive contaminants have been identified.

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LIST OF TERMS

DOE	U.S. Department of Energy
GM	Geiger-Mueller
HPGe	Hyper-Pure germanium
UO	unusual occurrence

EVALUATION OF HISTORICAL DRY WELL SURVEILLANCE LOGS

1.0 INTRODUCTION

High-resolution germanium (HPGe) passive spectral gamma-ray surveys have been acquired in the vadose zone boreholes within the SX Tank Farm (U.S. Department of Energy (DOE 1996)) at the Hanford Site, near Richland, Washington. These borehole surveys will be the baseline against which future monitoring surveys will be compared. The HPGe baseline surveys also provide the opportunity to interpret the historical Tank Farm borehole survey logs.

During the preparation of the field activity report for the 241-SX-109 single-shell tank (DOE 1995b), changes in the gamma-ray activity that had been previously unreported were identified in the Dry Well surveillance logs from 1986 through 1989 for borehole 41-09-09. These changes in gamma-ray activity indicated a dynamic condition in the subsurface.

The possibility of other dynamic conditions having been recorded by the Dry Well surveillance logs initiated this review of the historical survey data. (Dry Well surveillance logs are commonly called gross gamma-ray logs). Several dynamic conditions have been identified and will be discussed in this report.

The purpose of this report is to present a method by which the historical surveillance logs can be evaluated for indications of changes in the vadose zone contaminant plumes that are not attributable to radioactive decay. The review is limited to ten of the 95 vadose zone boreholes and groundwater wells within the SX Tank Farm. The borehole selection criteria is described later with the evaluation of the historical surveillance logs.

Identifying the source of the radioactive contaminants within the vadose zone, the migration pathway, and the mechanism of migration is beyond the scope of this report.

The report discusses: (1) the pedigree (limitations) of the historical surveillance logs, (2) the processing options of a software program written to summarize the hundreds of surveys for a single borehole, and (3) the results of the surveillance log evaluation. Conclusions and recommendations are also provided.

2.0 LIMITATIONS OF HISTORICAL SURVEILLANCE LOG DATA

Tank leak detection was the objective of the Tank Farms Dry Well surveillance logging program from 1975 through 1995. A summary of the surveillance logging program is discussed in Appendix A. Additionally, Appendix B includes a general summary of borehole geophysical logging equipment and analysis considerations for measuring the subsurface gamma-ray radiation. The tank leak detection program was adequate for the type of tank failure for which it was designed (ie. rapid release of at least 19,000 L (5000 gal) of liquid into the subsurface soils).

However, significant limitations of both the accuracy and precision of the Dry Well surveillance logs restrict their use for environmental monitoring and contaminant plume tracking. Environmental monitoring and plume tracking is characterized by slow transport of the contaminants through the

subsurface. The summaries (Appendices A and B) show that several variables within the logging program could severely limit the pedigree of the logs for environmental monitoring (e.g., multiple logging trucks, multiple probes with questionable calibration, and no tracking of the truck and probe combinations used to acquire each survey).

This report shows that some limited value can be attributed to the historical leak detection surveillance logs for environmental monitoring and identifying dynamic zones of radioactive contamination.

3.0 SOFTWARE PROGRAM TO REVIEW HISTORICAL SURVEILLANCE LOGS

A software program (TFGROSS¹) was written to evaluate the historical Tank Farms Dry Well leak detection log data. To enable review of several hundred log surveys for a single borehole, the program corrected errors within a survey log and performed calculations to compress the survey log data into representative numeric values. The details of the software program are discussed in Appendix C.

The Dry Well survey files for selected boreholes were copied from their storage location on the server computer to a local analysis computer while protecting the original survey data values.

The program was used to identify invalid survey data values and replace them with a representative value from the adjacent valid survey measurements. A program option was used to normalize (depth shift) the surveys to a common gamma-ray feature within each survey. Finally, the program was used to compute the net gamma-ray activity (grade thickness product) of the contamination intervals within each survey. The computed results are presented in Section 4.0 of this report.

An improvement of the data analysis is recommended. On each survey date, multiple boreholes were surveyed with a combination of one truck, one probe, and one setting of the electronic instrumentation. If all the surveys on a single date are above or below the average for all the boreholes surveyed, it would be reasonable to normalize all the surveys of the single date and apply a correction to each survey acquired. These additional analysis enhancements should be investigated to identify if they improve the computed results.

4.0 EVALUATION OF HISTORICAL SURVEILLANCE LOGS

Boreholes were selected for review based on the baseline survey acquired with the HPGe detector. The baseline logs are presented in the SX Tank Farm summary data reports referenced in DOE 1996. The boreholes selected generally contained zones of contamination below the base of the tanks (16.8 m [55 ft]) with the contamination levels exceeding 200 counts per second (cps) for the Dry Well surveillance logs. Boreholes with high levels of contamination (preventing use of the sodium-iodide detector, probe type 4) generally were not selected for review in this report. The boreholes selected, the logging probe type, the first and last survey date, and the total number of surveys are presented in Table 1.

¹TFGROSS is a software program developed by Westinghouse Hanford Company.

Table 1. Borehole Analysis by the TFGROSS Program.

Borehole	Probe Type	Date First Survey	Date Last Survey	Survey Count
41-00-08	4=NaI	1/15/1975	10/19/1993	208
41-02-02	4=NaI	1/14/1975	7/26/1995	896
41-04-03	4=NaI	1/14/1975	11/22/1995	601
41-07-08	4=NaI	1/15/1975	6/9/1994	279
41-09-09	4=NaI 14=Shielded	1/15/1975 7/14/1987	6/9/1994 6/9/1994	319 71
41-10-01	4=NaI	1/15/1975	6/9/1994	254
41-10-08	4=NaI	1/15/1975	6/10/1994	217
41-11-10	1=GM-Green 2=GM-Red 4=NaI 14=Shielded	11/29/1979 1/15/1975 1/15/1965 5/25/1977	6/10/1994 6/10/1994 7/16/1980 7/25/1980	41 131 93 6
41-14-09	4=NaI	1/15/1975	6/9/1994	184
41-15-07	4=NaI	1/15/1975	6/9/1994	84

The data computed by the TFGROSS program is presented graphically as data plots. The monitoring surveys for each borehole analyzed are summarized into a single figure. Each figure contains three plots.

Two of the plots (left most and right most) are the first and last survey (e.g., 1975 and 1994) for the borehole being analyzed. These plots have two linear x-axis scales for presenting the measured gamma-ray activity (counts per second, cps) for visualizing both the background activity and the activity of the contaminated area. The narrow-line of the gamma-ray data plot uses the top scale of 0 to 200 cps. The wide-line data plot uses the bottom scale, which changes with each borehole analyzed.

The center plot in each analysis figure is a summary of the multiple borehole surveys. The x-axis of the analysis summary plot indicates the survey year, from 1975 through 1995. The computed results of each survey are plotted as dots (or other simple symbols). The small dots are the average background for each survey (i.e., AVGBKG variable described in Appendix C). The background activity of each survey is plotted against the right scale of 0 to 100 cps. The large dots represent the grade thickness product (ft-counts/sec) for each survey and are plotted against the left scale, which varies for each borehole analyzed. The grade thickness product is the net-contamination which is a sum of the detector count-rate for the contamination zone above the background activity. The net-contamination calculation is described in Appendix C.

Much of the scatter in the grade thickness product is from counting statistics. Frequently, when the surveys are acquired annually the scatter is greater than would be expected for counting statistics. A possible cause of the excessive scatter is that different logging trucks were used for the annual surveys and the different instruments contributed to the survey differences. This problem will be investigated further.

The analysis results are not presented by borehole number. The presentation order is according to the complexity of interpretation, from the simple to the complex and from the obvious to the subtle.

4.1 BOREHOLE 41-15-07

Borehole 41-15-07 contains one zone of contamination at 17.7 m (58 ft), Figure 1. The first survey (1/15/75) is plotted on the left. The maximum measured gamma-ray activity is 453 cps. The contamination interval is defined by five data values (93 + 238 + 453 + 325 + 85) with a summed net peak area (grade thickness product) of 1072 cps. The grade thickness product is plotted using the left scale of 0 to 2000. The background for the first survey is 24.5 cps and is plotted with the right scale of 0 to 100.

The computed background and grade thickness product for each survey (from 1975 through 1994) are shown in the plot. The background and grade thickness product indicate that some instrumentation problems were present on several of the surveys acquired during 1975, as shown by the anomalous values.

