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Hanford Tank Farms Vadose Zone

Addendum to the TY Tank Farm Report

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Executive Summary

In 1994, the U.S. Department of Energy (DOE) Richland Operations Office (DOE-RL) requested the DOE Grand Junction Office (GJO), Grand Junction, Colorado, to perform a baseline characterization of gamma-emitting radionuclides in the vadose zone at all Hanford single-shell tank (SST) farms using high resolution spectral gamma-ray logging methods in existing boreholes surrounding the tanks. In 1998, Congress established the Office of River Protection (ORP) at Hanford, an autonomous organization that reports directly to DOE Headquarters. ORP is responsible for managing all aspects of the Tank Waste Remediation System (TWRS) project, including characterization of the vadose zone potentially impacted by the SSTs. The responsibility for the baseline characterization project, originally under the auspices of DOE-RL, was transferred to ORP in December 1998.

The TY Tank Farm Report, which was prepared as part of this characterization project, was issued in January 1998 as document number GJO-97-30-TAR, GJO-HAN-16. The TY Tank Farm Report summarized the results of the spectral gamma logging at the TY Tank Farm that were originally reported in Tank Summary Data Reports for each individual tank and provided background information, a history of the farm, geology and hydrology reviews, and a description and review of adjacent waste sites. Data derived from logging existing boreholes in the TY Tank Farm were used to develop a three-dimensional model of the distribution of the contamination in the vadose zone.

Since the original report was issued, additional data have been collected and additional insights into the nature and distribution of contamination have been gained. The purpose of this addendum is to present these additional data and to provide revised visualizations of the subsurface contaminant distribution in the TY Tank Farm.

Additional data collected include spectral gamma logging using a high rate logging system (HRLS). This new system has been developed and deployed in the TY Tank Farm to measure cesium-137 (^{137}Cs) concentration levels in high gamma flux zones where the spectral gamma logging system was unable to collect usable data because of high dead times and detector saturation. This new system can measure ^{137}Cs concentrations up to about 100 million picocuries per gram (pCi/g). ^{137}Cs concentrations of more than 10^7 pCi/g were detected in one borehole (52-03-03) when logged with the HRLS.

On the basis of the evaluation of all new information and the work previously published in the TY Tank Farm Report, contaminated intervals judged to be localized to the borehole or otherwise non-representative of subsurface contamination were removed from the data set used to create the three-dimensional visualizations of subsurface contamination. As a result, the plumes depicted in the visualizations are more realistic than in the original report and have been used to provide a rough estimate of contaminant inventories. The visualizations in this addendum will also prove useful in directing future characterization work in the TY Tank Farm.

Since the TY Tank Farm Report was issued, repeat logging measurements were collected in selected borehole intervals approximately 3 years after the initial baseline data. In one borehole these measurements have indicated possible concentration increases that may be attributed to migration of contaminants through the vadose zone. Data analyses of historical gross gamma logging by Myers et al. (1999) indicate gamma count rate increases between 1975 and 1994 in one borehole. Repeat logging data suggest that contaminant migration may be occurring in the vicinity of one borehole near tank TY-106. However, the repeat logging was limited in scope and the gross gamma logging program was discontinued in 1994; no comprehensive vadose zone monitoring program currently exists.

This addendum completes the baseline characterization of the TY Tank Farm. The purpose of the characterization was to identify the nature and extent of contamination associated with gamma-emitting radionuclides in the TY Tank Farm using existing boreholes. The TY Tank Farm Report supplemented by this addendum serves as a baseline against which future measurements can be compared to identify changes in the vadose zone, track contaminant movement, and identify or verify future tank leaks. The visualizations represent a "snapshot" of the nature and extent of contamination associated with gamma-emitting radionuclides present in the vadose zone at the time of baseline logging. Baseline logging for the TY Tank Farm was performed in early- to mid-1996.

1.0 Introduction

The TY Tank Farm is located in the northwest portion of the 200 West Area of the Hanford Site and consists of six 758,000 gallon (gal) single-shell tanks (SSTs) (Figure 1). These tanks were constructed between 1951 and 1952 to store high-level radioactive waste generated during chemical processing of irradiated uranium reactor fuel. This waste was generated primarily at the T Plant, which is located about 2,400 feet (ft) northeast of the TY Tank Farm. Five of the six tanks in the TY Tank Farm are designated as "assumed leakers" (Hanlon 2000). A total volume of approximately 60,800 gal of liquid waste is estimated to have leaked from these tanks into the vadose zone sediments. Only tank TY-102 is currently classified as sound (Hanlon 2000). Gross gamma logging was discontinued in the leak detection boreholes in 1994 and leak detection monitoring has since been based on internal tank measurements.

In 1994, the U.S. Department of Energy (DOE) Richland Operations Office (DOE-RL) requested the DOE Grand Junction Office (GJO), Grand Junction, Colorado, to perform a baseline characterization of gamma-emitting radionuclides in the vadose zone at all Hanford SST farms using high resolution spectral gamma-ray logging methods in existing boreholes surrounding the tanks. DOE-GJO developed the Spectral Gamma Logging System (SGLS), which consists of a downhole sonde and surface support system (cable, winch, and electronic systems mounted in a custom-built truck). The downhole sonde contains a detector made from an n-type high purity germanium (HPGe) crystal with an approximate system efficiency of 35 percent. Using the SGLS, the baseline characterization of the TY Tank Farm was completed in 1996. The results of the geophysical logging and radionuclide concentration log plots for individual boreholes were compiled and presented in six individual Tank Summary Data Reports (DOE 1997a, 1997b, 1997c, 1997d, 1997e, and 1997f).

The TY Tank Farm Report was the sixth tank farm report to be completed by the Hanford Tank Farms Vadose Zone Project, and it was issued as document number GJO-97-30-TAR, GJO-HAN-16. Since it was completed, additional spectral gamma-ray logging was performed, and a high rate logging system (HRLS) was developed and deployed to collect data from borehole intervals where the SGLS detector was unable to collect data as a result of high gamma activity. Modifications to the TY Tank Farm Report and contaminant visualizations are warranted to address the additional data. This document will discuss those modifications and serves as an addendum to the original report.

1.1 Background

A compilation of all borehole data collected for the baseline characterization was presented in the TY Tank Farm Report issued in January 1998. Included within that report were three-dimensional visualizations of contaminant distribution in the vadose zone around the TY Tank Farm.

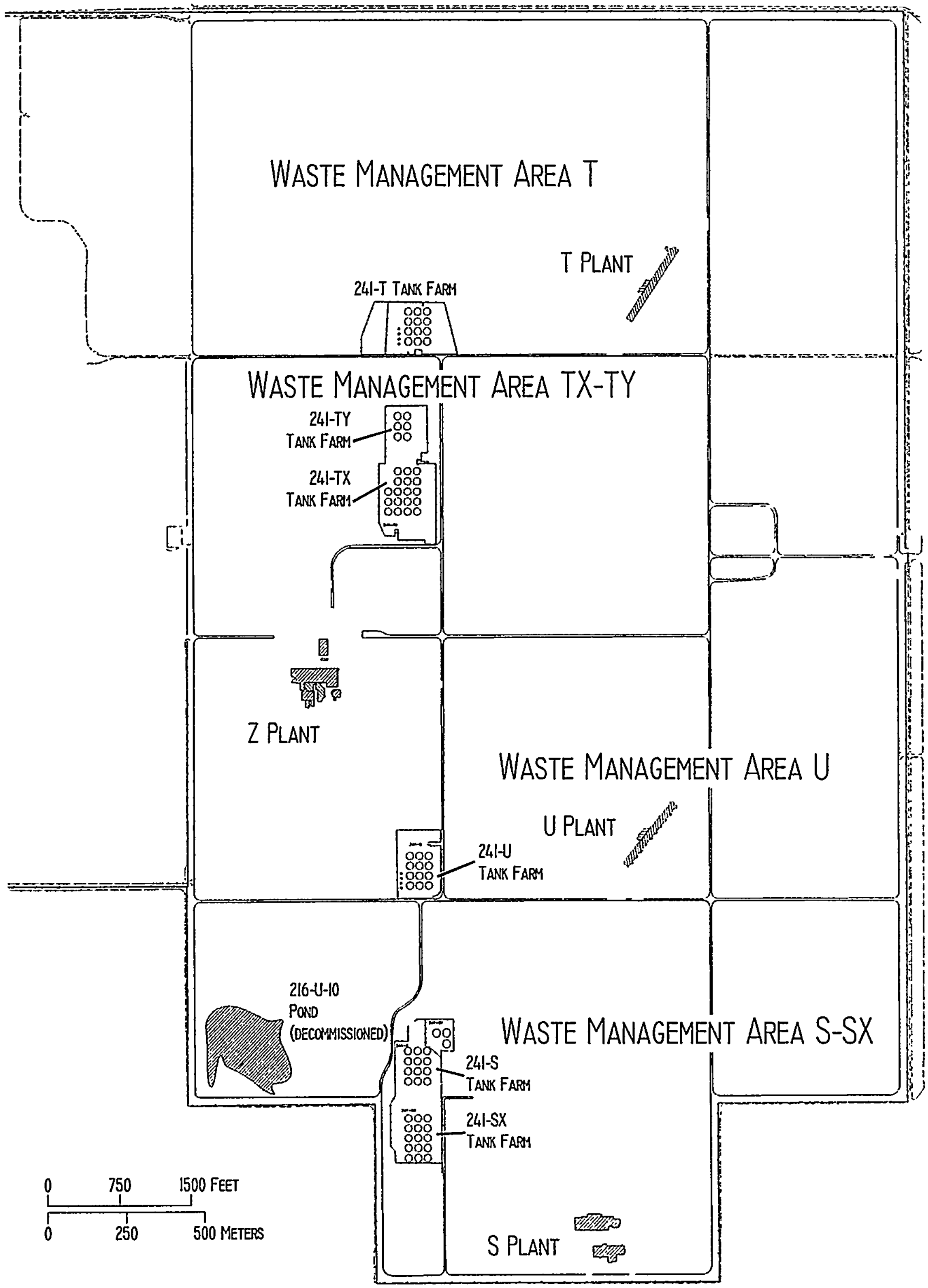

Figure 1. Map of the 200 West Area Showing the Location of the TY Tank Farm

RCRA groundwater monitoring at the T and TX/TY waste management areas (WMAs) moved from interim status detection monitoring to assessment monitoring in 1993 when specific conductance in downgradient wells 299-W10-17 and 299-W14-12 were exceeded. Specific conductance values in well 299-W10-17 have shown some variability, but have remained well above the critical mean established from four quarters of groundwater monitoring data from upgradient wells. Specific conductance values in well 299-W14-12 dropped significantly between 1993 and mid-1996, but they appear to have stabilized at values above the critical mean during late 1996 and 1997. Although not a direct indication of contamination, higher values of specific conductance appear to be associated with elevated activities of technetium-99 (^{99}Tc), tritium, iodine-129 (^{129}I), and cobalt-60 (^{60}Co). Results of a Phase I Groundwater Quality Assessment published in January 1998 suggest that elevated ^{99}Tc and associated co-contaminants (e.g. chromium, tritium, nitrate, ^{129}I, and ^{60}Co) are consistent with a small volume tank waste source within the TX/TY WMA (Hodges 1998).

Since the original TY Tank Farm Report was issued in 1998, additional data have been obtained and enhancements have been made in the spectral data evaluation process. In particular, shape factor analysis has allowed identification of intervals where contaminant dragdown is a dominant factor in boreholes using single, 6-inch (in.)-diameter casings. Additional spectral data have been collected from repeat logging of several selected borehole intervals. Finally, a High Rate Logging System (HRLS) has been developed to investigate intervals of high gamma flux where the SGLS was unable to collect usable spectral data.

1.2 Purpose and Scope

The purpose of this addendum is to present additional data that are relevant to the TY Tank Farm, and to provide revised visualizations of subsurface contamination that are based on re-evaluation of the original data sets, as well as incorporation of HRLS data. Tank farm conditions, operational history, current status, and geologic conditions are discussed in the original TY Tank Farm Report and relevant Tank Summary Data Reports, and will not be repeated in this addendum. The reader is referred to those documents for more detailed information.

Results of shape factor analysis, SGLS repeat logging, and HRLS logging are summarized in tables included in appendices to this report. Only SGLS repeat and HRLS log plots are included. Shape factor log plots were included in the tank farm report, and, in the interest of brevity, are not included with this addendum.

In general, the results of shape factor analysis and HRLS data have been incorporated into the interpreted data set used to create the visualizations. SGLS repeat logging data were not included. The primary justification for excluding repeat data is that only a small fraction of the total logging footage was re-logged. The purpose of the baseline characterization project is to provide a "snapshot" of the nature and extent of gamma-emitting contamination. To routinely insert these data would thus distort the original baseline. Contaminant plumes shown in the visualizations are based on the original baseline data, as modified by analysis results and professional judgment of the analyst, with HRLS results included in intervals where the SGLS data were unusable.

Areas of potential contaminant movement are identified on the basis of comparison of repeat logging data and original baseline data, as well as analysis of gross gamma data collected between 1975 and 1994. However, it is difficult to draw firm conclusions regarding recent contaminant movement because only limited repeat logging data are available and routine borehole monitoring was discontinued in 1994. An independent evaluation of historical tank farms gross gamma data collected between 1975 and 1994 was recently issued (Myers et al. 1999) and results of this study are included where appropriate.

2.0 Summary of Additional Data

Additional data presented in this addendum include HRLS logging and SGLS repeat logging. Also referenced in this addendum is work performed by Myers et al. (1999), which summarizes the historical gross gamma logging data for the TY Tank Farm. This analysis identifies areas of possible contaminant movement within the vadose zone during the time frame when the data were collected.

2.1 High Rate Logging System (HRLS)

During SGLS logging operations in the TY Tank Farm, one subsurface interval exhibited a very high field of gamma-ray flux, such that the SGLS detector became saturated, yielding no usable spectral data.

DOE-GJO developed a special downhole sonde capable of recording gamma-ray spectra while operating in intense gamma-ray fields. The detector is a 6-millimeter (mm) by 8-mm, n-type HPGe crystal with a very low relative efficiency. It can be operated with either of the SGLSs. This system is referred to as the HRLS. It is configured to provide useful results for radionuclide concentrations ranging from several thousand to about 100 million picocuries per gram. Information regarding this system is provided in a base calibration report (DOE 1999).

The HRLS operates normally in gamma-ray fluxes intense enough to "saturate" the SGLSs. Saturation refers to the circumstance in which the detector records spectra in which the peaks (full energy peaks) are tiny or even absent. This situation is an extreme manifestation of "pileup," that contributes to degradation of spectra (Knoll 1989). "Pulse pileup" occurs when the photon flux at the detector is so great that the probability is high that two or more photons will deposit their energies in the detector within a time interval that is short compared to the time resolution of the system. The electrical charge liberated by the several photons is then processed as if just one photon were involved. Pulse pileup events give output pulses with variable amplitudes because the amplitude of each output pulse depends on the total energy of the several captured photons that contribute to the pulse. The pulses with variable amplitudes add counts to the spectral background continuum, and the photons that participate in pileup are lost, in the sense that they contribute to the spectral background instead of a peak. Consequently, as pileup events increase in frequency, the spectral peaks become more and more obscure. Because peak counts are lost, the peak intensities are no longer proportional to the source concentrations.

Like the SGLSs, the HRLS is essentially nonparalyzable. "Nonparalyzable" and "paralyzable" describe system behavior during "dead periods" of data acquisition (Knoll 1989). In nonparalyzable systems, the deposition of photon energy in the detector is followed by a brief time interval, or dead period, of fixed duration, during which the output electrical pulse is being processed. The system is unresponsive to any additional photons that enter the detector during the dead period. If the gamma-ray flux is intense, a significant number of photons may enter the detector during dead periods, and are uncounted. Thus, the count rate rises as the gamma flux increases, but the count rate does not rise as rapidly as the flux. The count rate is non-linear in relation to flux, but linearity is imposed by applying the dead time correction to the recorded count rates (DOE 1995).

In a paralyzable system, of which certain of the old Hanford Geiger-Mueller-based monitoring systems are examples, the deposition of photon energy in the detector is followed by a dead period, but the duration of this period is lengthened if additional photons enter the detector during the dead period. Thus, on average, the dead periods grow longer as the gamma flux increases. A consequence is count rates from paralyzable systems may be ambiguous in high gamma-ray fluxes and may significantly underestimate contaminant concentrations.

Two tungsten shields, that can be used individually or in combination, are available to extend the range of the HRLS detector. One is a 0.31-in.-thick tungsten pipe sleeve, designated as the external shield, that fits over the sonde housing. The other is a 0.7-in.-thick tungsten "cup" designated as the internal shield, that fits over the high rate detector, filling the excess space inside the sonde normally occupied by the SGLS detector. By using the shields individually or in combination, the measurement range of the high rate detector can be extended from several thousand picocuries per gram without shielding to about 100 million pCi/g using maximum shielding.

The efficiency of the HRLS detector decreases rapidly with increasing gamma-ray energy, which is a consequence of the small size of the HPGe crystal. As a result, the HRLS is significantly more sensitive to ^{137}Cs relative to other radionuclides such as ^{60}Co or europium-152/154 ($^{152/154}Eu$).

The HRLS presented a particularly difficult calibration challenge. Construction of test zones with uniformly distributed gamma-emitting radionuclides at high activity levels is not practical, for reasons of personnel exposure, cost, long-term surveillance requirements, and disposal. Hence, the calibration had to be carried out using existing calibration models. As a result, the relative degree of uncertainty for measurements made with the high rate tool is significantly higher than the uncertainty in the SGLS data. The calibration is described in detail in the calibration report (DOE 1999).

For the SGLS, dead time, casing, and water corrections are computed by the analytical software and the output values are concentrations in picocuries per gram. However, it was not practical to collect data for determination of casing and water correction factors for the HRLS. Only a dead time correction is applied to high rate data by the analysis software. Depending on the borehole configuration and whether or not shields were used, it may be necessary to apply correction factors to the data after processing is completed.

Calibration measurements for the HRLS were made with a 0.28-in. steel sleeve in place over the sonde to simulate the effects of 6-in.-diameter schedule-40 casing, which is the most common borehole casing used in Hanford tank farm boreholes. HRLS data accurately reflect contaminant concentrations in unsaturated intervals with 6-in. schedule-40 casing. When other casing configurations are present, a correction factor must be applied. These correction factors were determined by calculating the attenuation for the assumed casing thickness relative to attenuation associated with a 0.28-in. thickness of steel. No water correction factor is available for HRLS spectral data.

When shields are used, an additional correction factor must be applied. Factors were determined for all three shield configurations (internal shield, external shield, and both shields) from field measurements of ^{137}Cs activity at 662 kilo-electron volts (keV). Shield correction factors for other energy levels can be determined by extrapolation of relative attenuation calculations.

^{137}Cs was the predominant radionuclide detected in the TY Tank Farm. All boreholes logged in the TY Tank Farm appear to have been constructed with either 6- or 8-in.-diameter schedule-40 casing. HRLS data correction factors for ^{137}Cs (662 keV) are provided in the following table:

Nuclide	6-in. Casing (0.280 in. thick)	8-in. Casing (0.322 in. thick)	Internal Shield	External Shield	Both Shields
^{137}Cs	1.000	1.06	27.42	3.758	96.40

2.2 Repeat Logging

Repeat logging using the SGLS is useful to evaluate possible contaminant movement over time by comparing concentration data. Analysis of historical gross gamma logging by Myers et al. (1999) has also proved useful for determining potential movement, particularly in zones of high gamma flux. A sufficient amount of time has not passed since the implementation of the HRLS to collect repeat data that would provide meaningful comparisons.

2.2.1 Spectral Gamma Logging System (SGLS)

Repeat logging was performed for selected borehole intervals in the TY Tank Farm using the SGLS. These boreholes were selected for repeat logging primarily to check for possible contaminant movement and to check for additional contaminants, specifically in intervals that exhibited elevated total gamma count rates in the absence of significant ^{137}Cs contamination. The repeat logging typically was performed with longer system counting times over limited depth intervals of interest. To provide for proper comparison of spectral log data between the original baseline and the repeat logging, baseline data were adjusted for decay then compared to the repeat logging results. To maintain consistency of the baseline data, repeat logging results were not included in the interpreted data set used in the development of the TY Tank Farm contaminant visualizations.