The HPGe survey of this borehole had confirmed that the high gamma-ray activity at 17.7 m (58 ft) is from ^{137}Cs . The time rate of decay (30.2 years) of ^{137}Cs is shown on the plot as a narrow-line. Some spread between the rate of decay line and the measured activity is expected from the counting statistics of the borehole surveys. The counting statistics of the Dry Well surveillance logs were computed but were not presented in this report. The variations observed are greater than counting statistics.

The source of the large variation and the net-contamination area are probably variations from the logging equipment, which can easily encompass the spread observed in the data. Appendix A noted that there were several logging vehicles and that the detectors were subject to failures within the 20-year service time, which required replacing, at a minimum, the sodium-iodide crystal.

The conclusion, regardless of the uncertainty introduced from counting statistics and the variations within the measuring equipment, is that the contamination plume at 17.7 m (58 ft) in borehole 41-15-07 is not moving, is stable, and is decaying in place, at least within the system variance.

Figure 1. Analysis of Surveillance Logs from Borehole 41-15-07.

4.2 BOREHOLE 41-14-09

Vadose zone monitoring borehole 41-14-09 contains one interval of ^{137}Cs contamination at 19 m (62 ft), as identified from the HPGe survey, Figure 2. The activity measured by the surveillance logs had never exceeded 200 cps and had never been reported as a UO.

The ^{137}Cs decay line plotted with the grade thickness product indicates that the contamination plume at 18.9 (62 ft), while low in concentrations, is stable and is decaying in place.

These first two analyses demonstrate that the Dry Well surveillance logs can identify stable contamination plumes that are not moving and are decaying in place. A reduction of error (variance) may be possible with further work.

4.3 BOREHOLE 41-07-08

Borehole 41-07-08 contains one interval of ^{137}Cs contamination at 18 m (59 ft), by HPGe survey, Figure 3. The activity measured by the Dry Well surveillance logs has shown that the contamination level was continuously increasing from 1976 through at least 1986. Three UO reports have been written about this vadose zone monitoring borehole.

Occurrence Report 76-119 on August 31, 1976, had indicated that the measured gamma-ray activity at 18 m (59 ft) had increased from 54 cps on 7/22/75 to 312 cps on 8/31/75. The permanent corrective action was: "The leak volume appears well confined with mostly lateral movement. No corrective action indicated."

Occurrence report 76-163 on December 3, 1976, had reported a gradual increase in radiation that had doubled from 381 cps on 10/5/76 to 846 cps on 11/30/76. The permanent corrective action was: "the leak volume appears well confined, but is exhibiting slow lateral movement. No corrective action indicated."

Occurrence report 77-34 on March 2, 1977, had reported "a gradual increase in radiation meeting the action criteria by a doubling of a radiation peak..." The measured activity at 18 m (59 ft) had increased from 732 cps on 12/2/76 to 1643 cps on 3/2/77. The permanent corrective action of this third Occurrence Report was: "the leak volume appears well confined, but is exhibiting slow lateral movement. No corrective action indicated."

The annual surveys between 1983 and 1993 are indicating poor repeatability. The use of different logging trucks, probes, and electronic instrument settings each year is probably the cause of most of the scatter. Preliminary evaluation of other boreholes with annual surveys have similar scatter, which may correlate. Plans are to examine the log surveys for a correlation. If a correlation can be established for a day when multiple boreholes were logged with the same equipment then a correction can be applied.

The radiation levels in this borehole had continued to increase until 1986. The maximum activity at 18 m (59 ft) was 63,450 cps.

The surveillance logs since 1988 (especially since 1992) are showing a decrease in the net-contamination activity and the rate of decrease appears to be greater than the decay rate of ^{137}Cs .

Figure 2. Analysis of Surveillance Logs from Borehole 41-14-09.

Figure 3. Analysis of Surveillance Logs from Borehole 41-07-08.

The conclusion is that borehole 41-07-08 has shown a long-term and dynamic change in activity level with a significant increase from 1976 through 1986. The decrease that has been occurring since 1992 can not be completely explained as radioactive decay; continued monitoring should be performed at least quarterly (every 3 months).

4.4 BOREHOLE 41-00-08

Borehole 41-00-08 has two intervals of ^{137}Cs contamination (i.e., 19.5 and 22.6 m [64 and 74 ft]). The borehole, Figure 4, has been sealed with cement grout, which accounts for the elevated background activity. The 1975 survey log shows only one contamination interval at 22.6 m (74 ft). While the 1993 survey shows two contamination intervals, the new interval is located at 19.5 (64 ft). The activity at 22.6 m (74 ft) that was measured by the Dry Well surveillance logs is stable and is decaying in place.

The new contaminant interval at 19.5 m (64 ft) in 41-00-08 has a maximum peak activity of about 200 cps, but has been increasing steadily since about 1984. The surveys since 1992 may indicate that this contamination is becoming stable because the rate of increase apparently is decreasing.

The conclusion is that borehole 41-00-08 has shown an active contamination interval that should be monitored at least quarterly until stability can be demonstrated.

4.5 BOREHOLE 41-11-10

Vadose zone monitoring of borehole 41-11-10 identifies three zones of ^{137}Cs contamination, Figure 5. The moderate sensitivity logs obtained using the Green-GM (Geiger-Mueller) probe from Dry Well surveillance logs are analyzed for this borehole. The 1979 survey shows two contamination intervals. The highest activity interval occurs at 20.7 m (68 ft) and a low activity interval at 23.5 m (77 ft).

The grade thickness product of the contamination plume at 23.5 m (77 ft) indicates that the ^{137}Cs is stable and decaying in place. The peak at 23.5 m (77 ft) is plotted on a scale of 200 cps. However, the grade thickness product for the dominant contamination plume at 20.7 m (68 ft) does not fit the ^{137}Cs decay line, indicating that some small amount of contaminant is being introduced. The plot scale at 20.7 m (68 ft) is 0 to 60,000 cps. The average background activity is not included on the plot, however, the background activity supports the position that the change is not from a system change.

The 1994 survey identified a third zone of the contamination at 25 m (82 ft) that is now the second highest concentration of ^{137}Cs in this monitoring borehole. The plot of the grade thickness product indicates that 1984 was the year when the contaminant was first detected at the borehole. The rate of change since 1993 appears to be accelerating. The increase in contamination at 25 m (82 ft) is not coming down the borehole from 20.7 m (68 ft) or from 23.5 m (77 ft). The contamination is from lateral movement.

The conclusion is that borehole 41-11-10 has a zone of rapidly increasing activity and must be monitored at least quarterly.

Figure 4. Analysis of Surveillance Logs from Borehole 41-00-08.

Figure 5. Analysis of Surveillance Logs from Borehole 41-11-10.

4.6 BOREHOLE 41-09-09

Borehole 41-09-09 was identified in DOE 1995b with an active contaminant zone, Figure 6. There was one zone of contamination at 19.5 m (64 ft) in 1975. The 1994 survey log shows a very high contamination zone at 22.6 m (74 ft). The activity that was recorded at 22.6 m (74 ft) of 80,000 cps is the highest sodium-iodide count rate analyzed in this report.

The ^{137}Cs at 22.6 m (74 ft) has been increasing since 1984. This is the third borehole that has identified 1984 as the year when a contamination plume was first identified. The rate of increase appears to be lower since 1990. However, the change in the rate may be the result of electronic dead-time that has not been corrected.

The contamination zone at 19.5 m (64 ft) shows a stable contaminant zone that is decaying in place, through 1987. The deviation from the ^{137}Cs decay line after 1987 is likely due to an increase in measured activity at 22.6 m (74 ft), which is potentially impacting the calculation of the grade thickness product by preventing the lower portion of the gamma-ray peak from returning to the background counting activity.

The conclusion is that borehole 41-09-09 has a zone of rapidly increasing activity that must be monitored at least quarterly.

4.7 BOREHOLE 41-02-02

Vadose zone monitoring borehole 41-02-02 has been monitored weekly since 1975, Figure 7. Between 1975 and 1982 one zone of contamination was identified by each of the Dry Well surveillance logs at 14.6 m (48 ft). At the time of this report, the surveys between 1982 and 1984 have not been converted successfully to the new computer format, creating a data gap. The surveys from 1984 through 1995 show the contamination at two intervals instead of one, 14.6 and 15.5 m (48 and 51 ft). During the data gap interval, the contamination plume had changed from a single peak to a double peak.