2.2.2 Historical Gross Gamma-Ray Logging

An independent analysis of historical gross gamma-ray data collected in the TY Tank Farm between 1975 and 1994 was recently completed (Myers et al. 1999). All historical log surveys for individual drywells (boreholes) were evaluated for each depth interval with elevated gross gamma count rates. Although data quality for individual records is poorly defined, comparison of a number of measurements over time allows observations to be made regarding the stability of a contaminant interval. Figure 2 shows the location of a single borehole where analysis indicated that historical gross gamma-ray data were unstable.

2.3 Shape Factor Analysis

Experience with SGLS logging results in the TY Tank Farm and elsewhere indicated that observed contamination in many depth intervals appeared to be localized to the borehole casing. One mechanism that might result in this phenomenon is "drag down" or contaminants adhering to the outside surface of the casing that are carried downward as the casing advances through a contaminated zone. Another possible mechanism is contaminant movement along the outside of the casing or in the annular void space between the casing and the surrounding formation. However, this type of movement is considered to be relatively unlikely because the physics of flow through the vadose zone require that the formation pore space be saturated before significant movement into the annular void space can occur. Localized contamination on the inside of the casing can occur when particulate contamination enters the well from the surface or during drilling. For purposes of this report, contamination local to the borehole casing is referred to as "borehole effects" regardless of the mechanism of deposition.

In addition to localized contamination, the SGLS may also detect gamma activity associated with a discrete source remote from the borehole, such as contaminants contained within a buried pipeline that passes close to the borehole.

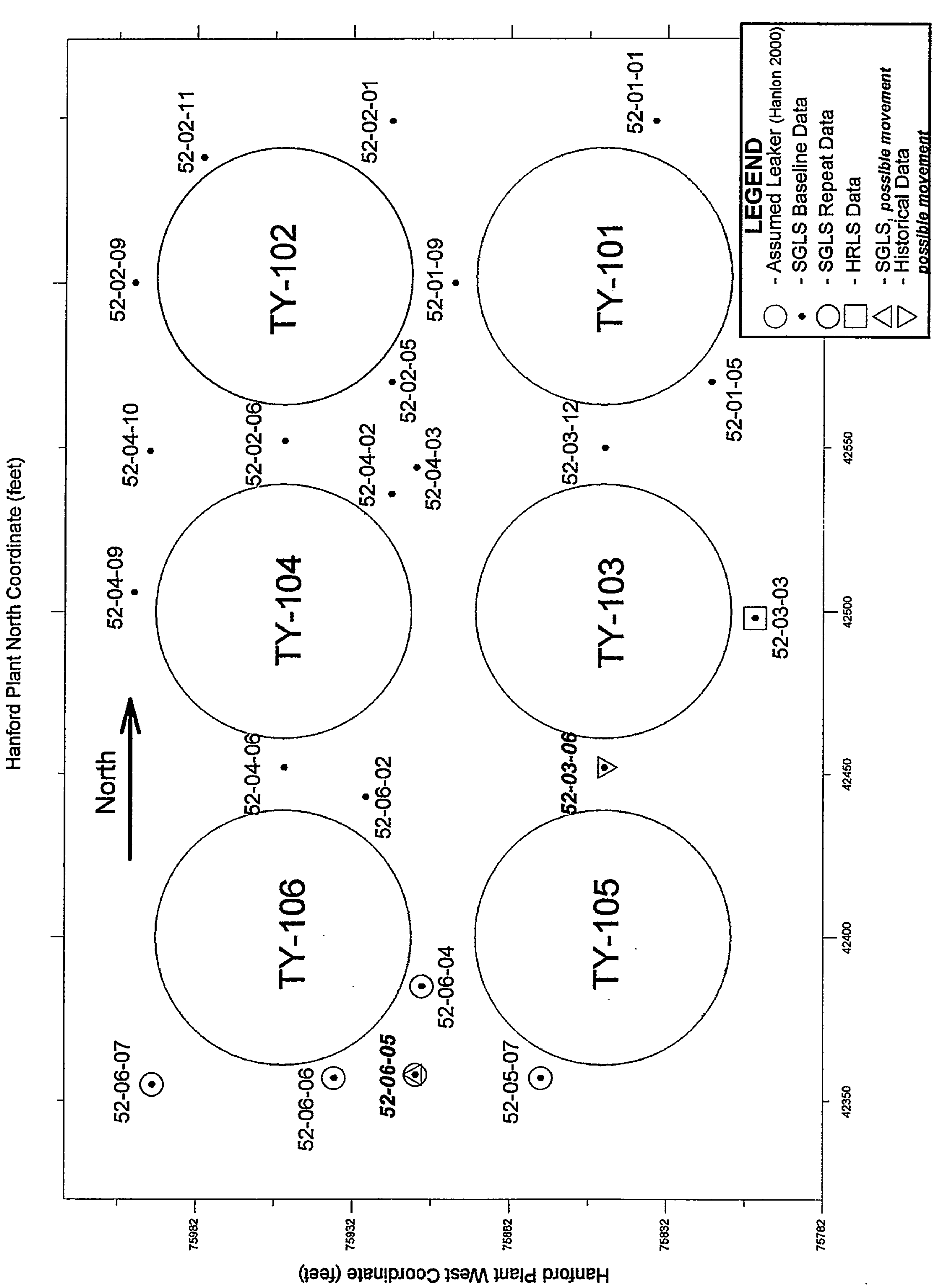

Figure 2. Map of the TY Tank Farm Showing Boreholes with Indications of Possible Contaminant Movement

Some indication that gamma radiation within a particular interval originates from the inside or outside of the casing, or from the within the earth surrounding the casing can be provided by an interpretive technique known as shape factor analysis. The technique of shape factor analysis is described in detail in Wilson (1997, 1998). In general, shape factor analysis relies upon ratios of certain intervals of the Compton continuum to discriminate between contamination that is localized to the casing, uniformly distributed in the formation, or that occurs as a discrete source at a distance from the borehole. At present, the method is only applicable to ^{137}Cs and ^{60}Co, but the principles can be extended to other radionuclides as well. In some cases, shape factor analysis can also identify a characteristic distortion of the low energy portion of a spectrum that may be caused by bremsstrahlung associated with the presence of a high-energy beta emitter such as strontium-90 (^{90}Sr) in the vicinity of the borehole.

Shape factor analysis was applied to the SGLS baseline data acquired in boreholes of the TY Tank Farm to identify zones of localized contamination that were not representative of subsurface contaminant plumes in the vadose zone. Results of shape factor analysis were used to modify the data set used to create the visualizations shown in the original TY Tank Farm Report. Continuing evaluation of shape factor and other data have led to further modifications of the data set.

3.0 Discussion of Results

Borehole logging events are referred to by letters A, B, C, etc. Each log event is a separate episode of data collection. Thus, Event A is the initial logging event and referred to as the baseline, while Events B or C are subsequent events that could refer to either repeat SGLS data or HRLS logging data. A log run refers to a single sequential set of log data collected during an event. Multiple log runs may occur with the same log event, for example, when using different shield configurations or when logging is terminated at the end of a day requiring a second day of logging to complete the borehole survey. Depth overlaps (1 ft) occur between log runs.

3.1 High Rate Logging

Logging was conducted using the HRLS in borehole 52-03-03, where SGLS baseline results indicated a zone of detector saturation resulting from a field of high gamma flux. Figure 2 shows the location of this borehole.

^{137}Cs concentration values calculated from the HRLS data collected are presented in a table in Appendix A. The table summarizes borehole information where HRLS logging was conducted in the TY Tank Farm. Included in the table are the depth intervals logged with the system, correction factors for the different shield configurations, and comments that generally include an assessment of relative stability by Myers et al. (1999). Appendix A also includes log plots for the HRLS logging events.

3.2 Repeat Logging

SGLS repeat logging in the TY Tank Farm was performed for selected depth intervals in five boreholes. Repeat data were collected less than 3 years after the SGLS baseline data were collected.

A table included in Appendix B summarizes SGLS repeat logging performed in the TY Tank Farm and indicates the zones of investigation in each borehole, the logging unit number and counting times, the reason for repeat logging, and an evaluation of the results. Appendix B also includes comparison plots between baseline and repeat logging events. To provide a meaningful comparison, baseline contaminant concentrations were adjusted for decay to match the repeat logging date and plotted. Figure 2 shows the locations of these boreholes and denotes if possible concentration increases have occurred that may indicate contaminant movement. These boreholes would be candidates for additional logging in a monitoring program. On the basis of comparison of baseline and repeat logging in five boreholes, no definitive evidence of contaminant movement exists. However, borehole 52-06-05 indicates potential concentration increases that may suggest contaminant movement. However, the difference in calculated concentration values is within the measurement uncertainty and no definitive conclusion can be drawn.

Baseline SGLS logging in borehole 52-06-07 detected ^{60}Co at concentrations of about 0.1 to 0.5 pCi/g from approximately 199 ft to the bottom of the logged interval at 213 ft. Repeat logging of this borehole, the deepest monitoring borehole in the TY Tank Farm, was performed to confirm the presence of ^{60}Co and to investigate the borehole interval below 213 ft. The repeat logging detected low levels of nearly continuous ^{60}Co contamination between 199 and 237 ft. This ^{60}Co contamination occurs above and below the groundwater level at 220.4 ft. Comparison of repeat and baseline data shows that the repeat values tend to be slightly higher than the decayed baseline values, but the differences are within the range of the measurement uncertainty. There is no conclusive evidence for change, other than decay, over a period of about 2.75 years. Independent assessment of historical gross gamma data for borehole 52-06-07 collected between 1975 and 1994 identified an interval of anomalous gamma activity from 86 to 100 ft that is attributed to ^{60}Co (Myers et al. 1999). This interval appears to be stable (Myers et al. 1999), and ^{60}Co levels appear to have since decayed to levels below the minimum detectable level (MDL) for the SGLS. However, because the gross gamma logs extend only to a depth of 150 ft, the historical data cannot be used to confirm or refute the contamination detected by the SGLS.

This interval of deep ^{60}Co has been intentionally left out of the interpreted data set used to create the visualizations, even though it is considered to be representative of subsurface contamination. The justification for excluding this interval is based on the absence of other boreholes that penetrate to the same depth. Absence of any other data to provide horizontal control tends to result in extrapolation of the plume beyond the range that can be justified by available data.

4.0 Three-Dimensional Visualizations

An objective of this addendum is to create revised three-dimensional visualizations of the major contamination plumes within the vadose zone in the vicinity of the TY Tank Farm and to present views derived from those visualizations. ^{137}Cs and ^{60}Co were the predominant contaminants in the TY Tank Farm. ^{154}Eu was also detected in the vadose zone sediments but it occurred in only one thin interval that was interpreted as a pipeline. The software package from C Tech Development Corporation called "Environmental Visualization System" (EVS) was used to create the visualizations in both the original TY Tank Farm Report and in this addendum. However, some improvements to the data input and calculation parameters to the model have been implemented since the original report and will be described in the following sections.

4.1 Interpreted Data Set

The first step in the visualization process is to create an interpreted data set that represents the input to the kriging process. Construction of the interpreted data set begins by creating a single text file that contains all the spectral gamma-ray data collected from both the SGLS baseline and HRLS logging activities. This data set includes the horizontal coordinates and depth of each data point and the calculated concentration value at that point for each contaminant of interest. The data set is then manually edited to remove borehole intervals that are judged to be localized to the borehole and thus not representative of the subsurface contaminant distribution.

Tables included in Appendix C list all of the boreholes (grouped by tank) in the TY Tank Farm that were included in the interpreted data set. The tables summarize the borehole contamination information from both SGLS and HRLS logging activities and the disposition of that data relative to the three-dimensional visualizations. Appendix C also includes log plots of each borehole showing the SGLS and HRLS data used to create the visualizations in this addendum.

Data for borehole 52-06-07 were intentionally left out of the interpreted data set used to create the visualizations but were included in Appendix C. The deep ^{60}Co contamination data (200 to 237 ft) would have severely distorted the visualizations, causing false plumes to be represented deep within the vadose zone; however, all information regarding the deep ^{60}Co contamination is discussed in Section 3.2, Appendix B, and shown on the sphere plots presented in Appendix D (Figure D-2).

Concentration values in the interpreted data set for TY Tank Farm have not been corrected for decay. In the addendum to the SX Tank Farm Report (DOE 2000), data were corrected for decay to January 1, 2000. However, as work progressed in other tank farms, it was found that decay corrections would lead to significant loss of data, particularly for ^{60}Co, which has a half life of about 5 years. In several cases, correction for decay to January 1, 2000 would lead to situations where the maximum ^{60}Co value for a specific plume would fall below the minimum detectable level for the SGLS. Either the values would have to be portrayed below the MDL, or the plume would be lost. Therefore, the decision was made to report data in terms of the time at which the baseline logging was performed. For the TY Tank Farm, the time span for the baseline is early to mid-1996. HRLS data were collected about 3 1/2 years later. Adjustments for decay (extrapolated backward) were made to the HRLS data for consistency with the baseline.

4.2 Development of Three-Dimensional Visualizations

The original visualizations utilized an "adaptive gridding" option that produces a model that contains estimated values everywhere inside a user-specified rectangular domain. In this addendum a "convex hull boundary" option is selected. This option produces an irregular boundary that is defined by the distribution of measured data points, effectively restricting the extrapolation of parameters to that area enclosed by the data points.

The data set derived from the SGLS data consists of measurement data at 0.5-ft intervals in vertical boreholes with a lateral separation generally on the order of tens of feet, resulting in a much greater data density in the vertical direction compared to the horizontal direction. To minimize processing time, search routines in the kriging algorithm utilize a limited number of data points closest to the calculation point, creating a situation in which a contaminated interval in a borehole tends to have an undue effect on nearby points. Because adjacent points in a single borehole are closer than points from another borehole, the data search routine is truncated after collecting all data points from a single borehole. To offset this effect, data points in individual boreholes were averaged over 5-ft intervals, significantly reducing the size of the input data set and the processing time. More importantly, it "forced" the search algorithm to bring in data from multiple boreholes at most calculation points, resulting in a more realistic extrapolation of concentration values into the region between boreholes. To maintain fidelity to the original data, sphere plots and other representations of measurement data are based on the interpreted data set, which contains actual values at 0.5-ft vertical increments.

4.2.1 Geostatistical Model

The EVS software determines geostatistical structure by calculating three-dimensional variograms that are plots of the variance of the data as a function of the distance between data points. The variogram is described by two parameters, the range and sill. The range is the distance beyond which the data points are no longer correlated (i.e., they are independent of one another), and the sill is the variance of all the data.

For the TY Tank Farm, the data did not show any significant decrease in variance as the data point-spacing decreased, implying that spatial correlation is poor and that more closely spaced data points are required to assess spatial variability. As a result, the geostatistical model takes on the form of the simple global variance value.

4.2.2 Three-Dimensional Plume Calculation and Visualizations

Kriging was used to estimate the contaminant concentration values at points on a three-dimensional grid. Once this concentration grid was developed, visualizations of the estimated contaminant concentrations could be produced in the form of a solid surface model. The visualization can be moved, rotated, and viewed from any angle or direction; color printouts can also be produced.

Kriging is a spatial estimation technique that uses a weighted moving average technique in which the weighting factors are chosen to minimize the estimated variance. The influence of each sample point is determined by proximity, and weighting factors are based on the geostatistical structure. The kriging process calculates the average radionuclide concentrations of a volume of sediment by using the information from nearby sample points.

The kriging software applies a horizontal-to-vertical anisotropy ratio that allows the user to influence the "fabric" of the data set. The anisotropy ratio applies a biased weighting to data points in horizontal and vertical directions from a given data node. The program default is 10, which means that data points a given distance in the horizontal direction from a node will have an influence 10 times greater than data points at the same distance in a vertical direction.

Analyses were performed at several anisotropy values and the value that yielded results that appeared to best represent the measured distributions of contaminants was determined through trial and error. The primary criteria controlling selection of an appropriate anisotropy value was the appearance of the resulting plume while honoring the spectral gamma-ray data. Higher anisotropy values tend to produce more lateral exaggeration, which may result in a "stringy" appearance. Lower anisotropy values tend to increase the influence of contaminant values in the vertical direction, resulting in a more "bulbous" appearance. An anisotropy value of 4 was applied during the kriging of the ^{137}Cs and ^{60}Co visualizations presented in this addendum.

For the two contaminants of interest (^{137}Cs and ^{60}Co), the MDL was generally on the order of 0.1 pCi/g. In the preprocessing module, a value of 0.01 pCi/g was substituted for non-detects in the data file, which allowed the presence of non-detects in the data set to have an impact on computation of nodal values during the kriging process. This is necessary because data analysis is based on the logarithm of contaminant values. During post-processing, values less than 0.1 pCi/g were ignored.

During the kriging process, grids are constructed to encompass all data points in three-dimensional space. The horizontal extent of the grid is governed by the positions of the boreholes. The model does not extrapolate beyond the extent of either the range value or the kriging limit. As a result, both the grid and the associated visualizations can extend only to the maximum depth of the boreholes and the extent of the range.

In the visualization process, solid surfaces are created by connecting the three-dimensional points in space that have equal concentrations. The outermost solid surface of the plume is defined by a user-selected contamination threshold value or isolevel. As the isolevel is increased, progressively higher radionuclide concentration surfaces can be visualized. To view an inner surface, a cut section is inserted through the solid surface plume. Where a low concentration volume surrounds a zone of higher concentration, a cut surface is helpful in visualizing the variation in concentration.

Tanks were portrayed by creating solid three-dimensional surfaces at the location of the tank centers. In regions occupied by tanks, the model does not insert a contamination barrier so that contamination in a borehole can have some influence on concentrations on the opposite side of the tank. In a geostatistical estimation calculation, the closest boreholes will have the greatest influence and the model will be close to the actual distribution, except for areas where there are few or no boreholes.

4.3 Potential Uncertainties and Inaccuracies

The visualizations presented in this report are based on estimated ^{137}Cs and ^{60}Co values as determined by geostatistical estimation (kriging) procedures applied to an interpreted data set that has been averaged over 5-ft depth intervals. In addition to the uncertainties associated with geostatistical estimation applied to an interpreted and averaged data set, there are other sources of uncertainty that must be considered. These include uncertainties in the assay calculation process as well as counting error. The uncertainty in assay calculation is discussed in the base calibration report (DOE 1995) and subsequent re-calibration reports. It is estimated by combining errors associated with the calibration efficiency determination, counting statistics of the calibration measurements, and uncertainties in the model concentration values. The counting error is associated with the random nature of the radioactive decay process.

Potential model inaccuracies may also result from zones of high ^{137}Cs concentrations (and resultant detector saturation). Where SGLS detector saturation occurred in borehole 52-03-03 of the original baseline, no concentration values could be calculated, or they were highly suspect. Therefore, a value of 10,000 pCi/g was placed in the database for kriging operations. This setup had minimal effect on the TY Tank Farm data set because there was only one zone in borehole 52-03-03 with ^{137}Cs concentrations high enough to saturate the SGLS detector. In this addendum, ^{137}Cs concentration values computed from HRLS data were substituted in the previously saturated interval.

The calibration of the logging system assumes contamination uniformly distributed in a homogeneous medium that is effectively infinite in extent relative to the detector in both horizontal and vertical directions. This assumption is valid for most situations except at the very top and the bottom of the boreholes or where the concentration changes rapidly with depth or distance from the borehole. The data acquisition interval used to log the TY Tank Farm boreholes (0.5 ft) provides adequate spatial resolution to characterize the situations where the contamination is not homogeneous in the vertical dimension.

Most inaccuracies or errors in the visualizations are insignificant compared to the inaccuracy caused by the introduction of contamination along the borehole and the generation of so-called false plumes. However, the potential for the generation of a false plume from contaminated boreholes is considered during the interpretation process. Specific borehole intervals suspected to be primarily borehole contamination have been removed from the interpreted data set as discussed previously.

A major potential source of error in the visualizations for the TY Tank Farm is the lack of any data from under the tanks. Significant levels of contamination could be under some tanks, in particular under tanks TY-103, -105, and -106. However, no such data are available from this area. If such data were to be included, it is likely that the plumes portrayed in the visualizations would extend further into the area underneath the tanks. Lack of data in the high gamma flux intervals dominated by ^{137}Cs also affects the portrayal of ^{60}Co distributions.

The visualizations are intended to provide the reader with an understanding of how gamma-emitting contaminants that have leaked from the tanks may be distributed in the vadose zone sediments. A valuable attribute of the visualizations is that they can be utilized to define areas of concern in which to focus future characterization and monitoring efforts.

The contamination plumes presented in the visualizations were evaluated by comparing the visualizations with the spectral gamma-ray log data from the individual monitoring boreholes surrounding the tanks. The interpretation of each plume or group of plumes is discussed in Section 4.4.

4.4 Discussion of Visualizations

The following section presents a discussion of the visualizations created with the interpreted data set. The visualizations are provided in Appendix D in the order in which they are discussed.

Appendix Figures D-1 and D-2 illustrate the man-made radionuclides (^{137}Cs and ^{60}Co) that were derived from the interpreted data set for all boreholes logged in the TY Tank Farm. These figures portray the data values at 0.5-ft intervals as spheres that are colored and sized to show the relative radionuclide concentration. The concentration values are presented with logarithmic color scales that range from 0.1 to as high as 10 million pCi/g. The borehole numbers are indicated to facilitate correlation of the three-dimensional representation of the data in the remaining figures and the interpreted data set plots presented in Appendix C.

Figures D-3 through D-13 show horizontal planar slices at various depths in the TY Tank Farm. These slices illustrate the distribution of radionuclide contaminants (^{137}Cs and ^{60}Co) that occur at concentrations greater than their listed isolevels in picocuries per gram. The depths of these slices were selected to indicate a balance of the highest concentration and maximum extent of plumes between the selected depth intervals.

The horizontal slice from the 2-ft depth (Figure D-3) shows three plumes of ^{137}Cs contamination bisecting the TY Tank Farm in a north-south direction. The highest ^{137}Cs concentration value at this depth is located along the northeast quadrant of tank TY-104. This contamination can be attributed to various sources, including unplanned releases, surface spills, and ancillary equipment or facilities.

Figure D-4 shows ^{137}Cs contamination at a depth of 5 ft. The area of the three plumes has decreased in size.

The slice at the 20-ft depth (Figure D-5) shows one contaminant plume continuing from the 5-ft depth along the south quadrant of tank TY-106. This slice represents the maximum vertical extent of ^{137}Cs contamination originating from a surface source.

The slice at the 41-ft depth (Figure D-6) represents an area above the base of the tank farm's excavation surface (about 50 ft). It shows three contaminant plumes: along the northwest quadrant of tank TY-102, southeast of tank TY-101, and east of tank TY-103.

Although not classified as a leaker, the contamination along the northwest quadrant of tank TY-102 suggests that the tank may have leaked. In 1975, borehole 52-02-11 was drilled to 45 ft, perforated, and injected with an unknown amount of salt solution ($NaNO_3$). The purpose of the injections, according to the driller's log, was to study resistivity measurements for leak-detection development. Results of these tests were not available. This borehole was deepened in 1977 to 100 ft. It is possible that the ^{137}Cs contamination detected in this interval was the indirect or direct result of the injection tests and not a tank leak (DOE 1997b). Other boreholes around tank TY-102 show no corroborating evidence of ^{137}Cs contamination from a tank leak.

The ^{137}Cs detected along the east side of tank TY-103 may correlate with the ^{137}Cs detected along the southeast quadrant of tank TY-101. However, there are few data points in this area to confirm this assertion. Note that on this and subsequent slices, the ^{137}Cs contamination east of TY-103 appears to terminate abruptly along northeast- and northwest-trending lines at the eastern margin of the tank farm. This is a consequence of the convex hull option, which limits the portrayal of contamination to the volume enclosing the boreholes.

Figure D-7 shows contaminant distribution at the 47-ft depth, which is slightly above the base of the tank farm excavation surface. At this depth, the ^{137}Cs plumes northwest of tank TY-102 and east of tank TY-103 appear to be expanding. The maximum ^{137}Cs concentration in TY Tank Farm (about 10^7 pCi/g) was detected at this depth on the east side of tank TY-103.

The slice at the 56-ft depth (Figure D-8) represents undistributed sediments of the Hanford formation just below the tank farm excavation surface. In addition to ^{137}Cs east of tank TY-103,

^{60}Co is shown between tanks TY-103 and TY-105, and both ^{137}Cs and ^{60}Co occur southwest of tank TY-105.

The slice at the 75-ft depth (Figure D-9) represents the maximum vertical extent of the ^{137}Cs contamination detected along the south side of tank TY-105. At this level, it appears that the ^{60}Co plumes north and south of tank TY-105 may have merged. The abrupt truncation of the ^{60}Co plume along a northeast-trending line is the result of the convex hull option.

Figure D-10 shows contaminant distribution at the 97-ft depth, which is within the Early Palouse soil. Many of the boreholes in the TY Tank Farm are limited to the upper 100 ft of the vadose zone. This depth represents the approximate vertical extent for which data are available over all of the tank farm. ^{60}Co concentration values are increasing toward the bottom of the logged interval between tanks TY-103 and TY-105, and the vertical extent of contamination in this area may not be defined.

The two slices at depths of 133 and 145 ft (Figures D-11 and D-12), show the distribution of deep ^{60}Co contamination along the southern end of the tank farm between tanks TY-105 and TY-106. This contamination is below the boundary between the Plio-Pleistocene and Early Palouse units, which is generally considered to act as a barrier between downward migrating vadose zone contamination and the groundwater. ^{60}Co is present at the bottom of logged interval in borehole 52-06-05, which suggests that the bottom of the contamination plume has not been determined in the area south of tanks TY-105 and TY-106. Moreover, it is possible that the ^{60}Co detected below 200 ft in borehole 52-06-07 may represent an extension of this plume to the southwest. Only those boreholes that penetrate to these depths are shown on the visualizations.

Figures D-13 through D-15 are three-dimensional visualizations that illustrate the major contamination plumes within the vadose zone at the TY Tank Farm. The figures show the plumes created with the EVS software superimposed over the SGLS and HRLS data from the interpreted data sets. In these three figures, the plumes of interest are presented with a degree of transparency to also show the data that define the plumes.

Figure D-13 shows the distribution of ^{137}Cs plumes viewed from above and looking toward the northwest. Figure D-14 shows low levels of ^{60}Co contamination in the vicinity of tanks TY-101 and TY-102 that are not plotted as a plume in the visualization; the calculated concentration levels were below the 0.3-pCi/g isolevel threshold. In addition, the ^{60}Co plume shown on Figure D-14 south of tanks TY-105 and TY-106 is shown as two separate bodies. This is due in part to the use of the convex hull option that limits the downward extrapolation of concentration values beyond the maximum extent of the boreholes.

Figure D-15 shows the distribution of the ^{137}Cs contamination as viewed from below and looking toward the southeast.

Figure D-16 shows a view looking toward the northwest from slightly above showing the internal structure of the ^{137}Cs and ^{60}Co plumes. The internal structure is shown along two vertical planes (east-west and southwest-northeast) that intersect at borehole 52-05-07 south of tank TY-105. The deeper ^{60}Co plume is shown as a separate lobe, but it is possible that the upper and lower plumes may be continuous. Most boreholes do not extend deep enough to provide data below about 100 ft.

4.5 Contaminated Volume and Total Activity Estimate

With completion of the revised visualizations, it became possible to calculate an estimate of the volume of contaminated soil and total activity inventory as a function of contaminant threshold level within the plumes shown in the TY Tank Farm visualizations.

Volume estimates are prepared by numerically integrating the volume within the specified isosurface. Contaminant inventories (in Curies) are calculated by numerically integrating the total activity within the isosurface. The total activity for each volumetric element is determined by multiplying the specific activity (concentration) in picocuries per gram by the mass per unit volume (density) for each element. A density of 1.8 grams per cubic centimeter (g/cm^3) was assumed in the volume calculation.

These estimates are based on kriged values extrapolated from the interpreted data set, where concentration values have been averaged over 5-ft intervals, and represent the volumes of the contaminated formation and total radioactivity for ^{137}Cs and ^{60}Co. The total activities represent values at the time of the baseline logging in 1996, and have not been corrected for decay. These estimates are based entirely on the data from the baseline spectral gamma characterization program, with HRLS data included in zones of detector saturation. The data sets used for the volume and total activity inventory estimates do not include any data from historical gross gamma logs or any soil sample data.

The contribution from ^{60}Co may be slightly underestimated because these data are not always measured accurately in zones of high gamma flux. A further limitation of this inventory is that no data are available from directly under the tanks, where the highest concentrations of radionuclides are presumed to exist. Also, EVS extrapolates the contaminant plumes through the volume occupied by the tanks. This may result in a minor error in the volume of contaminated soil in the upper part of the plumes. However, given the nature of the estimates and the relatively sparse data set, these errors are not likely to significantly affect the estimates.

The following tables list the contaminated soil volume and total activity that occurs at or above each threshold level for ^{137}Cs and ^{60}Co:

Contaminant Threshold (pCi/g)	^{137}Cs Contaminated Volume (Cubic Meters)	Total Activity (Curies)
0.5	4,998	1.28
5	1,107	1.26
50	442	1.21
500	139	1.05
5,000	22.1	0.78
10,000	11.9	0.69
25,000	7.8	0.54
40,000	6.3	0.46

Contaminant Threshold (pCi/g)	^{60}Co Contaminated Volume (Cubic Meters)	Total Activity (Curies)
0.1	29,600	2.51e-02
0.3	10,900	1.96e-02
0.5	7,507	1.71e-02
1	3,298	1.17e-02
5	179	1.72e-03

5.0 Conclusions

The purpose of this addendum is to provide an update to the original TY Tank Farm Report that was issued in 1998. The interpretations and conclusions in the original report are unchanged. However, since the original report was issued, knowledge has been gained that provides a more complete framework by which the contaminant distribution can be viewed. In addition, enhancements to the data collection have been made since the TY Tank Farm Report was issued. Some of the more important improvements in the understanding of the log data have resulted from the following:

- Moderate levels of ^{137}Cs and ^{60}Co exist within the formation at depths of at least 147.5 ft. Deeper ^{60}Co contamination was confirmed to exist in one borehole below the measured groundwater to a depth of 237 ft. Thus, the vertical extent of contaminant plumes is not fully defined because contamination was detected in a number of boreholes to the total depth of the borehole.

- Analysis of historical gross gamma logging data from 1975 to 1994 provides a qualitative evidence of contaminant movement. In addition, repeat logging using the SGLS has allowed for evaluation of possible concentration increases between 1996 and 1999. However, there has been no comprehensive effort to monitor changes in vadose zone contamination since 1994.

- The HRLS has allowed determination of maximum concentration values in borehole intervals where the SGLS was saturated. ^{137}Cs concentrations as high as 10^7 pCi/g were detected in one borehole in the TY Tank Farm.

Integration of the HRLS data and re-calculation of the spatial distribution based on the revised interpreted data set have resulted in an improved visualization of subsurface contaminant distribution in the TY Tank Farm. Conclusions stated in the original TY Tank Farm Report remain appropriate and will not be reiterated. However, one finding of major significance is that evaluation of repeat logging data and an independent assessment of historical gross gamma data both appear to indicate that contaminant movement through the vadose zone has occurred in the past and may be continuing (Figures 2 and B-3). This information is based on SGLS repeat logging results, HRLS results, and work performed by Myers et al. (1999).

6.0 Recommendations

Recommendations included in the original TY Tank Farm Report have not substantially changed. The baseline data reported in the TY Tank Farm Report and in this addendum have provided an indication of the nature and extent of contamination associated with gamma-emitting radionuclides. Evaluation of historical data and relogging of selected holes suggest that contaminant migration appears to be continuing. However, the gross gamma logging program was terminated in 1994, and little new data are available to assess continuing migration from 1994 to the present. Therefore, it is imperative that a routine monitoring program be reinstated within the TY Tank Farm. It is not necessary to monitor all boreholes; the TY Tank Farm baseline data clearly indicate where monitoring data are required. In addition to routine monitoring, consideration should be given to implementation of a moisture logging program to detect and monitor changes in vadose zone moisture conditions.

Additional boreholes should be drilled and samples collected to further investigate contaminant plumes identified by the baseline study. This is particularly important for the area immediately to the south of tank TY-106, where deep ^{60}Co contamination was detected in the groundwater and where additional contaminants such as technicum-99 may be present.

7.0 References

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Appendix A
Summary of High Rate Logging Results for the TY Tank Farm

Table A-1. Summary of High Rate Logging Results for the TY Tank Farm

Borehole	Depth (ft) for Each Log Run	Shield/ Correction Factor [a]	Comment
52-03-03	45-50	IS/27.42	The maximum ^{137}Cs concentration value was 10,486,000 pCi/g measured at the 47.5-ft depth. Log plots of HRLS data were extrapolated backward to the baseline date (05/14/96) for consistency with the interpreted data set. When the HRLS data are extrapolated backward, the maximum ^{137}Cs concentration value increases to 11,382,000 pCi/g. The high intensity zone between 45 and 50 ft probably also contains ^{60}Co but was not detected by the HRLS. The presence of ^{60}Co contamination in the high intensity zone is inferred because it was detected immediately below the logged interval. Historical data (H/D[b]) indicate this interval is stable. The HRLS log plot showing the interpreted data set includes the interval of "no shield data" from 45 to 46.5 ft and 49.5 to 50.5 ft and the interval of "internal shield data" from 47 to 49 ft.
	49-52	NS/1.00	

[a] Shield configuration options: NS - No shield; ES - External shield; IS - Internal shield; BS - Both shields.
[b] H/D - Historical data from Myers et al. (1999).

Borehole 52-03-03

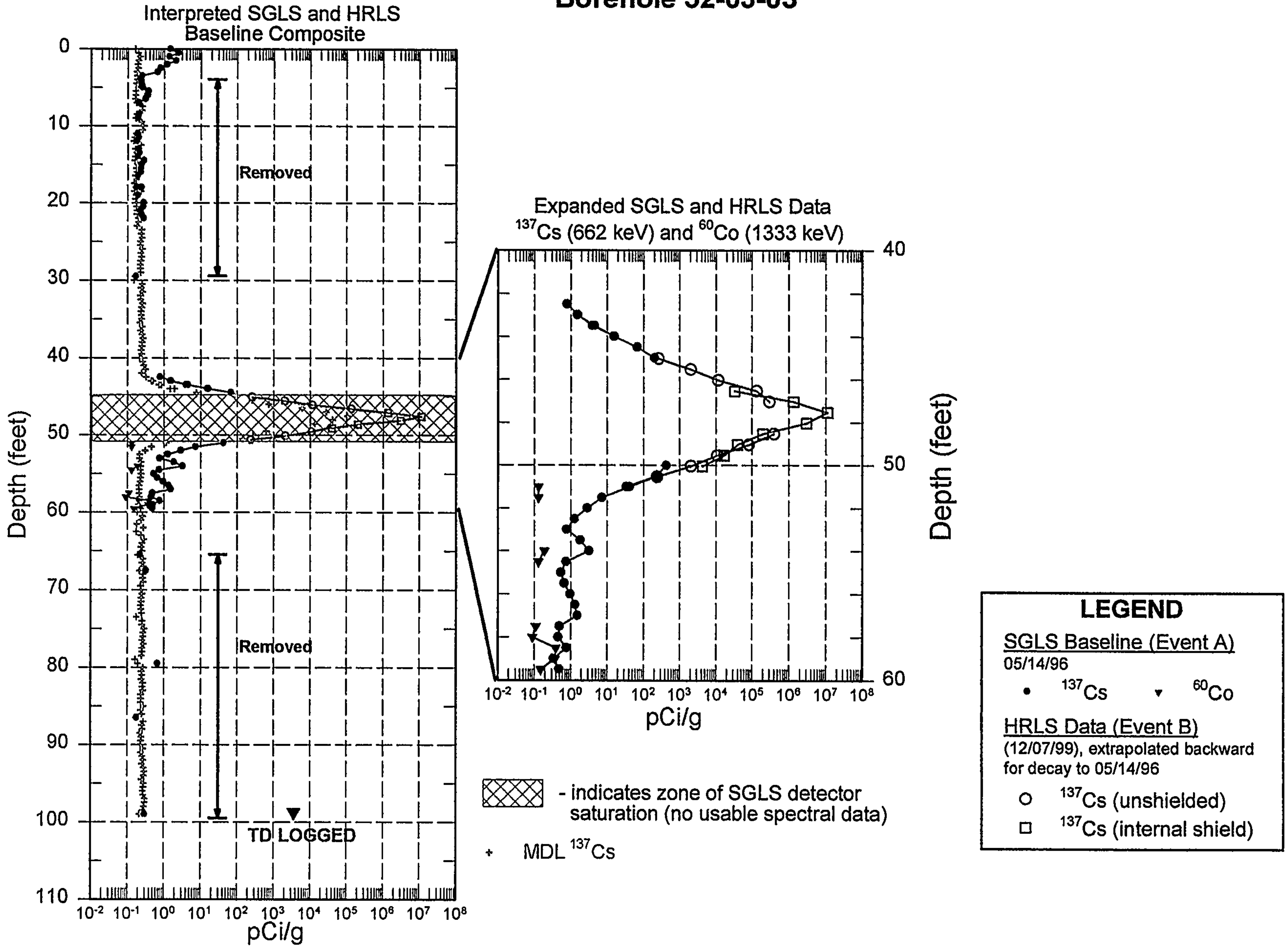


Figure A-1. Summary of High Rate Logging Results for the TY Tank Farm

Appendix B
Summary of Repeat Logging Results for the TY Tank Farm

Table B-1. Summary of Repeat Logging Results for the TY Tank Farm

Borehole	Depth (ft)	Logging Unit/ Counting Time		Reason for Repeat	Evaluation
		Baseline	Repeat		
52-05-07	50-97	G1 (100 s)	G2B (100 s)	CM[a]	SGLS repeat data suggest that ^{60}Co and ^{137}Cs concentrations are stable. H/D[d] indicate that the historical anomaly interval between 51 and 100 ft was unstable in the past. In addition to ^{137}Cs and ^{60}Co contamination identified by SGLS data, H/D infer from decay rate that in the past ^{125}Sb may have also been present. SGLS logging did not detect ^{125}Sb contamination.
52-06-04	45-55	G1 (100 s)	G2B (200 s)	TG[b]	Between 50 and 54 ft, SGLS baseline and repeat data measured anomalous total gamma activity that was not associated with any radionuclides identified in the spectra. The location of the anomaly is approximately at the base of tank TY-106. A possible correlation can be made with borehole 52-06-05 where total gamma anomalies were detected at 53 and 65 ft. H/D indicate that the historical total gamma-ray anomaly between 47 and 56 ft was stable. In addition to the ^{137}Cs contamination identified by SGLS data, H/D also infer from decay rate that in the past ^{125}Sb may have also been present. SGLS logging did not detect ^{125}Sb contamination.

[a] CM - Contaminant movement.
[b] TG - Elevated total gamma count rate in the absence of significant ^{137}Cs contamination.
[c] Aquifer - That portion of the borehole that penetrates the uppermost part of the aquifer.
[d] H/D - Historical data from Myers et al. (1999).