The plot of the grade thickness product indicates that the ^{137}Cs plume is not stable and has been slowly increasing, even though the maximum measured activity is less than 200 cps and no UO report has been issued. The surveillance logs since 1993 have been decreasing, and may be indicating a change in the subsurface conditions.

The conclusion is that borehole 41-02-02 should be monitored quarterly to establish the condition of the vadose zone contamination. If the contamination is stable and is not moving, the monitoring can be decreased to annual.

Figure 6. Analysis of Surveillance Logs from Borehole 41-09-09.

Figure 7. Analysis of Surveillance Logs from Borehole 41-02-02.

4.8 BOREHOLE 41-10-01

Borehole 41-10-01 contains one zone of ^{137}Cs contamination at 20.7 (68 ft) with low concentrations, Figure 8. The Dry Well surveillance logs have remained well below the 200 cps action level. The grade thickness product of the 254 surveys indicates that a possible increase in activity level has been occurring since 1984. The statistical uncertainty of the measured activity is high, however, the increasing trend is outside of 1 sigma, but less than 2 sigma.

Evidence of contaminant movement is subject to further study. Therefore, it is recommended that borehole 41-10-01 should be monitored quarterly to establish the condition in the vadose zone. If the contamination is stable and not moving the monitoring can be decreased to annual.

4.9 BOREHOLE 41-04-03

Vadose zone monitoring borehole 41-04-03 contains one zone of high gamma-ray activity at 6.1 m (20 ft), Figure 9. The high gamma-ray activity is from pipeline(s) that are relatively close and were used to transport waste to the underground storage tanks. The borehole surveys between 1975 and 1995 are unusual for a pipeline because they are showing a continuous decrease, not erratic changes as would be expected from a pipe that carries high-level radioactive waste. However, the tanks have received no waste since the 1960's.

There is an 18 month gap in the historical survey data that has not been located on the archival storage tapes. The high survey frequency overflowed the data base before the data was archived.

Because of the unusual rate of decrease in the historic surveys the data is presented in this report. There is a significant decrease from 3600 to 1200 cps of the computed grade thickness product from the Dry Well surveillance logs between 1975 and 1995. The rate of decrease is about 200% greater than what can be explained as the decay of ^{137}Cs . The ^{137}Cs decay line is not plotted.

The HPGe survey (DOE 1995a) of this borehole had measured three anthropogenic radionuclides at low concentration levels. The radionuclides and approximate concentration levels are: ^{137}Cs at 5 pCi/g, ^{154}Eu at 2.7 pCi/g, and ^{60}Co at 0.3 pCi/g.

The change with time of the grade thickness product of the Dry Well surveillance logs between 1975 and 1995 was evaluated by an outside expert (Appendix D). The outside expert was not told that the contamination zone was from a pipeline.

The stability of the instrumentation was evaluated for systematic and random errors. A root mean square of consecutive surveys was calculated and analyzed for validity. A decay projection, consistent with the measured radionuclides, was fit to the decreasing peak area.

The conclusion of the analysis of the 41-04-03 Dry Well surveillance logs was that there are strong indications that some portion of the radionuclides are moving. It is recommended that borehole 41-04-03 should be monitored quarterly.

Figure 8. Analysis of Surveillance Logs from Borehole 41-10-01.

Figure 9. Analysis of Surveillance Logs from Borehole 41-04-03.

4.10 BOREHOLE 41-10-08

Vadose zone monitoring borehole 41-10-08, Figure 10, was identified in an occurrence report (75-04 on 1/7/75) with "a rise in radiation levels at the 16.2 to 17.4 m (53 to 57) foot depth." The peak readings shown in the occurrence report had indicated that the activity increased rapidly from 53 cps on 9/25/74 to a maximum of 328 cps on 11/26/74. Between the maximum reading and the date of the occurrence report, several weekly surveys showed an apparent decrease in peak activity.

This borehole was selected for analysis based on the occurrence report.

The rate of decrease in the grade thickness product during 1975 had indicated that the radionuclide was characteristic of the 368-day half life of ^{106}Ru . However, the rate of change had appeared to be accelerated during 1976, prompting concern. The change at 16.6 m (54 ft) in borehole 41-10-08 was evaluated by an outside expert (Appendix E).

The evaluation (Figure 11) confirmed that the decrease in measured activity for the 12 months of 1975 was from radioactive decay of ^{106}Ru . However, during the first half of 1976 the activity consistently had decreased, by a factor of 75%, which is much faster than radioactive decay. After the abrupt decline in 1976, the rate of decrease again had returned to the 368 day half-life of ^{106}Ru . The high logging frequency made it possible to capture the rapid changes that were occurring in the subsurface. An annual survey would have missed this event.

The conclusion is that between October and December of 1974 the leading edge of a contamination plume containing ^{106}Ru intersected borehole 41-10-08 between 15.2 and 18.3 m (50 and 60 ft). The concentration of ^{106}Ru in the plume was constant as it migrated past the borehole and the radioactive decay was observed. Then, between January and June of 1976, the trailing edge of the plume migrated beyond the monitoring range of the borehole. The residual radionuclide present in the formation (after June 1976) from the plume had continued to decay to non-detectable levels.

The radioactive plume that intersected this borehole was moving laterally and not vertically through the formation at this location.

Figure 10. Analysis of Surveillance Logs from Borehole 41-10-08.

Figure 11. Filtered Data from Borehole 41-10-08 Compared to Ru-106 Decay.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Three conclusions of the Tank Farms Dry Well surveillance logs evaluation are as follows:

- Historical Tank Farms surveillance logs are useful. Activities to convert the log data from the obsolete computer format to a current architecture are justifiable.
- Changes in borehole gamma-ray intensities in the vadose zone around the SX Tank Farms do exist and continued borehole geophysical monitoring is necessary.
- The geologic strata around the Tank Farms are influencing contaminant transport and further review is necessary.

Two recommendations that derived from the Tank Farms Dry Well surveillance logs evaluation are as follows:

- The historic surveillance logs of all the single-shell Tank Farm boreholes should be reviewed for indications of dynamic radioactive plume conditions.
- The historic surveillance logs that were acquired prior to 1975 should be retrieved from storage for all Tank Farms wells that indicate dynamic subsurface conditions. They may assist in identifying the event or events that had introduced the contaminants in the vadose zone.

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APPENDIX A

TANK FARM DRY WELL SURVEILLANCE LOGGING PROGRAM SUMMARY

The Dry Well surveillance logging activity for detecting leaks from the single-shell underground storage tanks began operation in 1975. The monitoring program is summarized in Table A-1.

Table A-1. Dry Well Surveillance Logging Activity Summary (sheet 1 of 3).	
Number of Tank Farms	12
Total number of single-shell tanks	149
Number of monitoring boreholes (Dry Wells)	780 appx
Monitoring frequency	varied from weekly to annually; depended on tank status and monitoring requirements
Number of monitoring trucks	1975-1981 (pickup truck units, manual operation, output to punched paper tape) 1981-1995 (5 logging vans with computer control)
Monitoring probe types used	1 - Red Geiger-Mueller (heavily shielded) Gross Gamma (Very High Gamma) 2 - Green Geiger-Mueller Gross Gamma (High Gamma) 3 - Moisture (neutron source, single close-spaced thermal neutron detector) 4 - Sodium-Iodide Gross Gamma (Low Gamma Activity) 14 - Lead Shield added to Sodium-Iodide (Moderate Gamma Activity)
Logging Speed	13.7 m (45 ft) per minute
Sample Interval	30 cm (1 foot)
Logging Sample Time	1 second per sample interval
Borehole Identification	Borehole identification entered as 6 digit number on thumb wheels. (Tank Farm, Tank, Hole Location)
Equipment Identification	Probe type entered as 2 digit number on thumb wheels. Truck number and probe serial number not recorded.
Down-hole detector electronics, Logging cable, and Truck mounted electronics	<ul style="list-style-type: none"> Electrical power to the down-hole detector assembly was supplied through the single conductor logging cable. The detector pulses were transmitted back up the logging cable by capacitance coupling. The truck mounted electronics analog style. Counts analog pulses from detector for input to micro-computer

Table A-1. Dry Well Surveillance Logging Activity Summary (sheet 2 of 3).