Table B-1 (con't.). Summary of Repeat Logging Results for the TY Tank Farm

Borehole	Depth (ft)	Logging Unit/ Counting Time		Reason for Repeat	Evaluation
		Baseline	Repeat		
52-06-05	50-147.5	G1 (100 s)	G2B (200 s)	TG[b]/CM[c]	SGLS baseline and repeat data detected anomalous total gamma activity at 51 to 54 ft and 62 to 66 ft that do not correspond to any identified radionuclides. SGLS repeat data indicate that ^{137}Cs and ^{60}Co concentrations between 52 and 141.5 ft appear to be stable. ^{60}Co concentrations between 142 and 147.5 ft may be increasing, but data are inconclusive. H/D[d] indicate that a historical total gamma-ray anomaly between 50 and 90 ft was unstable early. The interpretation of H/D was consistent with results presented by SGLS baseline data, which identified the ^{60}Co and ^{137}Cs as the major contaminants.
52-06-06	90-100	G1 (100 s)	G2B (100 s)	CM	SGLS repeat data suggest that ^{60}Co concentrations may be stable. ^{60}Co values from repeat data appear to be slightly lower than expected, but data are inconclusive. H/D indicate that a historical total gamma-ray anomaly between 72 and 82 ft was stable and infer from decay rate that ^{125}Sb was the likely contaminant. SGLS baseline logging did not detect ^{125}Sb contamination.

[a] CM - Contaminant movement.
[b] TG - Elevated total gamma count rate in the absence of significant ^{137}Cs contamination.
[c] Aquifer - That portion of the borehole that penetrates the uppermost part of the aquifer.
[d] H/D - Historical data from Myers et al. (1999).

Table B-1 (con't.). Summary of Repeat Logging Results for the TY Tank Farm

Borehole	Depth (ft)	Logging Unit/ Counting Time		Reason for Repeat	Evaluation
		Baseline	Repeat		
52-06-07	190-237	G1 (100 s)	G2B (100 s)	Aquifer[c]/ CM[a]	The purpose for the repeat logging was to extend the SGLS baseline data to the borehole's total depth. For baseline logging the total depth logged was 213 ft (above groundwater) and for repeat logging the total depth logged was 237 ft. SGLS repeat logging detected low levels of nearly continuous ^{60}Co contamination ranging from 0.12 to 0.43 pCi/g between 199 and 237 ft. SGLS baseline data presented on the log plot were adjusted for decay to compare the calculated concentration values with SGLS repeat data. SGLS baseline and repeat data show good repeatability and depth control. The repeat data suggest that ^{60}Co concentrations may be stable between 200 and 213 ft. A specific source of this contamination cannot be determined because no other boreholes are deep enough for a correlation of contamination zones. Historical total gamma-ray data were not available for this borehole below 150 ft. H/D[d] indicate a total gamma anomaly between 86 and 100 ft, that has since decayed away, and infer from decay rate that ^{60}Co was the likely contaminant. SGLS baseline logging did not detect ^{60}Co contamination.

[a] CM - Contaminant movement.
[b] TG - Elevated total gamma count rate in the absence of significant ^{137}Cs contamination.
[c] Aquifer - That portion of the borehole that penetrates the uppermost part of the aquifer.
[d] H/D - Historical data from Myers et al. (1999).

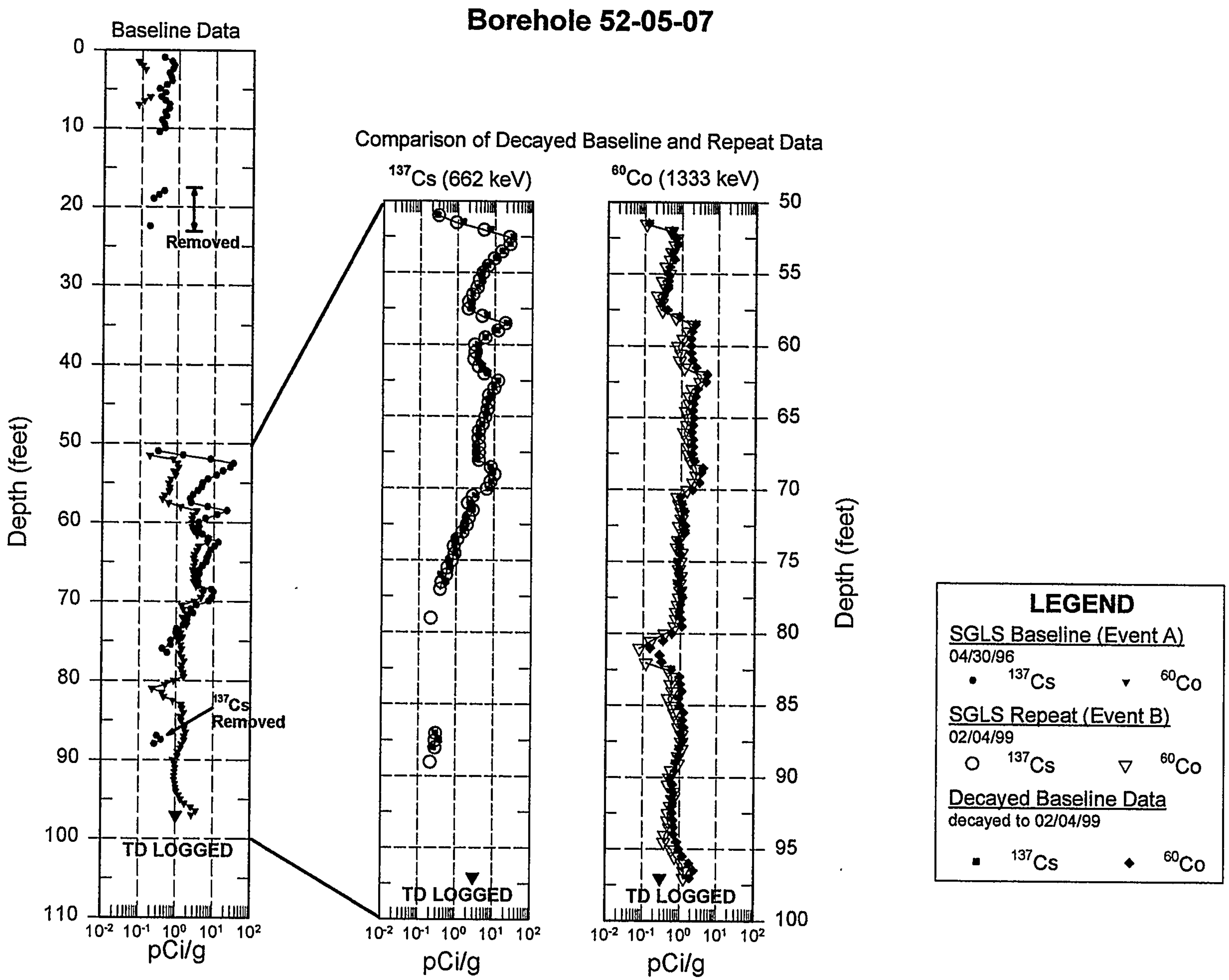


Figure B-1. Summary of Repeat Logging Results for the TY Tank Farm

Borehole 52-06-04

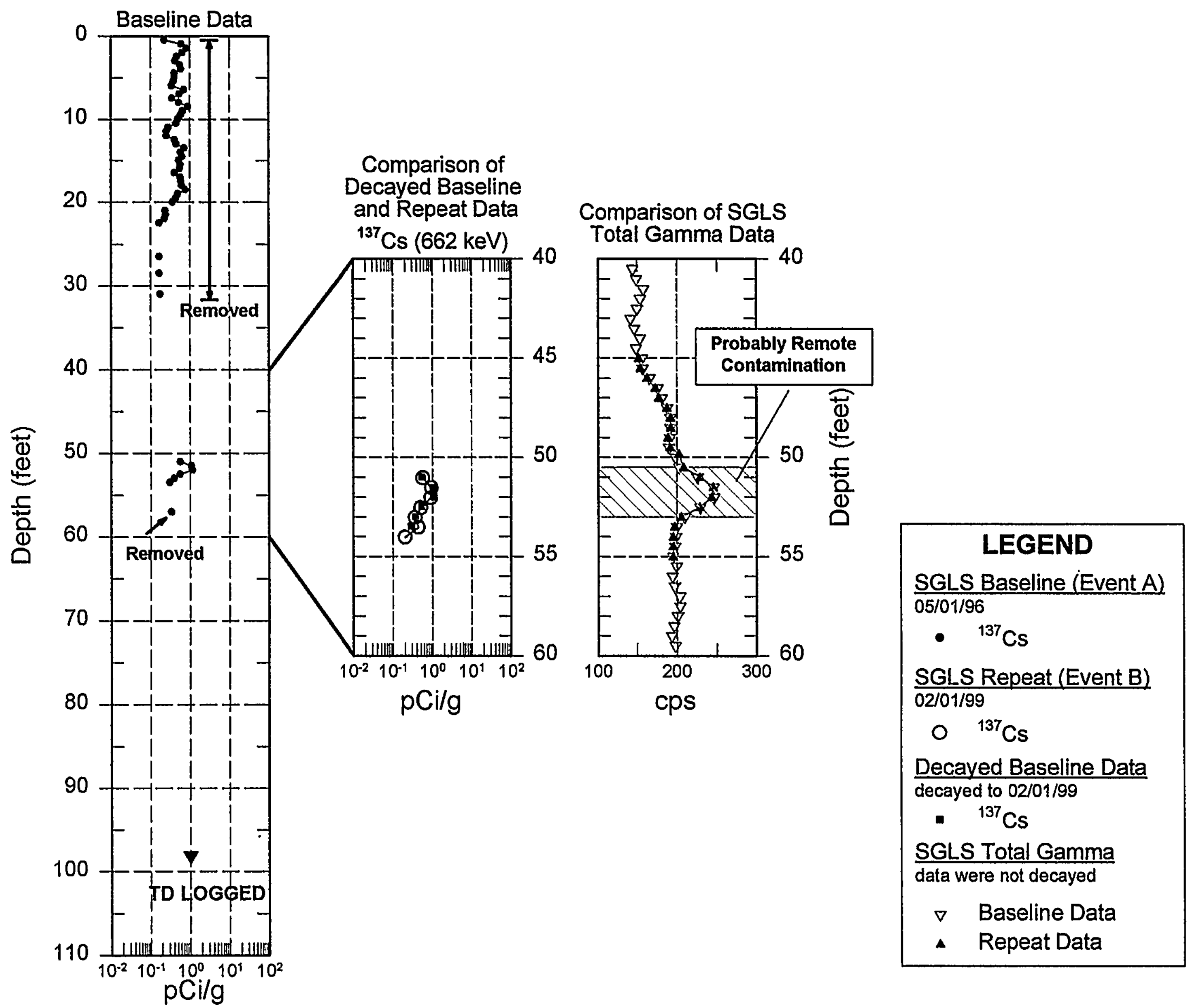


Figure B-2. Summary of Repeat Logging Results for the TY Tank Farm

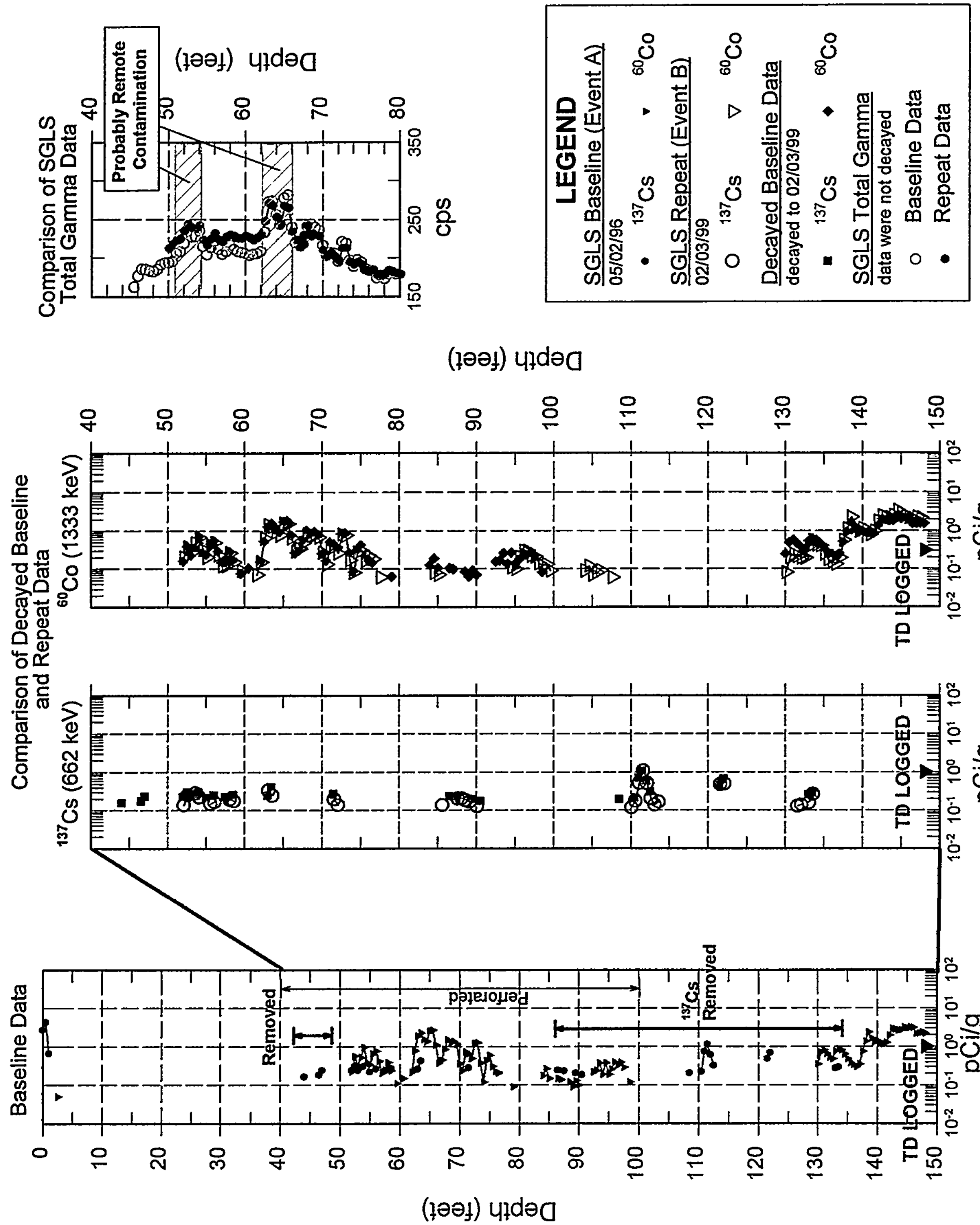


Figure B-3. Summary of Repeat Logging Results for the TY Tank Farm

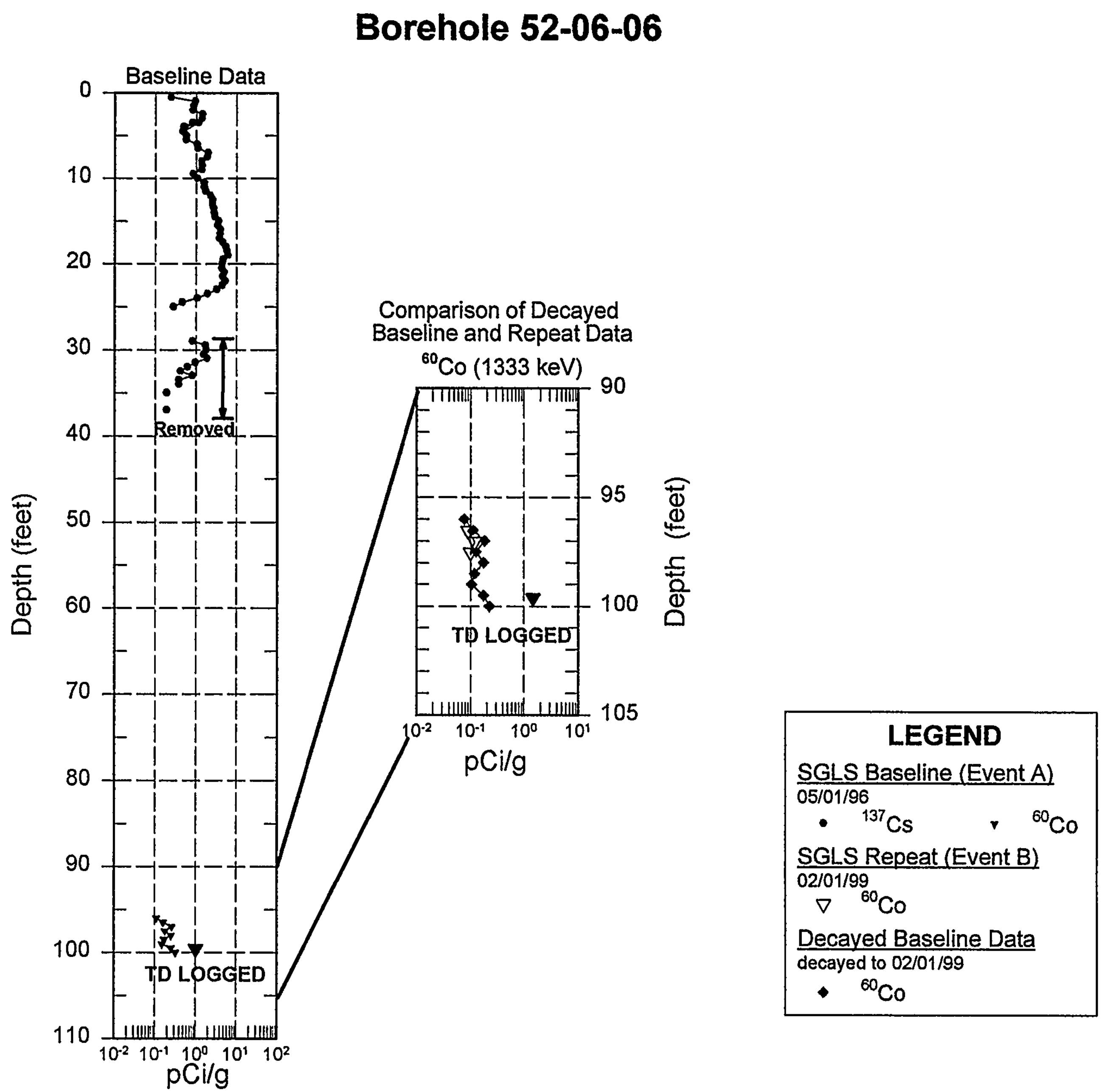


Figure B-4. Summary of Repeat Logging Results for the TY Tank Farm

Borehole 52-06-07

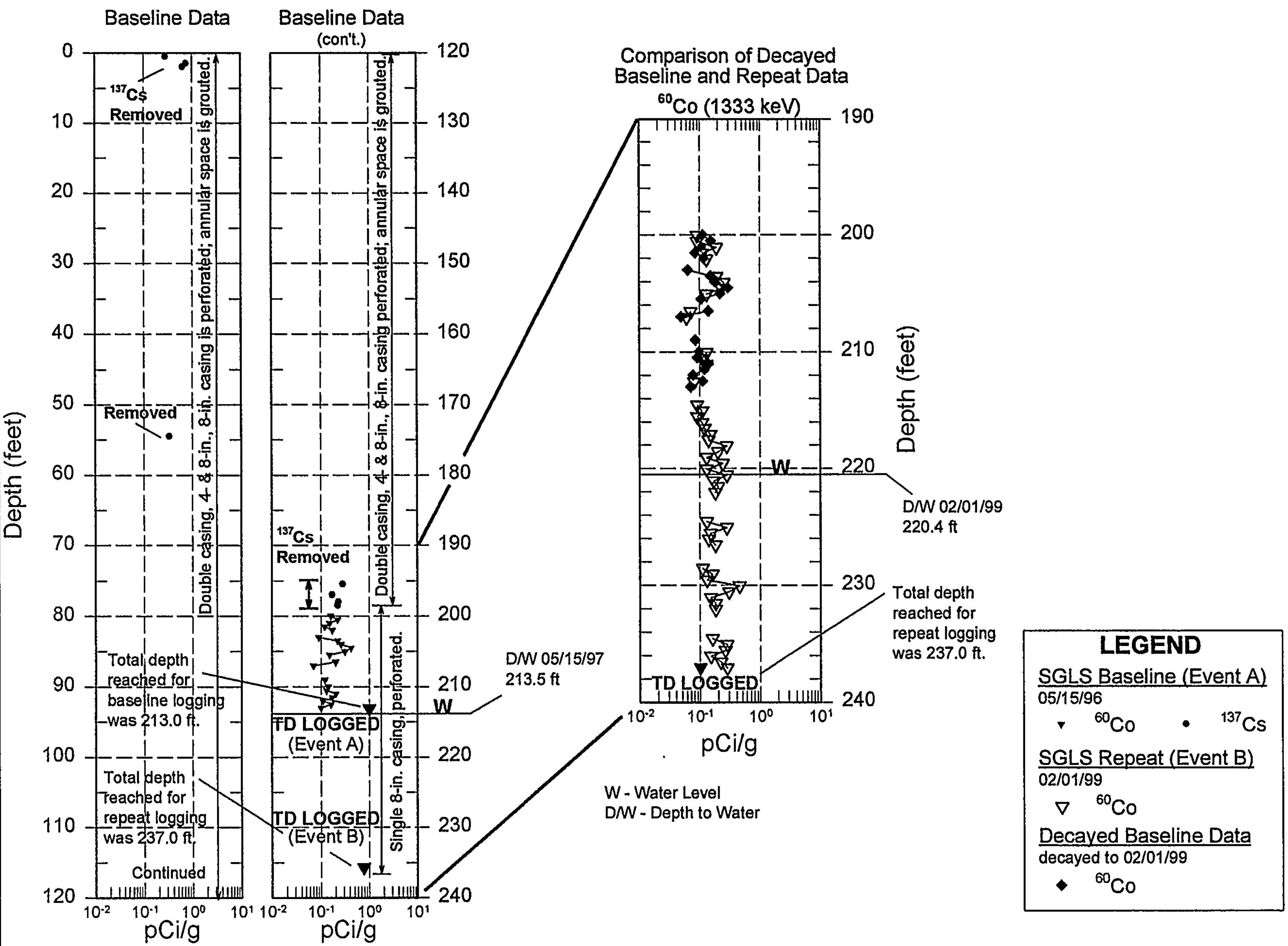


Figure B-5. Summary of Repeat Logging Results for the TY Tank Farm

Appendix C
Summary of Interpreted Data Set
for the TY Tank Farm

Table C-1. Summary of Interpreted Data Set for TY-101 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-01-01	0-0.5	SS[b]	Inc.[j]	^{137}Cs included.
	3.5	BE[c]		Isolated occurrence of ^{137}Cs removed.
	4-98.5	None	Ina.[k]	No man-made contaminants detected.
	99	BE	Inc.	^{137}Cs removed; fell in from the ground surface.
52-01-05	0-1	SS	Inc.	^{137}Cs included.
	1.5-38	BE		Intermittent ^{137}Cs removed; appears to be dragdown.
	38.5-44	P[d]	D[g]	^{137}Cs included. The ^{137}Cs contamination is located at or near the base of tank TY-101. H/D[e] indicate contamination between 45 and 58 ft was stable; a decay curve indicates that ^{106}Ru was the likely contaminant.
	47-47.5	BE	Inc.	Intermittent ^{137}Cs removed; appears to be dragdown.
	48-98	None	Ina.	No man-made contaminants detected.
52-01-09	0-1	SS	Inc.	^{137}Cs included.
	1.5-94.5	None	Ina.	No man-made contaminants detected.
	95-98.5	P	Inc.	^{60}Co included. ^{60}Co is present at the bottom of the logged interval, suggesting that the maximum depth of the contaminant plume has not been determined. H/D indicate that the interval between 50 and 62 ft was stable; a decay curve indicates that ^{106}Ru was the likely contaminant.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available; the borehole is finished with grout and multiple casings.

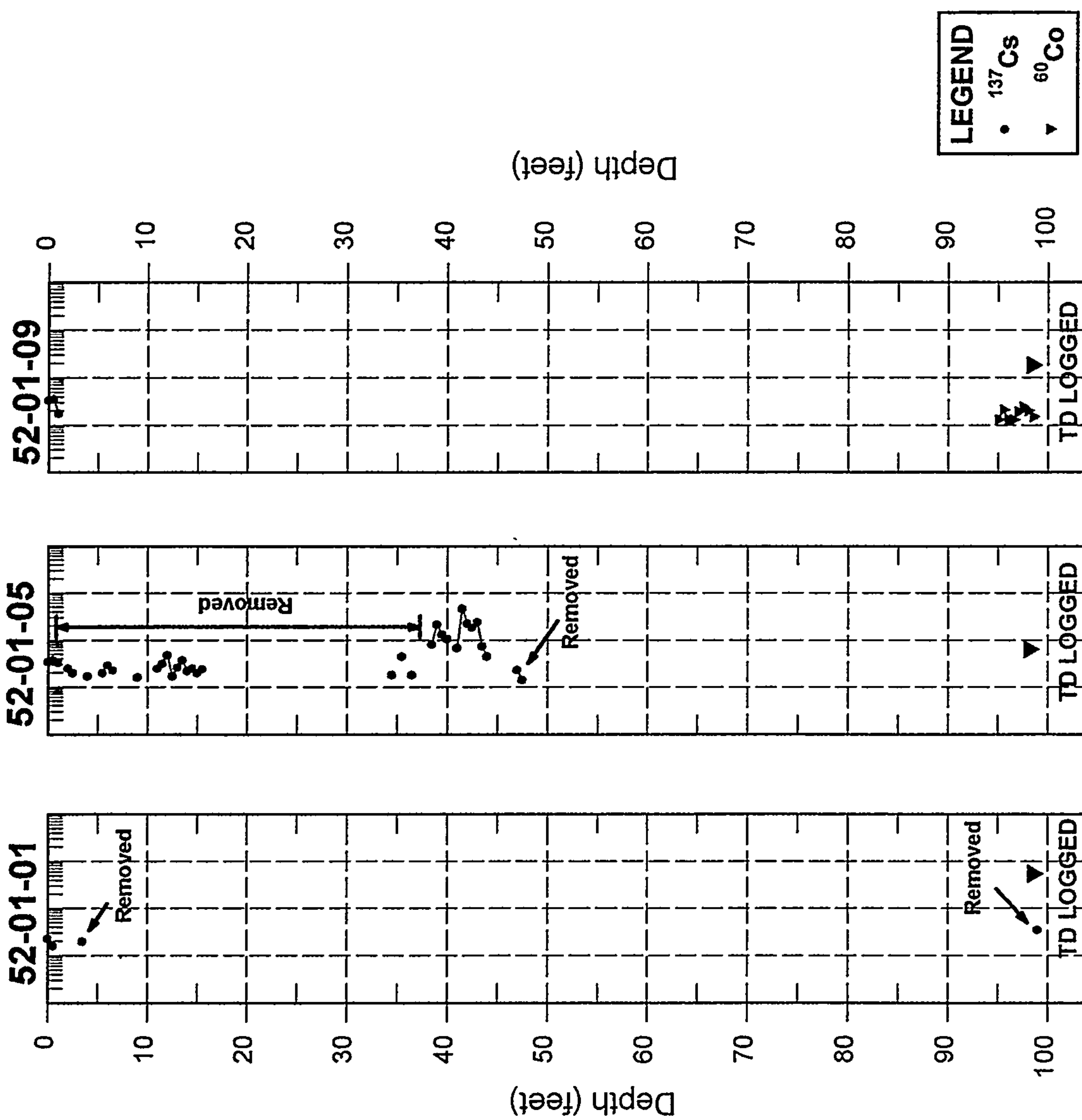


Figure C-1. Summary of Interpreted Data Set for the TY Tank Farm

Table C-2. Summary of Interpreted Data Set for TY-102 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-02-01	0-99.5	BE[c]	Inc.[j]	Isolated ^{137}Cs at ground surface removed; no other contaminants.
52-02-05	0-98.5	BE	Inc.	Intermittent ^{137}Cs removed.
52-02-06	0.5-2	SS[b]	Inc.	^{137}Cs included.
	2.5-20	BE		Intermittent ^{137}Cs removed; appears to be dragdown.
	20.5-99.5	None	Ina.[k]	No man-made contaminants detected.
52-02-09	0-98.5	BE	Inc.	Isolated ^{137}Cs at the ground surface removed; no other contaminants.
52-02-11	0.5-3	SS	Inc.	^{137}Cs included.
	3.5-10	BE		Isolated ^{137}Cs removed; appears to be dragdown.
	10.5-40.5	None	Ina.	No man-made contaminants detected.
	41-52.5	P[d]	D[g]	^{137}Cs included. This interval was identified as a historical total gamma anomaly and has behaved erratically several times in the past. H/D[e] indicate contaminants between 36 and 50 ft were unstable at an early date.
	53-95	None	Ina.	No man-made contaminants detected.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available; the borehole is finished with grout and multiple casings.

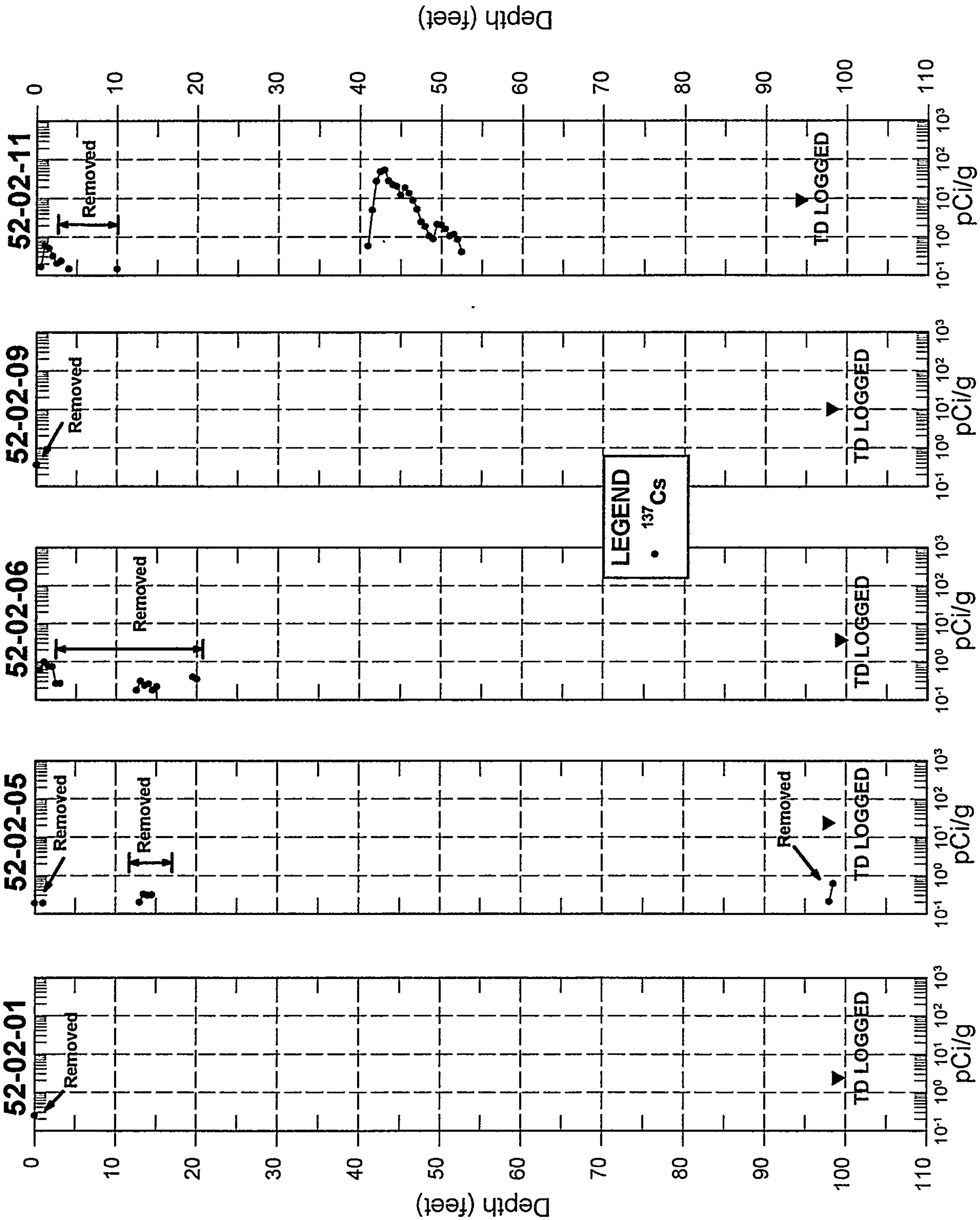


Figure C-2. Summary of Interpreted Data Set for the TY Tank Farm

Table C-3. Summary of Interpreted Data Set for TY-103 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-03-03	0-3	SS[b]	D[g]	^{137}Cs included.
	3.5-22	BE[c]	Inc.[j]	^{137}Cs removed; appears to be dragdown.
	22.5-41.5			Isolated ^{137}Cs removed.
	42-59.5	P[d]	D	^{137}Cs and ^{60}Co included. Contaminants are present below the base of tank TY-103. Between 45 and 50.5 ft, HRLS data were substituted for SGLS data. The maximum calculated ^{137}Cs concentration value of 10^7 pCi/g was measured at the 47.5-ft depth. H/D[e] indicate contaminants between 35 and 54 ft were stable. H/D indicate contaminants between 54 and 62 ft were unassigned because the time span covering the historical survey data is not long enough to make a determination.
	60-99	BE	Inc.	Isolated ^{137}Cs removed.
52-03-06	0-3	SS	D	Continuous ^{137}Cs and isolated ^{60}Co included.
	3-14.5	BE	Inc.	^{137}Cs removed.
	15-53.5	None	Ina.[k]	No man-made contaminants detected.
	54-100	P	D	^{60}Co included. The ^{60}Co concentration values are increasing toward the bottom of the logged interval, indicating that the maximum depth of the contamination plume has not been determined. H/D indicate that the interval between 44 and 98 ft is unstable. H/D also indicate that between 88 and 98 ft, the ^{60}Co is moving downward past the bottom of the logged interval.
	56-61	BE	Inc.	Isolated ^{137}Cs included.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available, the borehole is finished with grout and multiple casings.

Table C-3 (con't). Summary of Interpreted Data Set for TY-103 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-03-12	0-3	SS	Inc.	Continuous ^{137}Cs included.
	3.5-64.5	None	Ina.	No man-made contaminants detected.
	65-87.5	P	Inc.	Intermittent ^{60}Co included. H/D indicate early instability between 60 and 75 ft.
	88-99.5	None	Ina.	No man-made contaminants detected.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available, the borehole is finished with grout and multiple casings.

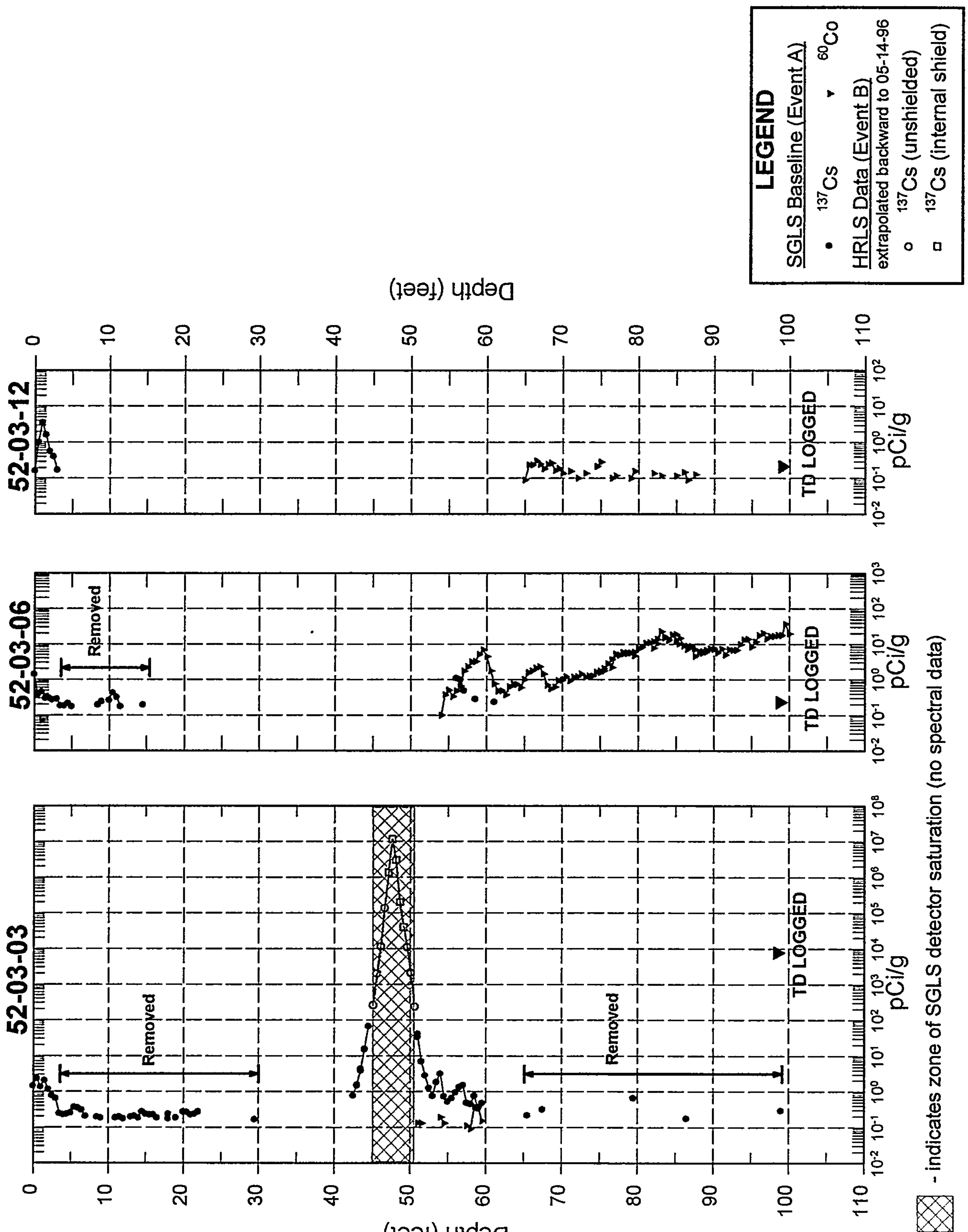


Figure C-3. Summary of Interpreted Data Set for the TY Tank Farm

Table C-4. Summary of Interpreted Data Set for TY-104 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-04-02	0-1	SS[b]	Inc.[j]	^{137}Cs included.
	7.5-24.5	BE[c]		^{137}Cs removed; appears to be dragdown.
	25-88.5	None	Ina.[k]	No man-made contaminants detected.
	89-97.5	BE	Inc.	^{137}Cs removed; fell in from the ground surface.
52-04-03	0-5.5	Pipeline	Ina.	^{137}Cs included. ^{154}Eu removed. This was the only occurrence of ^{154}Eu detected in the TY Tank Farm and was removed from the visualizations. H/D[e] indicate count rates between 0 and 8 ft were associated with tank farm activity.
	6-108	BE	Inc.	Intermittent ^{137}Cs removed. Perforated casing between 40 and 100 ft.
	108.5-146.5	None	Inc.	No man-made contaminants detected.
52-04-06	1-6	SS	Inc.	^{137}Cs included.
	6.5-12	BE		^{137}Cs removed; appears to be dragdown.
	12.5-98	None	Ina.	No man-made contaminants detected.
	98.5	BE	Inc.	^{137}Cs removed; fell in from the ground surface.
52-04-09	0	BE	Inc.	Isolated ^{137}Cs at the ground surface removed.
	0.5-83	None	Ina.	No man-made contaminants detected.
	83.5-99	BE	Inc.	^{137}Cs removed.
52-04-10	0-1	SS	Inc.	^{137}Cs included.
	1.5-66.5	None	Ina.	No man-made contaminants detected.
	67-129.5	BE	Inc.	Isolated ^{137}Cs removed.
	130-141.5	None	Ina.	No man-made contaminants detected.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available; the borehole is finished with grout and multiple casings.