Electronics Adjustments	<ul style="list-style-type: none"> • The truck mounted electronics was adjusted each time the logging probe was changed or repaired. • Adjustments were made to the amplifier gain and lower level discriminator to provide optimum discrimination between electronic noise and detector signal pulses.
Log Acquisition Program logic (generalized)	<ul style="list-style-type: none"> • Operator enters Borehole ID by thumb wheels. • Operator enters Probe Type by thumb wheels. • Program retrieves maximum survey depth, logging speed, sample increment from internal table. • Operator positions probe adjacent to borehole, to zero the survey depth and sends signal to computer. • Operator positions probe over borehole to be logged and sends signal to computer. • Computer program lowers probe to specified depth, starts winch motor to retrieve probe at constant rate, starts detector counter then begins acquisition loop. • When depth increment crossed the program: (stops detector counter, reads the counts, stores counts in temporary memory area, clears the counter, restart the detector counter, reset the depth increment, and return to the program loop to wait for the next depth increment). • At end of survey, data is stored for later transfer to analysis data base.
Corrections	<ul style="list-style-type: none"> • Electronics selected to minimize detector dead-time. No corrections for pulse pile-up or electronics dead-time are applied. • Depth coefficient verified daily by lowering probe into the specified borehole of known depth until cable tension switch toggled. Error of less than 1 percent required to pass. Difference between actual and truck measured depth are not applied to the log surveys acquired for that day.

Table A-1. Dry Well Surveillance Logging Activity Summary (sheet 3 of 3).

Log Processing	<p>Analysis of the monitoring surveys include:</p> <ul style="list-style-type: none"> • Plot each survey at 20 ft/in with the count rate plotted on a 5-cycle logarithmic scale. • If the survey for a borehole is significantly different from the previous (e.g., wrong borehole or improper equipment settings or equipment failure) the borehole will be resurveyed. • Compare each survey with the designated baseline survey for indications of catastrophic tank failure. • If borehole survey has an interval of high gamma activity then record depth location and maximum activity. Up to 2 depth locations of gamma activity can be recorded and monitored. • Report UO when an interval of high gamma activity exceeds 200 counts/second and each time the activity doubles.
Operator Verification of Equipment Operation	There is no visual feed back to the operator for verifying proper equipment performance.

Processing the Dry Well survey logs can not be completely automated and requires an integration of manual (human judgement) and computer analysis. The most frequent problems are:

- The gamma activity an individual survey depth location is occasionally -1 or 0, which is considered as a data gap. The data gaps are not limited to background intervals and can occur within contamination intervals. The data gaps can not be ignored, especially within a contamination interval. The frequency of data gaps requires that a substitution value be provided.
- Depth errors between successive monitoring surveys can be identified in boreholes containing contamination intervals. The apparent depth of the maximum counting activity can vary by plus and minus 4 ft. In boreholes with multiple zones of contamination, the range (spread) between the computed gamma activity of successive logs can be minimized (improve precision) if the log surveys are normalized to a common depth and a fixed calculation window is used.

Significant depth errors are anticipated prior to 1986. Between 1981 and 1986 automated depth control was developed and refined.

Several possible causes of the depth errors include the following:

- There were multiple logging trucks with potentially different settings/adjustments to the cable and winch, and different amounts of lubrication. It is likely that the depth system on each truck would record less or more cable into the hole on a routine basis.
- Dirt in the optical encoder (depth measuring device) can cause sporadic errors.
- The encoder signal to noise level may cause erratic counting in field conditions or with temperature changes.
- An early depth trigger (tension switch toggle) can be created by the logging cable dragging across the top of casing when going into the hole to the bottom of the hole.
- A late depth trigger can be created by the cable spiraling around inside the hole after the tool touches bottom and the weight sensitivity switch is set too low.

APPENDIX B

CONSIDERATIONS OF GEOPHYSICAL LOGGING EQUIPMENT AND ANALYSIS

Development and operation of borehole geophysical logging equipment and analysis of the measurement data requires integration of several scientific disciplines. The first in situ borehole geophysical measurement instrumentation was developed about 50 years ago and has evolved into a wide array of detector types (not just gamma-ray detectors). Geophysical logging has proven invaluable in some applications (such as petroleum and mineral exploration) where the equipment has been designed and optimized for each specific environment and to the geophysical variables most amenable to measurement.

Use of borehole geophysical measurement instruments has not been universally accepted for every application for several reasons. The reasons for limited acceptance range from nonmeasurable properties, elevated detection thresholds, improper detector configurations, and cost. Adding to the guarded acceptance of borehole geophysical measurements is the constant presence of the "Murphy Principle: If anything can go wrong, IT WILL!". There are countless instances where people with good intentions have attempted to quickly make geophysical measurements only to find, after complete failure, that their design assumptions were opposite to the actual conditions (assuming there was an opportunity to investigate further). In many of these instances, the failed activity hindered future involvement of subsurface geophysics far more than no measurement at all.

A summary of the considerations of geophysical logging equipment and analysis is presented to show the complexity and potential pit-falls. This summary does not include all of the gamma-ray detector types and data interpretation considerations. The items of consideration demonstrate the difficulty of acquiring accurate and repeatable measurements.

Unfortunately, failures can occur even when all the considerations are addressed and the response from the equipment is repeatable. It is possible that the data are invalid because of unidentified variables or improperly defined characterization studies.

Fortunately, with proper diligence to equipment calibration and investigation of the subsurface conditions, it has been shown that valid, accurate, and precise geophysical measurements can be acquired.

DETECTOR FAILURE

Sodium-iodide is the best scintillation (light emitting) type of the gamma-ray detectors and was used to acquire the majority of the leak detection log surveys in the Tank Farms. The detector can be connected to electronics for collecting both spectral and gross gamma activity. These detectors are subject to several type of failures, both catastrophic and progressive with time. Six kinds of detector failure are discussed:

- The crystal is hygroscopic. If the hermetic seal is lost the crystal will absorb moisture from the air and be transformed into powder in a relatively short time. Loss of the detector signal is gradual during this transformation.

- The crystals are subject to fogging or yellowing from natural aging, which will generally occur within a few years. The loss of detector signal is gradual and may appear to be even slower (several years) if the detector is operated as a gross-gamma system.
- The optical coupling (special optical grease) between the detector and the photo multiplier tube can degrade with time from vaporization. Loss of the detector signal is gradual and may appear even slower if the detector is operated as a gross-gamma system.
- The crystals are subject to cracking from either percussion shock (dropping) or thermal shock (eg. lowering the detector into water in the winter time). The fractures are generally significant and cause substantial loss of count rate. This is the ideal type of failure where the loss of signal is instantaneous, significant, and indisputable.
- The crystals are subject to micro-fracturing that will cause loss of gamma-ray energy resolution, but may not significantly reduce the gross gamma counting activity. Loss of the detector signal may be gradual.
- The crystals will begin to self-scintillate when their temperature exceeds about 120°F. This condition is generally temporary and does not necessarily permanently damage the crystal.

DETECTOR ELECTRONICS

Two electronic components are required at the sodium-iodide scintillation detector. One component (usually, a photo-multiplier tube) converts the detectors light pulses to an electrical voltage signal. The second component is a signal pre-amplifier. Frequent problems with these components include:

- The photo-multiplier tube must be shielded against magnetic fields. If not properly shielded, the magnetic field fluctuations present within the steel casing in the borehole will cause significant signal gain changes.
- Detectors that are subject to very high rates of gamma-ray activity must have modified high-voltage power supplies to prevent signal loss in the high gamma-ray activity zones.
- The pre-amplifier must be matched with the input from the detector and output to the up-hole counting electronics. If gamma-ray spectra are being collected, the pre-amplifier must collect the full light output of detector to provide the best possible gamma-ray energy resolution. The pre-amplifier must not reduce the system count rate limit by stretching to the detector signal (i.e., increase the detectors dead-time). The pre-amplifier must be capable of driving the signal over the attached logging cable to the up-hole electronics without significant loss of counting capabilities.

SYSTEM CALIBRATION

The logging system must be characterized and calibrated as a unit to assure that the response is valid. Daily verification of equipment operation must be performed with the results compared to acceptance limits.

System characterization must include:

- Identify the electronic signal to noise ratio and set the counting electronics (gain and threshold discriminator) to minimize conflicts.
- Identify whether the counting system is paralyzable or non-paralyzable at high gamma-ray counting activities (this will provide a double check on the electronics dead-time measurements).
- Measure the electronics and detector dead-time and either set a maximum count rate limit or define a correction curve.
- If pulse pile-up rejection electronics are present then perform measurements to verify operation and the impact on the dead-time electronics.

The system calibration must be performed each time the equipment is repaired and when the equipment is unable to meet the limits of the daily verification checks. The calibration must also be performed at a frequency that is at least 1/4-th of the "mean-time-before-failure" of the most vulnerable component (i.e., the sodium-iodide crystal).