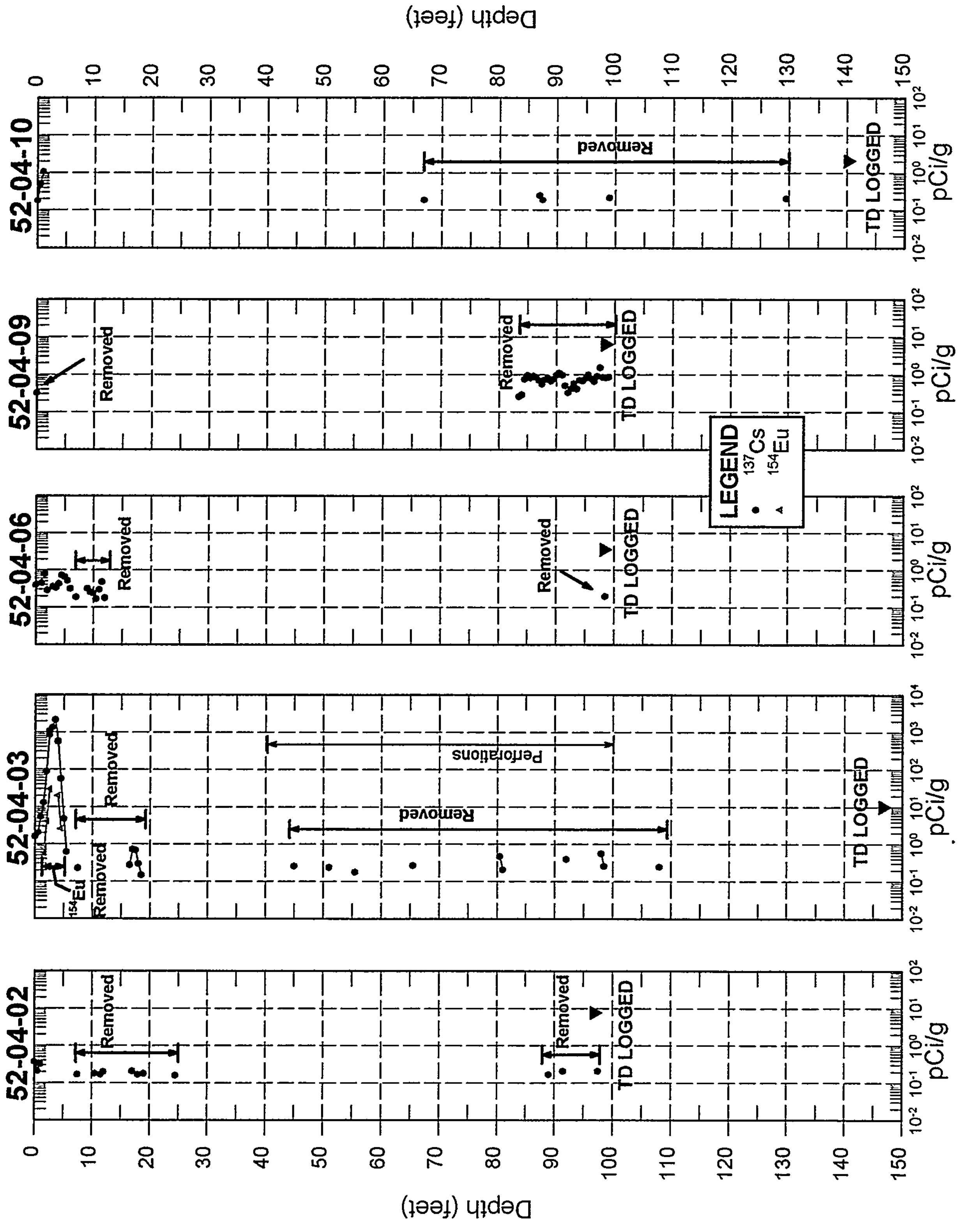


Figure C-4. Summary of Interpreted Data Set for the TY Tank Farm

Table C-5. Summary of Interpreted Data Set for TY-105 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-05-07	1-10.5	SS[b]	Inc.[j]	^{137}Cs and ^{60}Co included.
	11-17.5	None	Ina.[k]	No man-made contaminants detected.
	18-22.5	BE[c]	Inc.	^{137}Cs removed; appears to be dragdown.
	23-50.5	None	Ina.	No man-made contaminants detected.
	51-76.5	P[d]	D[g]	^{137}Cs and ^{60}Co included. H/D[e] indicate contaminants between 51 and 100 ft were unstable from an early date; the decay rate indicates that ^{125}Sb may have also been present between 51 and 82 ft.
	77-86.5			^{60}Co included; ^{137}Cs not detected.
	87-88			^{60}Co included; ^{137}Cs removed.
	88.5-97			^{60}Co included, ^{137}Cs not detected. ^{60}Co is present at the bottom of the logged interval, suggesting that the maximum depth of the contaminant plume has not been determined.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available; the borehole is finished with grout and multiple casings.

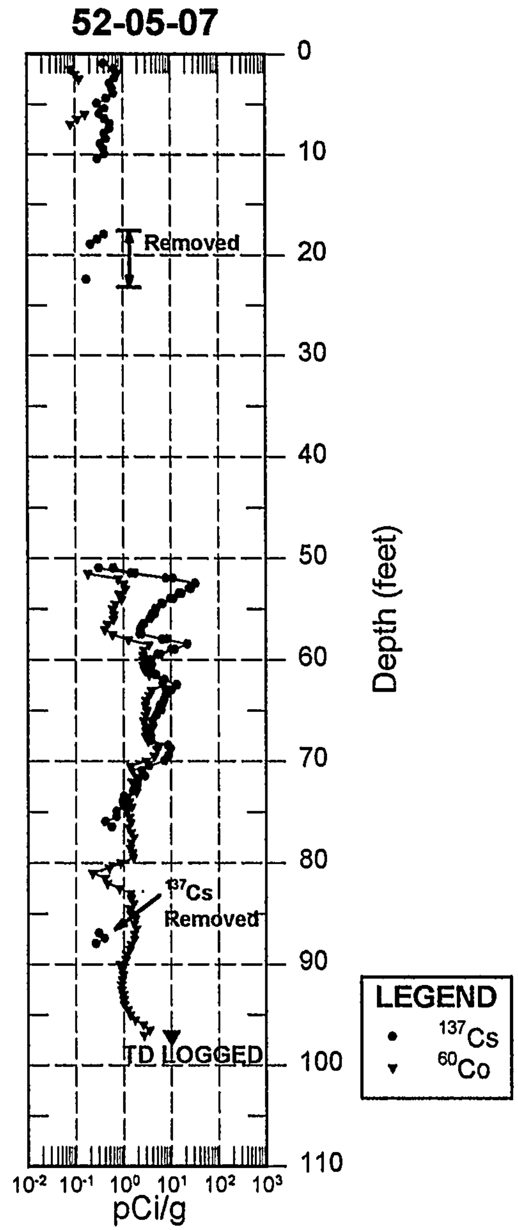


Figure C-5. Summary of Interpreted Data Set for the TY Tank Farm

Table C-6. Summary of Interpreted Data Set for TY-106 Boreholes

Borehole	Depth Interval (ft)	Source[a]	SFA[f]	Disposition/Comments
52-06-02	0-6.5	SS[b]	D[g]	^{137}Cs included.
	7-64	BE[c]	Inc.[j]	^{137}Cs removed.
52-06-04	0.5-31	BE	Inc.	^{137}Cs removed.
	31.5-50.5	None	Ina.[k]	No man-made contaminants detected.
	51-53.5	P[d]		^{137}Cs included. The ^{137}Cs contamination is located below the base of tank TY-106. H/D[e] indicate contaminants between 47 and 56 ft were stable; the decay rate indicates that ^{125}Sb may have also been present.
	54-56.5	None	Ina.	No man-made contaminants detected.
	57	BE	Inc.	Isolated ^{137}Cs removed.
	57.5-98	None	Ina.	No man-made contaminants detected.
52-06-05	0-1 and 2.5	SS	R	^{137}Cs and ^{60}Co included.
	3-43.5	None	Ina.	No man-made contaminants detected.
	44-47	BE	Inc.	^{137}Cs removed.
	52-71.5	P		^{137}Cs and ^{60}Co included. H/D indicate contaminants between 50 and 90 ft were unstable from an early date. Perforated casing between 40 and 100 ft.
	72-148			^{60}Co included. ^{60}Co is present at the bottom of the logged interval, suggesting that the maximum depth of the contaminant plume has not been determined.
	86.5-133.5	BE		^{137}Cs removed.

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available; the borehole is finished with grout and multiple casings.

Table C-6 (con't.). Summary of Interpreted Data Set for TY-106 Boreholes

Borehole	Depth Interval (ft)	Source [a]	SFA [f]	Disposition/Comments
52-06-06	0.5-24	SS	D	^{137}Cs included.
	24.5-37	BE	Inc.	^{137}Cs removed.
	37.5-85.5	None	Ina.	No man-made contaminants detected.
	86-100	P	Inc.	^{60}Co included. ^{60}Co is present at the bottom of the logged interval, suggesting that the maximum depth of the contaminant plume has not been determined.
52-06-07	0.5-2, 54.5, and 195.5-198.5	BE	N/A [l]	^{137}Cs removed. Double casing and grout are present from 0 to 199 ft. H/D not available below 150 ft.
	200-237	P	Inc.	^{60}Co included. The log plot presents both SGLS baseline (Event A) and repeat data (Event B). Event B data were extrapolated backward to match the baseline's logging date (05/15/96) for consistency with the interpreted data set. Perforated casing between 199 and 237 ft. Contamination may extend to depths greater than the borehole depth. (Data are excluded from visualizations; see text for discussion.)

[a] Source - Source of contamination in judgment of analyst.
[b] SS - Surface spill.
[c] BE - Borehole effects (e.g., dragdown, inside/outside casing contamination).
[d] P - Probable contamination plume.
[e] H/D - Historical data from Myers et al. (1999).
[f] SFA - Shape Factor Analysis.
[g] D - Contamination distributed in formation.
[h] Local - SFA indicates contamination is confined to the vicinity of the borehole casing.
[i] R - Contamination is remote from borehole.
[j] Inc. - Inconclusive generally due to low or rapidly changing concentrations.
[k] Ina. - Inapplicable to apply shape factor method in this instance.
[l] N/A - Not available, the borehole is finished with grout and multiple casings.

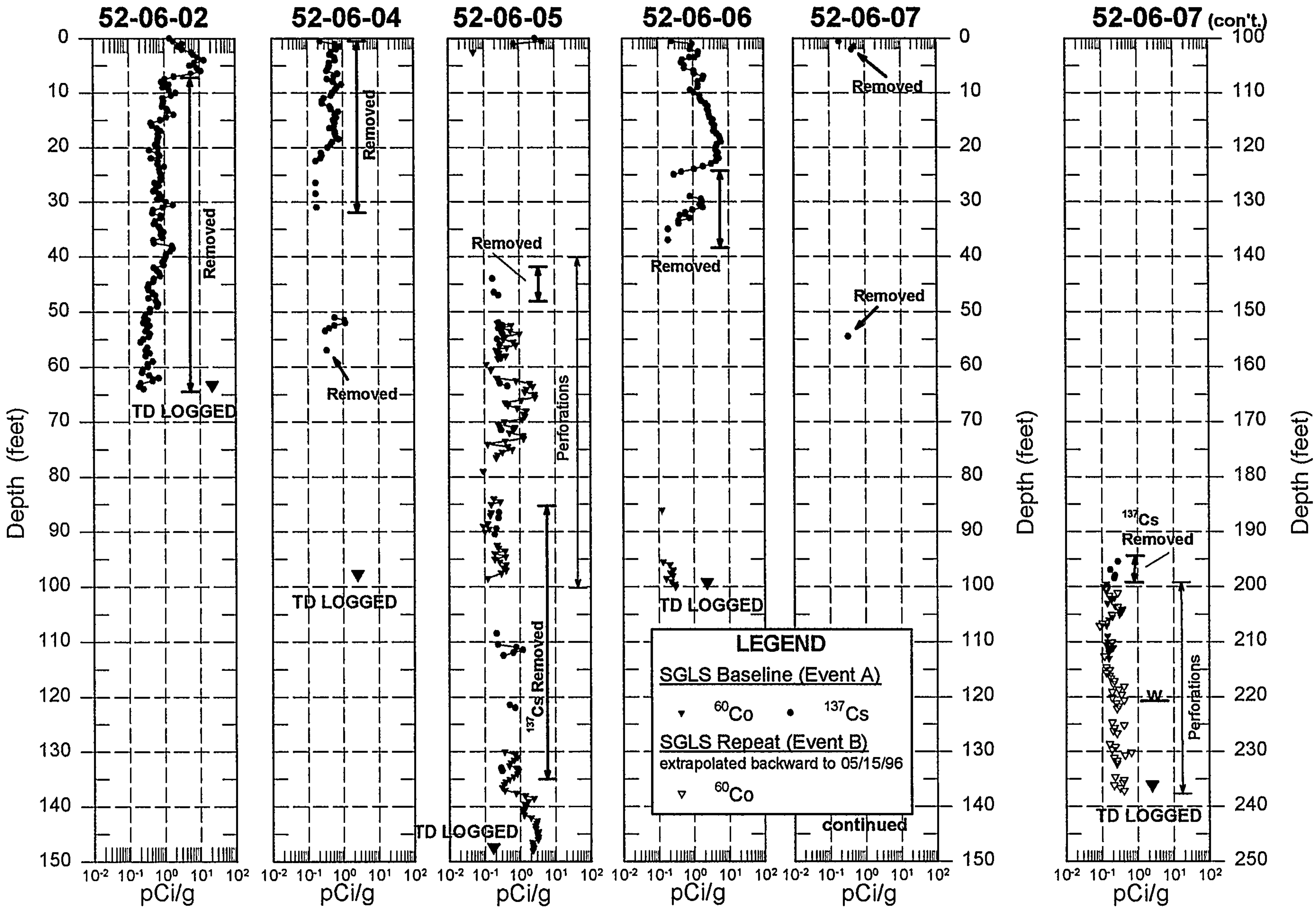


Figure C-6. Summary of Interpreted Data Set for the TY Tank Farm

Appendix D
TY Tank Farm Visualizations

Assumed leakers (Hanlon 2000) *are shown in red text.*

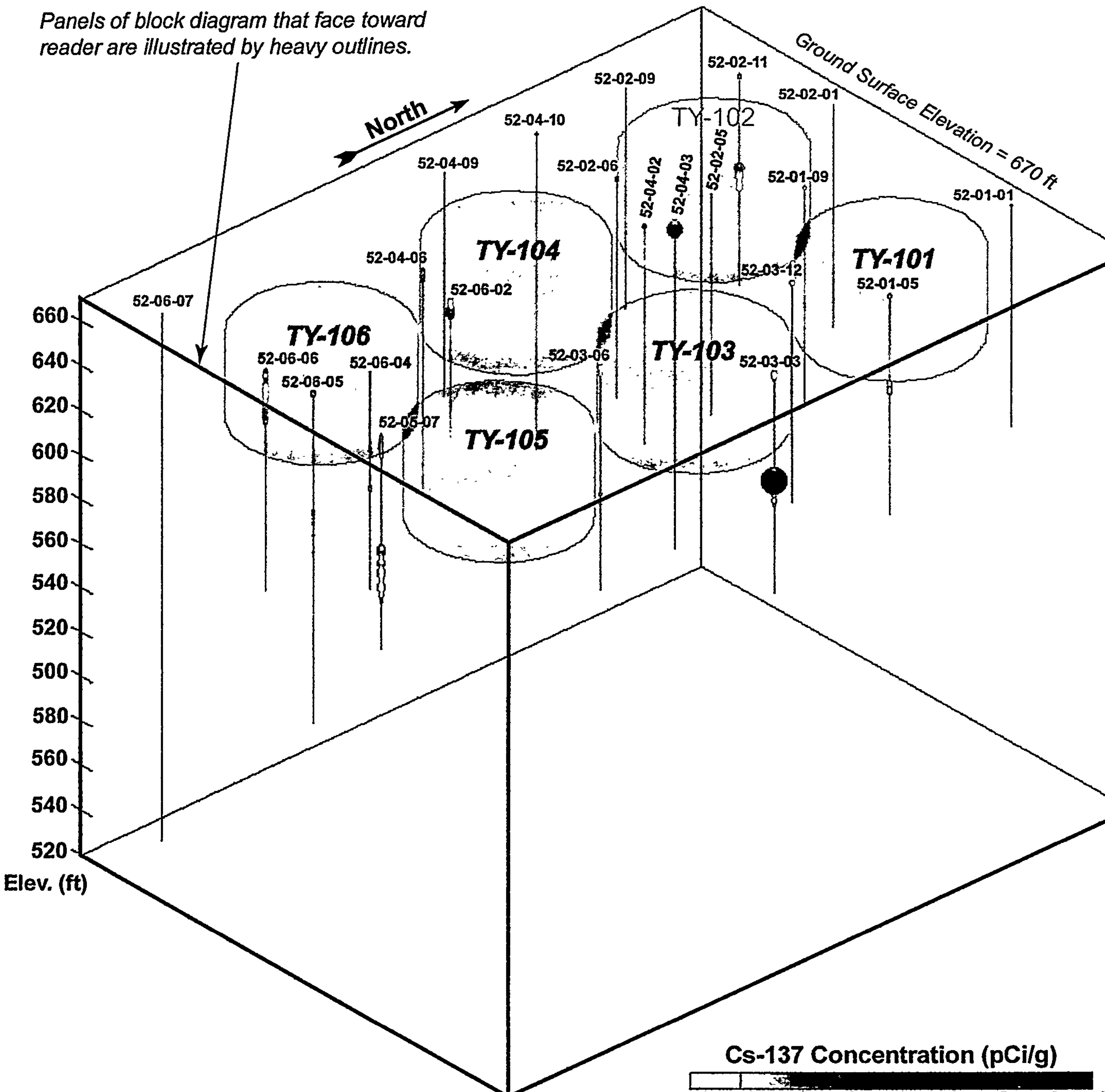


Figure D-1. TY Tank Farm Visualization

Assumed leakers (Hanlon 2000) *are shown in red text.*

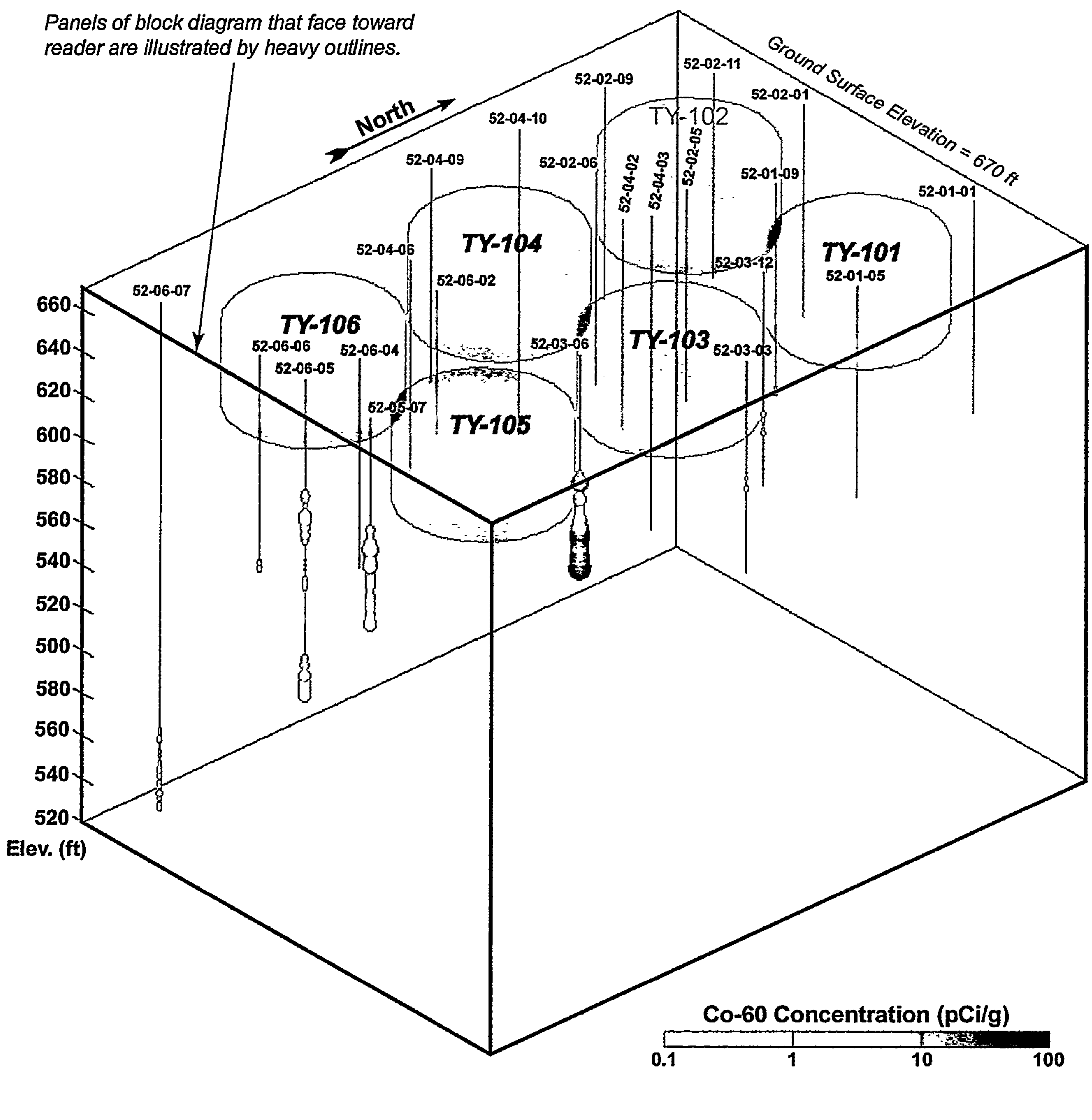


Figure D-2. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

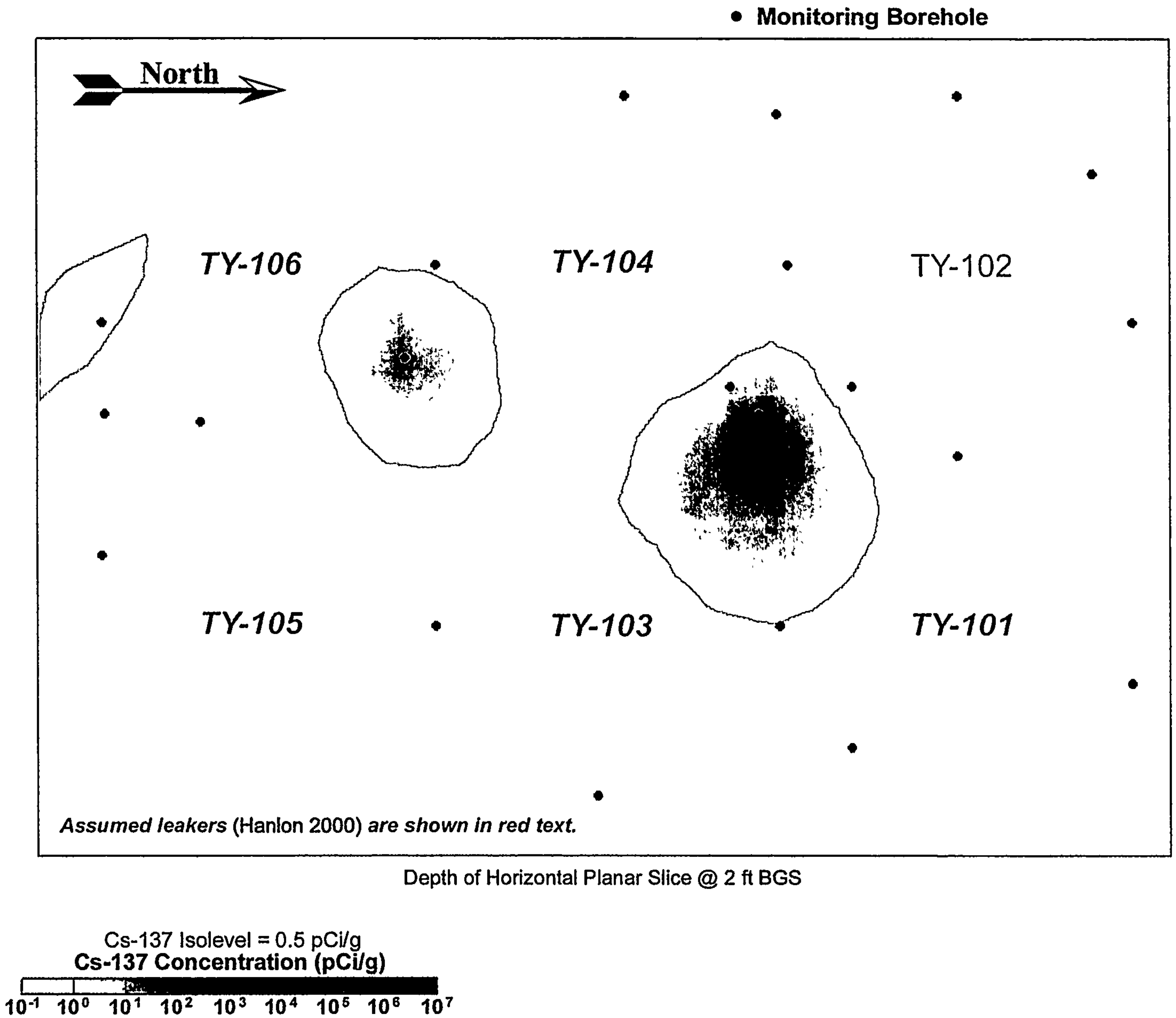


Figure D-3. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

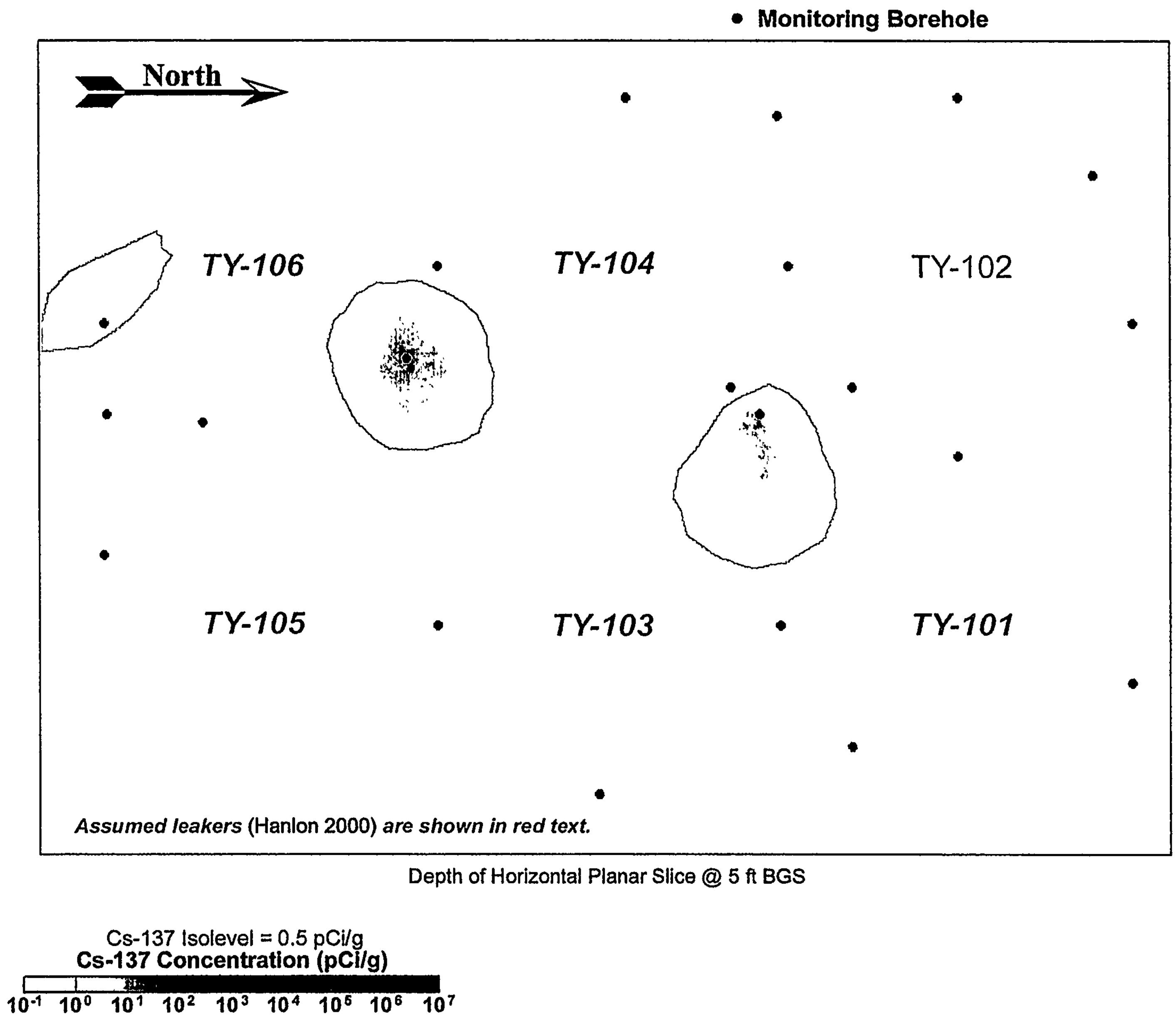


Figure D-4. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

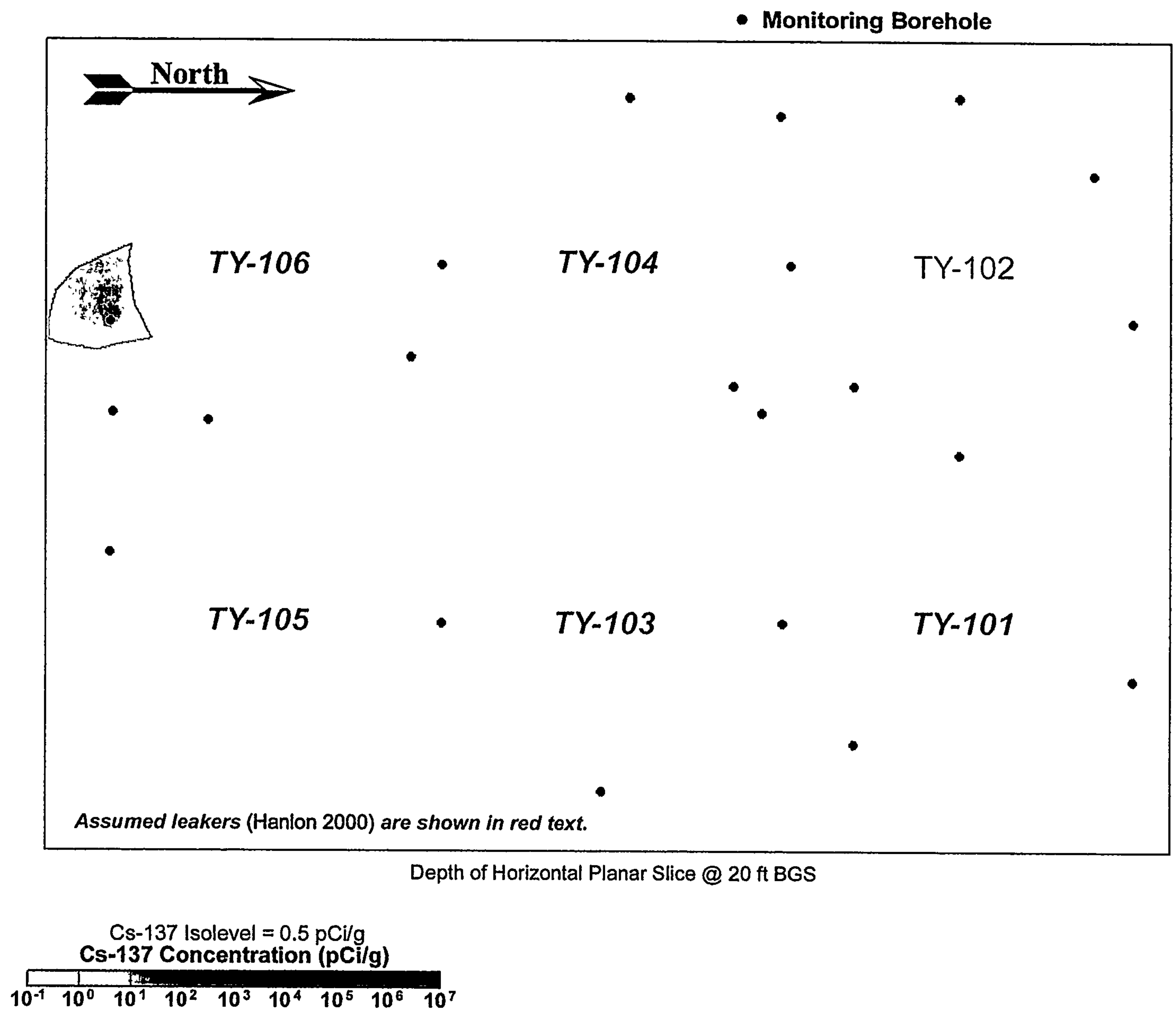


Figure D-5. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

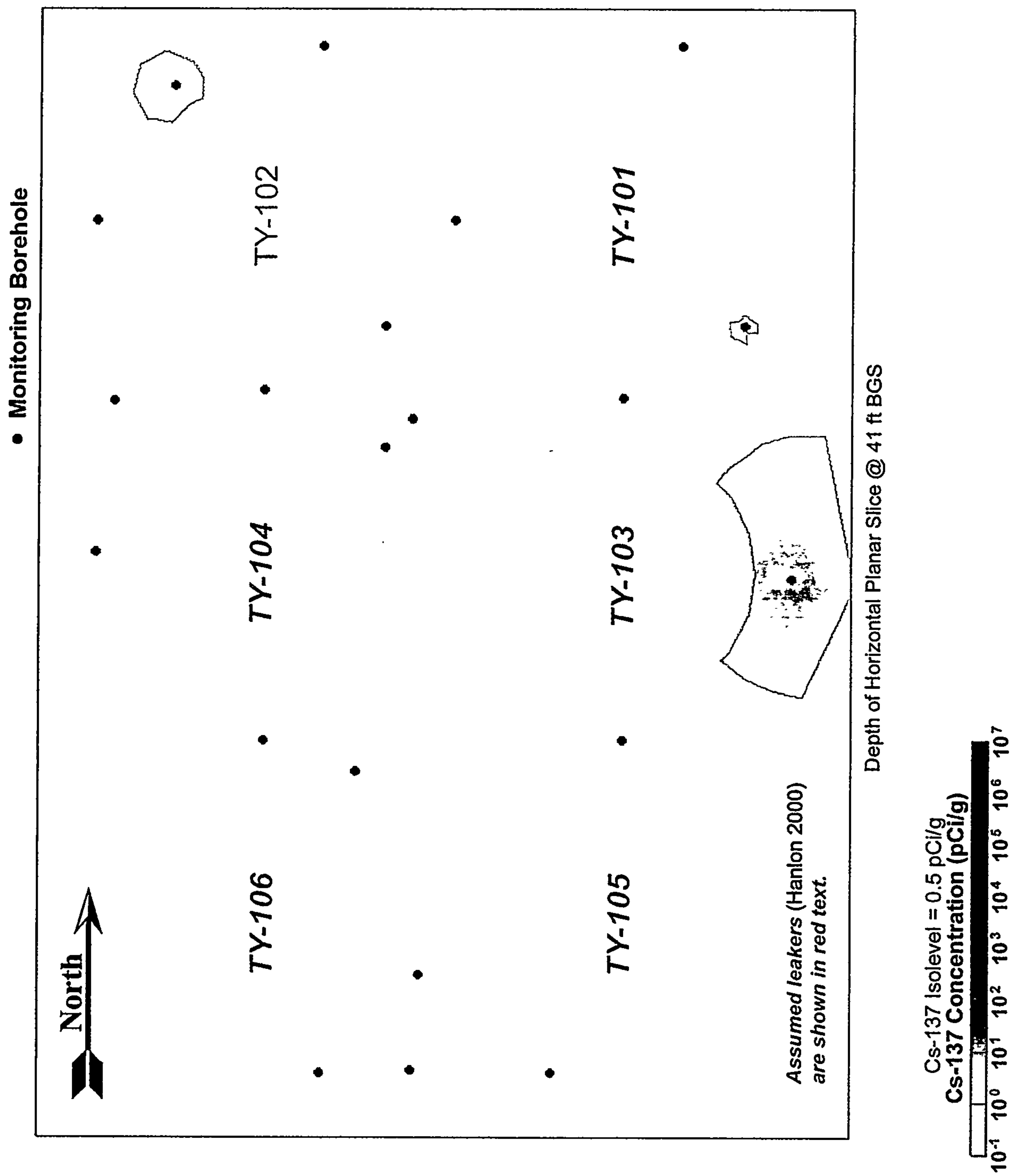


Figure D-6. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