Characterization and periodic calibration of the depth measurement system must also be performed.

HANFORD BOREHOLE GEOPHYSICS CONCERNS

Several borehole construction related problems have been identified at the Hanford Site. The presence of these problems must be identified when analyzing borehole geophysical logs. Failure to identify these problems can lead to improper conclusion and create unwarranted concern, UO reporting, and special investigations.

Borehole related effects include:

- Movement of radioactive contaminants in the void space between the casing and formation. In recent past, liquid waste that was discharged to the subsurface had encountered unsealed wells and had traveled directly to the groundwater. Since untreated liquid discharges to the subsurface have been discontinued the potential for environmental impact has been significantly reduced.

Even though there is concern when active vertical movement is identified in the subsurface even in the void space behind the casing. There is substantially more concern when the movement is identified as wide-spread and within the formation, instead of movement that is localized along the borehole wall.

- Radioactive contaminants from the surface have been washed into the borehole casing and have rapidly traveled to the bottom of the borehole. This is most common when the top of the borehole is flush with the ground surface and large amounts of water are released from rapidly melting snow.

Radioactive contaminants that were washed inside the casing will be smeared the full borehole length and may have their highest concentration at the bottom of the borehole. A swab of the borehole can generally identify this problem.

- Radioactive contaminants present in the formation when the borehole was being drilled have been transported to lower depths by the drilling process. In these cases the contamination will appear to be deeper than its actual location and may be interpreted incorrectly.

APPENDIX C

SOFTWARE PROGRAM FOR EXAMINING DRY WELL SURVEILLANCE LOGS

The software program "TFGROSS" was written to assist in analyzing the historical Dry Well surveillance logs. The program can be directed to identify and correct problems with the recorded data values, as discussed in Appendix A. The program options and input parameters are summarized below. Input parameters are saved for each borehole and can be changed each time the program is executed. The input parameters are presented on one screen form, an example is shown in Figure C-1.

SURVEY FILE NAMES

Each Dry Well survey is recorded as a separate file. The file name identifies the logging probe number (01 - 14) and the survey date (yymmdd). Processing of the survey files by TFGROSS is controlled by a file containing the survey file names; "File Containing Names of LOG Surveys". The default control file name is "INP.TMP". Each record contains either a survey file name or a comment. Comment records are indicated by an asterisk "*" in the first column.

AUDIT TRAIL

The TFGROSS program can change data values within an individual survey file. A file containing an audit trail of the changes is created each time the program is executed. The default file name is "CHANGES.TXT".

COMPUTED RESULTS

Numerical values computed by the TFGROSS program are written to a sequential ASCII file with one record for each survey file processed. The default file name is "ANALYSIS.TXT". Each record contains the same number of values. They are:

- 1 Survey number (1 to n)
- 2 Survey date; year and fractional portion (yy.ddd)
- 3 Survey date; YYMMDD (taken from file name)
Following added when "Locate Contamination Zones" option set to "Y".
- 4 Number of data values in the log survey.
- 5 Percentage of log survey values that are below BKGMAX.
- 6 Average of the background portion of the survey (AVGBKG). Average of only the survey values that are less than or equal to BKGMAX.
- 7 One sigma uncertainty of the mean background value. Equation is: $\text{SQRT}(\text{AVGBKG})$.
Following added when "NET Contamination" depth value entered.
- 8 PK character flag to identify NET Contamination values follow.
- 9 Depth location of peak being computed.
- 10 Maximum survey value if auto search permitted, or the survey value at specified depth if auto search not permitted.
- 11 Width of SUM WINDOW (feet)
- 12 NET Contamination { $\text{SUM} - (\text{AVGBKG} * \text{Width_Sum_Window})$ }
- 13 One sigma uncertainty of NET Contamination. Equation is: $\text{SQRT}(\text{NET})$.

DATA GAPS

Two processing parameters control the replacement of data gaps in an individual Dry Well survey. The input parameters are:

"Replace Gaps in Data Values (Y/N): ____ Change Values <=: ____"

The program will replace survey data gaps only for probe type "04" at this time. Problems have been encountered for the 1=Green-GM and 2=Red-GM probe types.

If the program option is activated then each survey is scanned for values less than or equal to the change value (usually +1). When a bad value is located it is replaced by the mid point between the previous and following valid value $[(low + high) / 2]$.

The survey file is re-written to disk. A record is written to the Audit-Trail file containing:

"CHANGE-VAL,well,log-date,depth,old-val,new-val"

LOCATE CONTAMINATION

The objective of this program option is to show log surveys that are not consistent with the norm.

Three processing parameters control the output to an ASCII file that high-lights intervals within each survey of suspect or definite contamination (high gamma-ray activity). The input parameters are:

"Locate Contamination Zones (Y/N): ____ With Values > : ____ (BKGMAX)

"ASCII File Showing Contamination Zones : _____"

NOTE: The numerical value above indicates the upper limit of background gamma-ray activity and is used by other options in the TFGROSS program. The default background (BKGMAX) is 50 counts/second.

The output file (default file name: "HI-ZONES.TXT") contains one record for each Dry Well survey processed. The file is intended for visual inspection and is not formatted for automatic processing. Each record contains:

- 1 Survey number (1 to n).
- 2 Survey date; year and fractional portion (yy.ddd).
- 3 Survey date; YYMMDD (taken from file name).
- 4 Depth of the maximum count rate.
- 5 String of 75 characters (150-ft survey depth) with each character representing the maximum gamma activity for its corresponding 61 cm (2 foot) interval. The character will be either (space, period, or digit[1-9]). The digit represents the number of times the measured gamma-ray value is above the (BKGMAX). The equation is: $SQRT[(cps(i)-BKGMAX) / BKGMAX]$. If the computed value is positive but less than 1 then a period (.) is output. If the computed value exceeds 9 then it is reset to 9.

This program option also computes values that are added to the "ANALYSIS.TXT" output file. They are:

- 4 Number of data values in the log survey.
- 5 Percentage of log survey values that are below BKGMAX.
- 6 Average of the background portion of the survey (AVGBKG). Average of survey values that are less than or equal to BKGMAX.
- 7 One sigma uncertainty of the mean background value. Equation is: $\text{SQRT}(\text{AVGBKG})$.

DEPTH SHIFT

The depth location of an interval of high gamma-ray activity can vary by several feet from survey to survey. Normalizing the surveys to a constant depth by adding a constant to the depth values of a survey improves evaluation of the computed results. Three program parameters control the depth shift option. They are:

"Depth Align Contamination Peaks to Depth : ____
 "Mode: 1=Lead Edge, 0=Peak, -1=Trail Edge : ____
 "Peak Search; Depth Range (def=20 ft) ft : ____"

An entry of zero (0) for the "Depth Align Contamination Peaks to Depth" turns the option OFF.

The "Peak Search; Depth Range" parameter defines a search window width above and below the entered depth for locating the desired contamination peak. The total window width is twice the entered value.

There are three alignment modes. All modes are limited to survey values that exceed BKGMAX. The alignment modes are:

- 1 Leading Edge. The rate of change between current and previous depth values is monitored. The maximum rate of change is used to select the survey depth that will be reset to the desired depth. The option tracks only the first leading edge and will not accidentally select a higher rate of change from a lower contamination zone.
- 0 Peak. Selects the depth with the maximum survey value within the peak search window "Peak Search; Depth Range".
- 1 Trailing Edge. Selects the depth with the largest negative rate of change.

The depth shift amount is computed as a constant between the observed and desired depth. The depth shift is applied, the survey file is re-written to disk, and an AUDIT-TRAIL record is written that contains:

"Depth-Align, log-date, from: depth, to: depth, amt: xxx"

COMPUTE CONTAMINATION

Three program parameters control calculation of the net contamination in a survey. The parameters are:

- "Calculate NET Contamination at Depth : _____
- "Depth Samples in FIXED SUM WINDOW (0=Auto) _____
- "Peak Search; Depth Range (0=no search) : _____"

An entry of zero (0) for the "Calculate Net Contamination at Depth" will turn the option OFF.

The "Peak Search; Depth Range" option permits the program to search within the depth window (above and below the entered depth) for the maximum survey value. An entry of zero (0) turns off the search option. After the maximum survey value is located, the "SUM WINDOW" is established (1/2 above and 1/2 below) to integrate (i.e., sum) the survey count activity.

An entry of zero (0) for the "FIXED SUM WINDOW" permits the program to extend the integration (summation) until the survey gamma values fall below BKGMAX.

The "NET Contamination" is sum of the gamma-ray activity (fixed or automatic window width) minus the background activity ($AVGBKG \times \text{number of samples within the window}$).

The TFGROSS program adds the following values to the "ANALYSIS.TXT" record for each survey processed:

- 8 PK character flag to identify NET Contamination values follow.
- 9 Depth location of peak being computed.
- 10 Maximum survey value if auto search permitted, or survey value at specified depth if auto search not permitted.
- 11 Width of SUM WINDOW (feet)
- 12 NET Contamination [$SUM - (AVGBKG \times \text{Width_Sum_Window})$]
- 13 One sigma uncertainty of NET Contamination. Equation is: $SQRT (NET)$.

Figure C-1. TFGROSS Input Parameters.

TFGROSS: Analyze TANK-FARM Gross-Gamma Log Surveys
Program Rev 1.00 May 9,1996

File Containing Names of LOG Surveys : INP.TMP
 AUDIT-TRAIL File to Record Changes : CHANGESc.TXT
 Computed Results File Name : ANALYSIS.TXT

Replace Gaps in Data Values [Y/N]: Y Change Values <= : 1

Locate Contamination Zones [Y/N] : Y With Values > : 50
 ASCII File Showing Contamination Zones : HI-ZONES.TXT

Depth Align Contamination Peaks to Depth : 0
 Mode: 1=Lead Edge, 0=Peak, -1=Trail Edge : 0
 Peak Search; Depth Range (def=20 ft) ft : 0

Calculate NET Contamination at Depth : 64
 Depth Samples in FIXED SUM WINDOW (0=Auto) : 3
 Peak Search; Depth Range (0=no search) : 3

Debug [0=None 3=Max] NOT-USED : 0

F10=Run Program Esc=Abort Program

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APPENDIX D

SX 104-03 DRY WELL LOG DATA ANALYSIS

This report is analysis of surveillance logs from borehole 41-04-03. The name of the computer directory contains the data is SX-104-03. The report in this appendix uses the SX-104-03 notation.

This appendix is a self-contained report that has its own figures and appendix.

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SX 104-03 Dry Well Log Data Analysis

INTRODUCTION

Dry well logging has occurred at the tank farms over the last 20 plus years. The original goal of this data collection was the detection of leaks from the tanks. Analysis of this data in light of recent advances in comparison techniques can shed additional light on the movements of contaminants in the earth formations surrounding tanks used for waste storage. Use of recently implemented high resolution downhole spectroscopy instrumentation defines boundaries for extrapolation of observed movements projected into the past 20 years. This report will examine one well, SX 104-03, and determine the types of changes observed by the dry well logging data.

DRY WELL LOG DATA

The instrumentation used is scintalator gamma ray detection, and the collection system is a gross count collected approximately every 1 foot increment with in the depth of the well. Figure 1 shows one such log collected on March 11, 1975, for the SX 104-03 well. The counts observed in the contaminated zone centered at 20 ft reach a maximum reading of 1800 counts. The remainder of the log intervals are at background levels due to the naturally occurring potassium, uranium, and thorium found in the soils surrounding the borehole. These observed counts average 30 counts, a factor of 60 reduction over the highest reading found in the zone at 20 ft.

Subsequent log data were recorded in this well near a frequency of 1 week. The reproducibility of the depth points from log run to log run is not adequate for comparison of any given log to another. This problem is compounded by the coarse sampling every one foot. A thin zone will not necessarily be sampled for a given log run at the maximum reading for the interval of activity. The logging program did not have as a goal the fine sampling since only notification of gross changes were targeted. For these reasons, analyzing each log data set for the maximum observed reading is not as accurate as finding the zone grade value near 20 ft. Thus all the counts over this higher reading interval were summed for each log data measured. Over the course of the logging program of nearly 20 years, the depth reference was observed to drift as much as 3 ft. This change is most likely caused by errors in the absolute depth reference and not any movement of the contaminant in the earth surrounding the borehole. This will be illuminated when a decay structure is compared to the overall readings for the 20 years.

Comparison of this log data with the data collected March 25, 1975 for this same well, does not lead to any definite conclusions. The sampling accuracy in both time and depth result in statistical deviations that are much larger than any possible changes observed for this 14 day time lapse. However, analysis of each log run over the 20 year time frame can greatly improve the statistical precision of any definition of possible contaminant changes.

In addition to the sum of the counts over the interval of maximum reading, an average background level was obtained. This value was found by averaging counts for the entire well log data for all intervals with values below 50 counts. This background level is caused by the natural radioactive elements in the earth soils. These background levels only change on geologic time scales and can therefore be used to determine the instrument stability for the dry well logging program. In fact, these background readings can be used to "re-calibrate" or normalize different instruments to the same readings. However, this is outside the scope of the present investigation. It is sufficient for this data set to simply verify using these background readings that the instrumentation used on this well was stable and constant within statistical precision.

Data Analysis

Therefore, each log data were analyzed to produce two numbers for the date of each log. The counts in the observed contaminated zone were added throughout the interval of observation. Likewise, a single average background count was determined for the remainder of the log where the levels were below 50. Figure 2 contains this data set for the time from Jan 29, 1975 until Nov 22, 1995. Dry well log data from 1982 to 1985 were not made available for this analysis. Note that the background count rate is plotted on the second axis on the right and is significantly lower than the contaminant zone count rate. This data has not been corrected for any isotope decay, but simply shown as observed. The reasonable consistency of the background levels speak well for the instrumentation stability over this 20 year period, and several versions of instruments were used to collect the data. In fact, most of the observed scatter is due to instrument variances and not just statistical variances due to counting statistics. Any error analysis of a data set includes counting statistics and instrument variances. The total observed variances is the precision of the data or entire system, and this number is the error that is used to analyze the data.

The logging frequency for this well is on the order of once per week. As can be seen in fig 2, the changes in the contaminant zone count rate is slow compared to this logging frequency. This enables the measurement of the observed variances by performing a simple root mean square, rms, over every 5 consecutive log data sets. An rms value is computed every two log reading before and after the reading of interest. These five values produce the rms or an observed standard deviation. These data are plotted in fig 3. The observed total system variance starts near 190 counts in 1975 and reduces to about 90 in 1995. These variances correspond to relative errors of 5% to 7% for each individual contaminant reading in each log. Counting statistics only would yield a value of relative error near 2.5% to 3.5%. The higher observed relative error is consistent with added sources of error due to instrumentation. This same phenomena is also observed for the average background values. The line in fig 3 is a simple linear regression and has no physical meaning. It is shown only for reference.

Filtering the original data over this same five point running average is also possible and produces much less variation. The consistency and high frequency of the data allows this filtering with no loss of detail information.

If the radionuclide contaminant was not changing concentration in a given interval of a well, then, the observed count rate would decay exponentially to natural background levels. The last points have count rates well above natural background levels and therefore still contain significant levels of contaminant. A single exponential decay does not fit the data for this well. This fact is clear after a simple examination of the data on a semi-log plot; there are large systematic differences from a single exponential. The next step in analysis is to consider a two decay component condition. That is, the presence of two isotopes with different decay rates.

Two or more isotopes with different decay rates would yield a two component decay structure with time. Clearly, the faster decaying isotope would reduce faster eventually leaving only the slower component. All of these details depend upon the relative concentrations, and individual decay rates. However, two closely matched decay rates produce results with only one observable decay rate within statistical precision limits. Appendix A contains a description of such a case where Eu-154 and Co-60 would be present together yielding a single observed decay rate somewhat less than the inherent Eu-154 half life of 8.5 years and more than the Co-60 half life of 5.27 years.

Gross count rate data only will often yield data that cannot be used to determine the presence of a given isotope. If the system is very simple, i.e. a single isotope, and no change in concentration, then the observed data would yield a single exponential to a constant background. This case could be argued to delineate the isotope in question. The gross count rate data of this well over the past 20 years does not allow this type of conclusion.

Towards the end of 1995, a high resolution spectroscopy logging system was run in this well. This data can be used to tag the isotopes and their decay rates for a valid projection of the observed gross count rate back in time. The observation was Cs-137 at 5 pCi/g, Eu-154 at 2.7 pCi/g, and Co-60 at threshold reading of 0.3 pCi/g. The units here are in activity levels, therefore, the total gamma ray emission from the three isotopes can be approximated by the percentage of activity for each radionuclide. This yields nearly 5/8th Cs-137 contribution and 3/8th contribution from a combination of Eu-154 and Co-60. These two isotopes are grouped since they have similar decay rates. (Refer to Appendix A.) It is true that the absolute intensity of total gross count rate from equal activities of Co-60 and Cs-137 would produce different weighted fraction for the total observed gross count rate. Data analysis could be performed to assay these isotopes to gross calibration efficiency factors, but is beyond the present scope of this work. Since the conclusion drawn here does not significantly depend upon the precise percentage of each contribution, these factors are adequate starting points for a least squares fit for activity decay. Simply fix the decay rates at the precise values determined from the high resolution spectroscopy and fit for the levels and relative mixtures that would generate the observed total count rate.

A natural first attempt to analyze data from this well would be to fit the observed gross count rate with two exponentials fixed at the observed levels at the end of 1995. Such a fit does not match the data within its variance. The conclusion is un-mistakable changes in isotope concentrations over the past 20 years. In fact, there appear to be increases in the contaminant concentrations as recently as 1990. Figure 5 contains this type of least squares fit compared to the filtered data. The solid line is the fitted sum of the two components, (one Cs-137 and the other is the effective combination of Eu-154 and Co-60). The dashed line is the Cs-137 component, and the dotted line is the other. Note the relative slow character of the Cs-137 over the combination Eu/Co component. This also represents a maximum possibility for the Cs-137 since the observable nearly reaches the Cs-137 both at the present time and in 1986. Most likely, the absolute level of Cs-137 is somewhat lower than shown here. It is clear that no combination of these two components can match the observed data within its statistical precision.

Note that the constant background was ignored in this fitting in order to simplify the math, since its effect on these large values is negligible. Also, no deadtime corrections were applied since this could not account for the relatively rapid changes observed. (It must also be noted that characterization of the dead time for the logging instruments is not known.) A dead time correction could only change the observed count rates in one direction, either to larger count rates or smaller count rates, but not both.

A least squares fit for a two component exponential structure does not yield an adequate fit within statistical precision. Since no reasonable fit results, concentration levels of one or more of the possible contaminants have changed beyond radioactive decay. Determining which isotope changed concentration is not uniquely possible. There are many possible combinations of changes that could produce the observed gross count rate with time. For example, it is possible that the Cs-137 contaminant was immobile for these 20 years, and the Eu-154 / Co-60 changed in accordance with the observed data. Under this scenario, we observe an increase in Eu-154/Co-60 near 1977. Subsequently, this combination isotope(s) significantly reduced somewhere between 1983 and 1986. Likewise, this combination contaminant has increased from 1986 to 1994, where a drop then occurs to the present. This oscillatory systematic deviation from the best two exponential fit rules out problems with lack of a dead time correction. Also, this count rate is not noticeable large for a significant dead time problem unless the instrumentation is very slow.

The data do not allow the conclusion that the Cs-137 contaminant did not move. However, if the scenario is played that Cs-137 concentration levels changed, then the relative amounts of Eu-154 and/or Co-60 changed even more than depicted above. Simply subtract the Cs-137 component line from the total gross count rate observed to see changes in any isotope over and above the Cs-137 that has remained constant.

The conclusion that contaminant concentration levels have changed over the past 20 years is not hindered by the gap in the data for the years 1982 to 1985. This data if added to the analysis might help determine the specifics of what changes have occurred over the past 20 years.

A more reasonable projection of activity into the past would be to fix the present close to the relative concentrations observed and project back and match only the levels at the very start of 1975. Then there would be observed a significant increase quickly in late 1975 with relative little change until some time after 1982. Then a significant increase is observed from 1986 until 1994, where contamination levels are presently continuing to decrease beyond simple radioactive decay.

PERSPECTIVE & CONCLUSIONS

The levels of contaminant concentration in this well are presently not very high, less than 10 pCi/g. Other zones in other wells in and out of the tank farms have shown many times this level of activity. The absolute levels of concentration is not as important as the fact that the levels are showing relatively rapid changes. The question is where is the contaminant coming from, what is the driver, and where is the contaminant going. Guessing that the Cs-137 is not changing in this well may prove to be invalid if near by well data and analysis show Cs-137 only and experiencing non decay changes in concentration. Such combination analysis of other wells would significantly add to the understanding of the processes occurring in the earth surrounding the tank(s).

The data taken by tank farms personnel in the dry wells can be used to ascertain level changes in concentration that dictate the vadose zone is not in a static state. As has been seen, the sensitivity of this data to concentration changes is excellent. The data simply requires analysis in light of the systematic changes that can occur in a quantitative description. Likewise, instrumentation errors can be present and yet not hinder analysis given correct analysis techniques that properly account for hardware deficiencies.

APPENDIX A "Two closely matched decay rate components"

Observation of radioactive decay is generally subject to gamma ray counting statistics. At some level of instrumentation and sampling time, two isotopes of different decay rates are indistinguishable from a single component of decay. One example of application to the Hanford Site is Eu-154 and Co-60, with inherent decay half lives of 8.5 and 5.27 years, respectively. High resolution spectroscopy could easily resolve these isotopes, but a gross gamma ray intensity system at poor statistical precision would not necessarily resolve these components on the basis of observed total count rate decay.

Consider a mixture of 1 part Eu-154 and 1/10 part Co-60; this happens to nearly match the condition observed in late 1995 by HPGe logging system in the dry well SX 104-03. A purely theoretical description of this hypothetical decay can be constructed by adding the two components. These summed values can then be fitted for a single exponential decay. The difference from a fitted single exponential can be compared to the true sum of the two components. Figure A1 is a plot of the results for a backward 20 years time frame. The intensity used for the Co-60 is 1000 and for the Eu-154 an intensity of 10,000, referenced to time zero. Figure A2 shows this same difference in percent of the 20 year activity levels. The average error is on the order of .025 of 1%. The fitted decay rate to the sum of these two components yields a half life (effective) of 8.4 years, somewhat less than the Eu-154 value of 8.5 years. However, it is clear that a single exponential is statistically indistinguishable from the sum of the two decay components over this 20 year time frame, for the instrumentation used to log this dry well. In the body of the document covering the SX 104-03, the quoted system observable relative variance was on the order of 5%.

This same conclusion is reached even if the two components have equal strength. Figure A3 is the result for this condition. Notice that the maximum observable error is 2/10 of 1%. In this case, the effective

fitted half life is 7.72 years, which is not a linear average of the two decay components. The sum of the two components is not a single exponential, but the deviation from a single exponential is 0.2% at the maximum value over the 20 year time period.

SX 104-03 Log Data Date: 3-11-75

Figure 1. Gross gamma ray data for dry well 104-03 of SX tank farm. The fine line is scaled 0 to 200 c/s, and the thick line is scaled 0 to 2000 c/s.

Well SX-104-03

Figure 2. Processed log data for each run from inception to present. Large points are the zone grade, and the small points are the average background readings.

Figure 3a. Total observed system error for the response due to the contaminated interval.

Figure 3b. Total observed system error for the response due to the natural background.

Figure 4. Filtered gross count rate on a running 5 point average.

Least Squares Fit

Figure 5. Least squares fit and components compared to contaminant interval gross count rate.

APPENDIX E

SX 110-08 DRY WELL LOG DATA ANALYSIS

This report is analysis of surveillance logs from borehole 41-10-08. The name of the computer directory contains the data is SX-110-08. The report in this appendix uses the SX-110-08 notation.

This appendix is a self-contained report that has its own figures.

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SX 110-08 Dry Well Log Data Analysis

INTRODUCTION

Dry well logging has occurred at the tank farms over the last 20 plus years. The original goal of this data collection was the detection of leaks from the tanks. Analysis of this data using recent advances in comparison techniques can shed additional light on the movements of contaminants in the earth formations surrounding tanks used for waste storage. This report will examine one well, SX 110-08, and determine the types of changes observed by the dry well logging data.

DRY WELL LOG DATA

The instrumentation used is scintillator gamma ray detection, and the collection system is a gross count collected approximately every 1 foot increment over the depth of this well. Figure 1 shows one such log collected in March 1975, for the SX 110-08 well. The counts observed in the contaminated zone located between 50 and 60 ft reach a maximum reading of 180 counts per second. The remainder of the log intervals are at background levels due to the naturally occurring potassium, uranium, and thorium found in the soils surrounding the borehole. These observed counts average 30 counts, a factor of 6 reduction over the highest reading found in the zone at 55 ft.

Analysis of these log data must reconcile the level of technology existing for the instrumentation. There are several sources of error. Depth control is dependent upon both the human setting of the reference or zero point as well as the mechanical accuracy of depth encoding. Poor sampling frequency in sample time and depth resolution affect the observable variance in any readings. The log data were collected for 1 sec at each 1 foot depth point.

The combination of poor depth control or absolute accuracy with gross changes in depth are particularly troublesome for analyzing thin zones. Thicker zones with detail structure will also appear to vary significantly from one log to another, even if the radionuclides are not changing in the earth formations. For these reasons, the use of the maximum reading in a well log is not as precise as adding the observed readings for an interval determined to contain gamma emitting contaminants. This zone averaging then produces a more repeatable total than a shifting high point that may have been jumped over by a 1 foot increment in sample point.

The series of logs run for this well were examined and found to not demonstrate any appreciable broadening or indications of downward contaminant migration. The system precision does not rule out small changes in depth profile of the contaminant. As will be seen, there is definite indications that the concentrations did significantly change beyond natural decay. Therefore, the most probable conclusion is that the contaminant moved laterally away from the borehole.

Each dry well log was processed to produce two values used in this investigation. First, the sum of the count rates over the interval centered at 55 ft. was recorded as a function of the log date. Second, the average background value for the remainder of the log was recorded for the log date. The average reading was determined by summing all intervals where the values did not exceed 50 c/s and dividing by the number of readings used for this sum.

The value of the background reading is crucial for the assessment of the stability of the instrumentation used to collect the data. The dry well logging program used several different instruments. If any given instrument was more efficient than another, then, the observed background would also demonstrate this difference. Instrument drift in the effective energy threshold for the gross count rate would also be evidenced by changes in the observed natural background. It may even be possible to adjust the readings

in the contaminated interval by normalizing to the average background for any given log as a method to "re-calibrate" the instrument or instruments for their different efficiency. However, this processing is beyond the scope of work for this investigation. The background reading is simply used here to determine that the data is stable and useful for time decay analysis.

Subsequent log data were recorded in this well near a frequency of 1 week until 1979 were the frequency was reduced. The reproducibility of the depth points from log run to log run is not adequate for comparison of any given log to another. The logging program did not have as a goal the fine sampling since only notification of gross changes were targeted. However, the high frequency of logging does allow for reasonable time decay structure.

Error Analysis

Figure 2 contains the summed count rate over the contaminated interval at 55 ft plotted as a function of the log date from Jan 15, 1975 until Jun 10, 1994. Note that the background count rate is plotted using the second axis on the right and is scaled lower than the contaminant zone count rate. This data has not been corrected for any isotope decay, but simply shown as observed. The reasonable consistency of the background levels speak well for the instrumentation stability over this 20 year period, and several versions of instruments were used to collect the data. In fact, most of the observed scatter is due to instrument variances and not just statistical variances due to counting statistics. The error analysis includes counting statistics and instrument variances. The total observed variances is the precision of the data or entire system, and this number is used to assess the data.

It is possible to measure the total system precision since the logs were run so often. A rapid one year half life would result in a 1.3% drop in gamma activity over a time lapse of one week. If the system variance is larger than this systematic decline, then, three subsequent log readings can be considered as three repeat values of the same condition. Therefore, a root mean square of each reading using the previous and the future values was calculated. This data is shown in figure 3a. Likewise, the relative variance is plotted using the second axis scaled in %. The observed relative variance for the log data for this dry well program is then near 5% for the first year and rises to a value between 35% and 40% for the remainder of the program. This will become important when the detailed decay structure analysis is brought out. The 35% to 40% variance is reasonable for the last 19 years, since the activity levels are near background levels and there is very little signal.

Figure 3b contains a similar calculation of the observed variance for the average background processed for each log data set. Here, the variance is relatively stable at 4%. The error is much smaller since most of the log depth intervals are used in the computation of the average background; where as, only a few points are used for the summed gross in the interval initially tagged as contaminated. After the fifth year of logging, (1980), there exists a decline in the observed background of about 10%. This change is of no real consequence since the activity has dropped to background levels and no other activity in this earth zone is observed.

Decay Structure Analysis

The changes in count rate for the contaminated interval is relatively rapid. Figure 4 is a plot of the same data shown in figure 2, but only for an eight year time span. It appears that the intensity levels starting in 1975 drops to nearly 1/2 after one year. Speculation is therefore that the contaminant is Ru-106 with a half life of 368 days. The next step in analyzing this well is to examine the gross count rate on a semi-log plot. This investigation then reveals that there is not a single exponential. Figure 5 is a plot of the data on a semi-log scale, as well as several exponential decay structures down to a background level.

The rapid drop in count rate of the contaminated interval of this well that occurs from the start of 1976 to 6 months later is not the signature of a two components decay structure. A two component decay structure is concave upwards, asymptotically reaching a constant on such a plot as shown in figure 5. Regardless of the exact identification of the isotopes, this behavior of count rate with time is the signature of concentration changes other than natural radioactive decay. Therefore, other analysis techniques must be employed in order to determine what events occurred in the earth formations surrounding the borehole.

Ru-106 is known to be one of the contaminants released to waste sites and held in tanks. Few other isotopes of known existence at Hanford are close to the 1 year half life of Ru-106. Proceeding on the basis that the observed count rate is due to Ru-106 yields the different decay structures shown in figure 5. Given this half life, then, only intensity is a variable and statements can be made concerning the changes in concentration. The solid line at the bottom is a least squares fit to the constant background after 1983. The other three decay curves are at the 1 year half life, but at different starting intensities.

A least squares fit for an exponential plus a background was performed for the data starting 7 months after 1976 to 1985. The resulting decay rate for this fit is a 0.91 year half life, very close to the expected 368 day half life of Ru-106. System variance could account for the difference from the fit value of half life. It must be remembered that the observed activity for this period is close to background levels.

Since the change of count rate with log date is not a two exponential (or more) system, the assumption of Ru-106 is strengthened. For this reason, a fixed 1 year half life decay structure is called for and demands changes in concentration. Following this approach, a one year half life decay is plotted in figure 5 in order to fit the observed data for the 1st year of the logging program. It is not possible to obtain a good fit over just this first year, and thus, two different levels of Ru-106 are indicated even for the first year of operation for this well. In fact, if a least squares fit is performed for the data over only this year, the resultant decay rate is 0.73 year half life. The logging program relative error measured for this time interval is 5%. On this basis, it is clear that either 1) the isotope existing at 55 ft in 1975 is not Ru-106 or 2) Ru-106 concentration levels are changing during 1975.

High resolution spectroscopy log data on this well does not exist during the years that are of use. Present log data collection would not yield any valuable information, since the activity has dropped to background levels. Basically, there are limitations to information from only gross gamma logging data. However, there are pieces of information that is possible using the available data. Namely, there was a significant concentration of gamma emitting contaminant in the depth interval at 55 ft during the first half of 1976.

PERSPECTIVE & CONCLUSIONS

The levels of contaminant concentration in this well are presently at background levels. The most significant fact is that the levels are showing relatively rapid changes. The question is where did the contaminant come from, what is the driver, and where did the contaminant go. Analyzing data from other wells might help to shed some light on the mechanisms occurring in the vadose zone in and around the SX tank farm. Such combination analysis of other wells would significantly add to the understanding of the processes occurring in the earth surrounding the tank(s). Likewise, use of later state of the art high resolution spectroscopy logging instrumentation would lead to less speculation and more definitive conclusions.

The decay rate of Ru-106 is rapid and therefore no recent detection is expected. The last 12 years did not experience any changes in isotopes. However, this does not mean that the earth formations have not experienced migrations driver, but that the isotope has decayed to levels that are undetectable. It is significant that during the time that Ru-106 was visible that concentration levels were seen to change. This is a relatively short time window to view changes, and yet they were viewed. Sampling only over a short time and viewing changes statistically leads to the conclusion that changes are probable.

The data taken by tank farms personnel in the dry wells can be used to ascertain level changes in concentration that dictate the vadose zone is not in a static state. As has been seen, the sensitivity of this data to concentration changes is excellent. The data simply requires analysis in light of the systematic changes that can occur in a quantitative description. Likewise, instrumentation errors can be present and yet not hinder analysis given correct analysis techniques that properly account for hardware deficiencies.

Figure 1. Dry well log data collected in March 1975

Well SX-110-08

Fig 2

Figure 3b. Measured system error for average background of entire well.

Figure 3a. Measured system error for contaminated interval

Well SX-110-08

Fig 4.

Figure 5. Filtered data compared to several decay structures and a constant background.

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