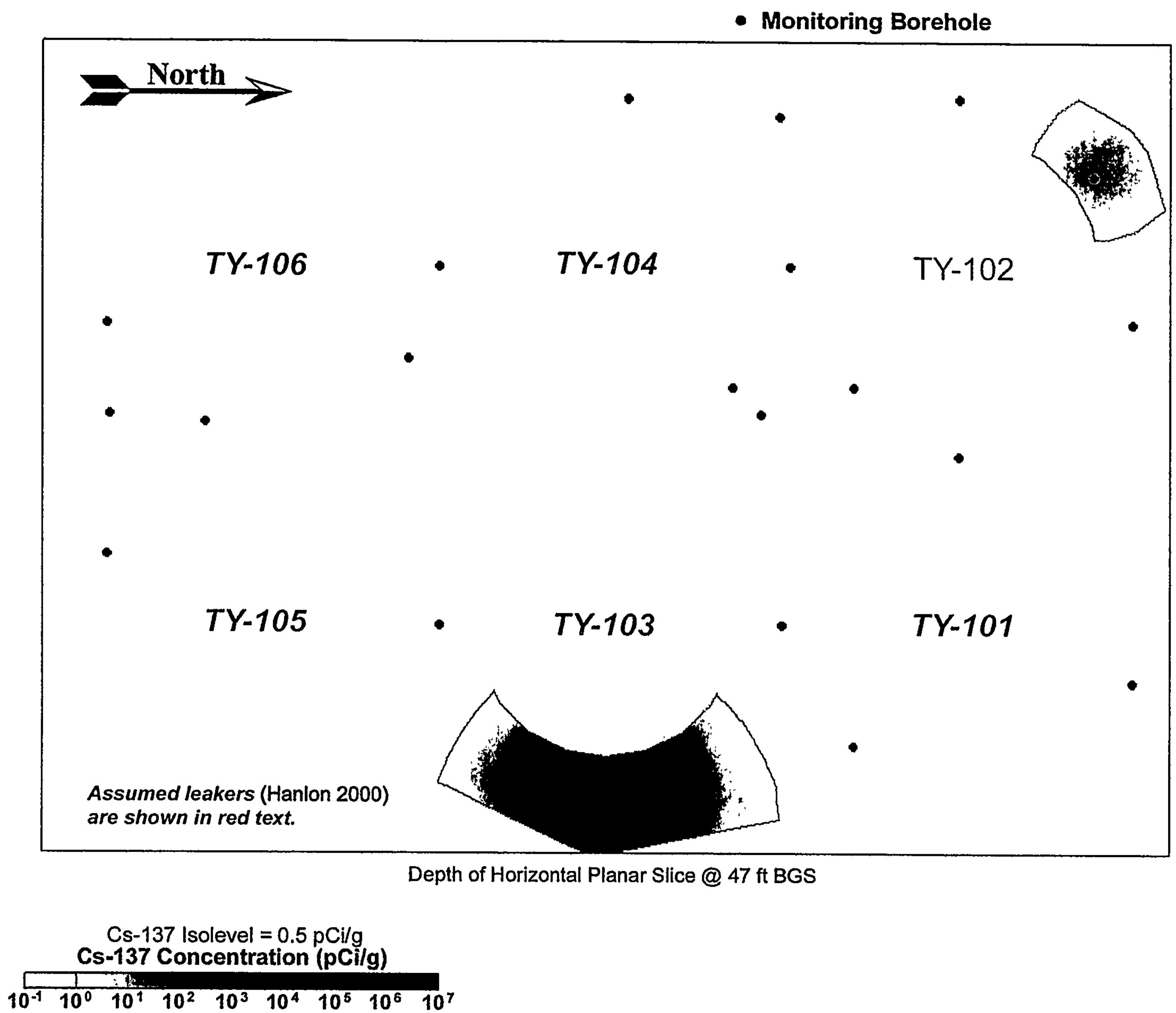


Figure D-7. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

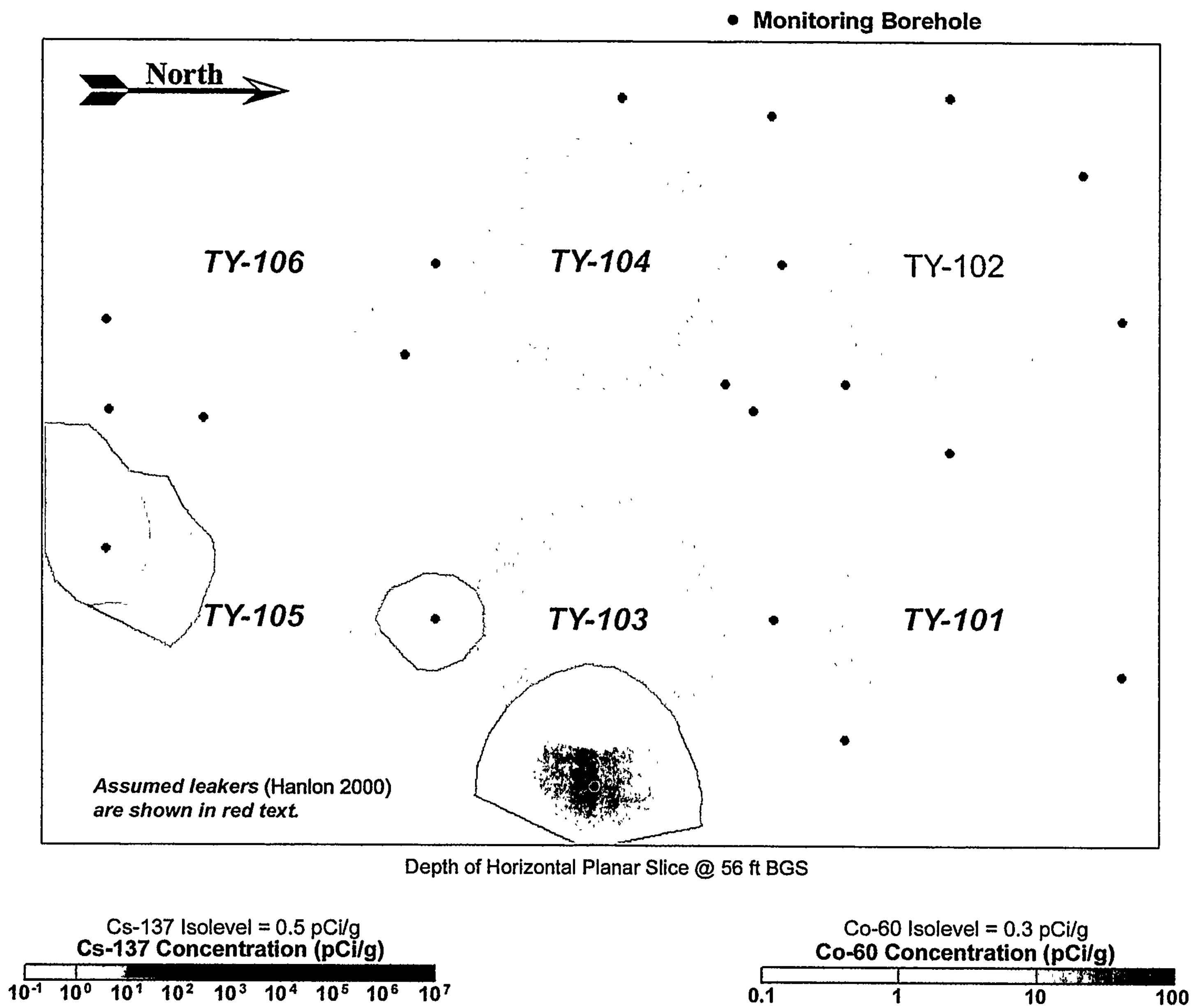


Figure D-8. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

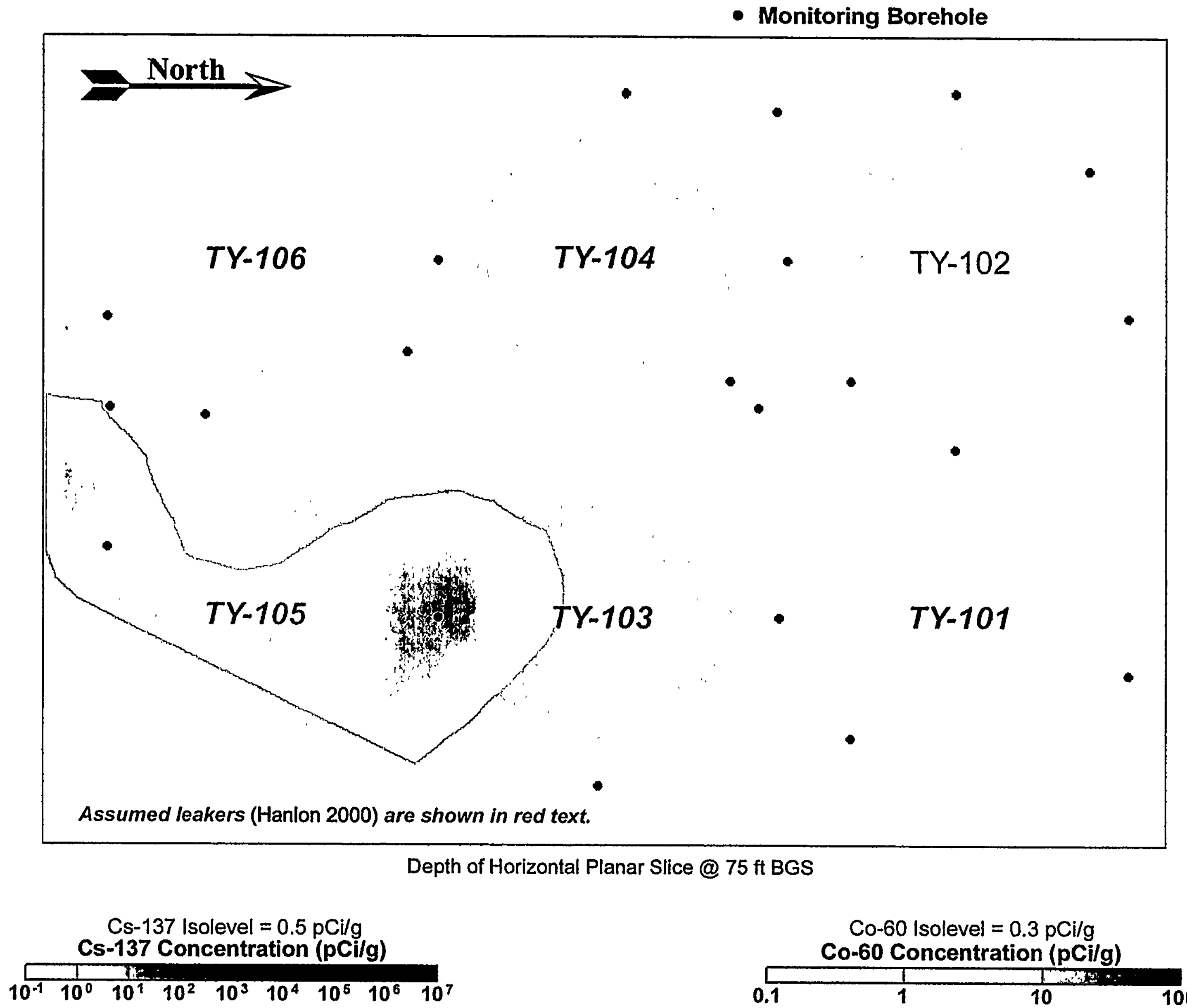


Figure D-9. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

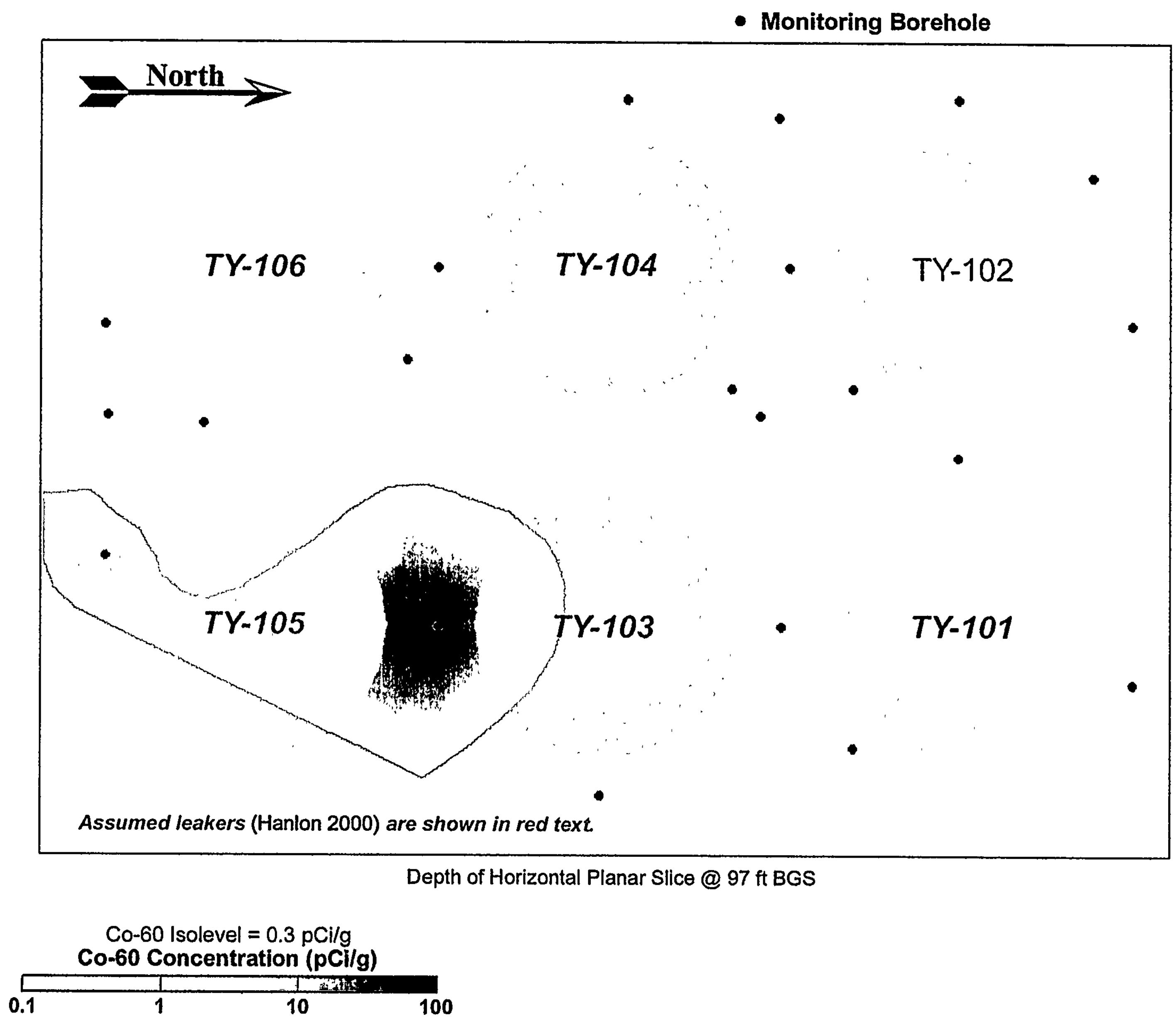
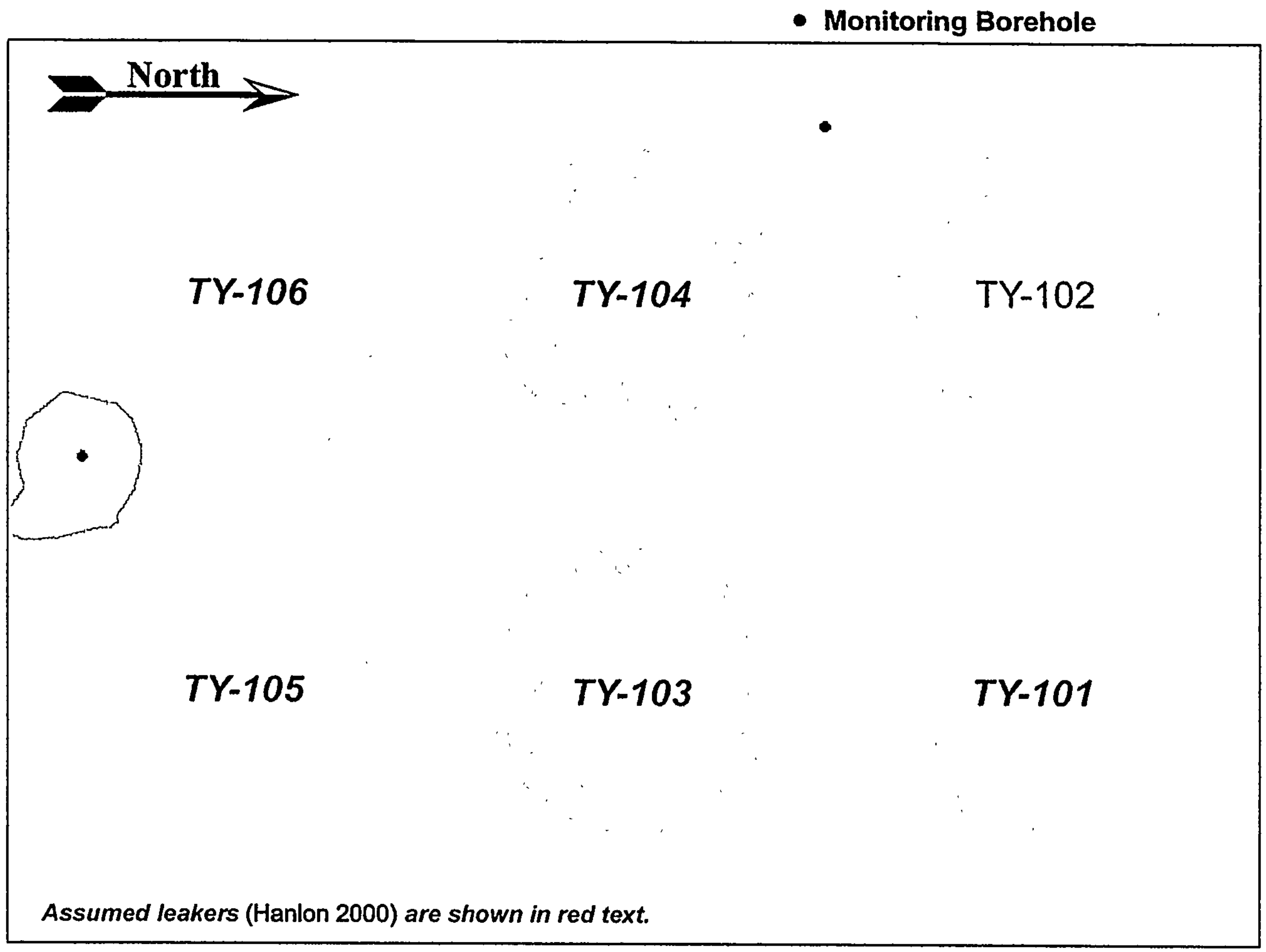


Figure D-10. TY Tank Farm Visualization

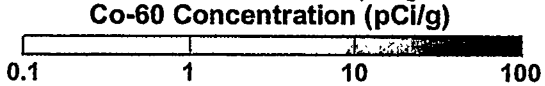
The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.



Depth of Horizontal Planar Slice @ 133 ft BGS*

Co-60 Isolevel = 0.3 pCi/g

Co-60 Concentration (pCi/g)



**Only boreholes that penetrate to this depth are shown on the visualization.*

Figure D-11. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

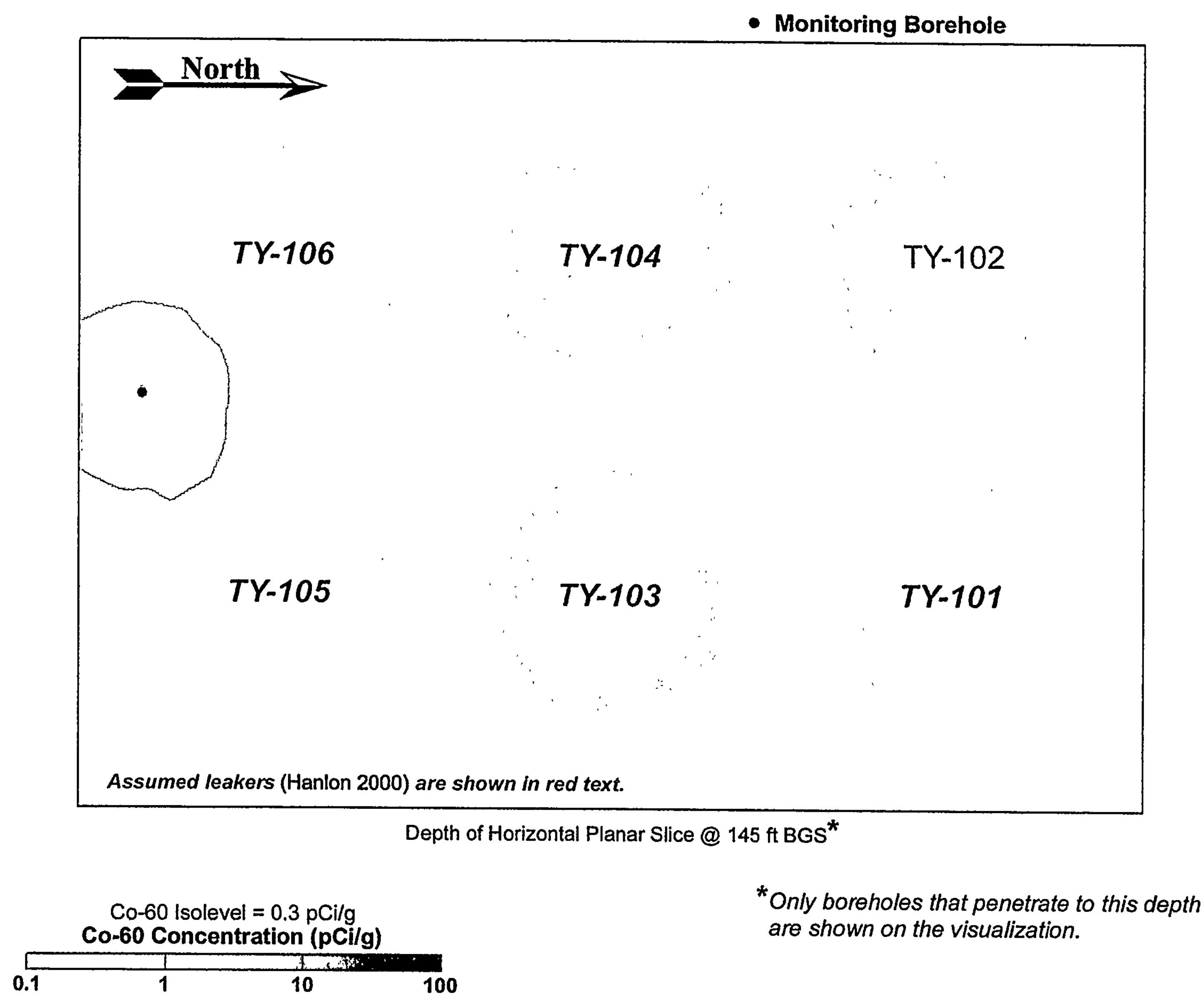


Figure D-12. TY Tank Farm Visualization

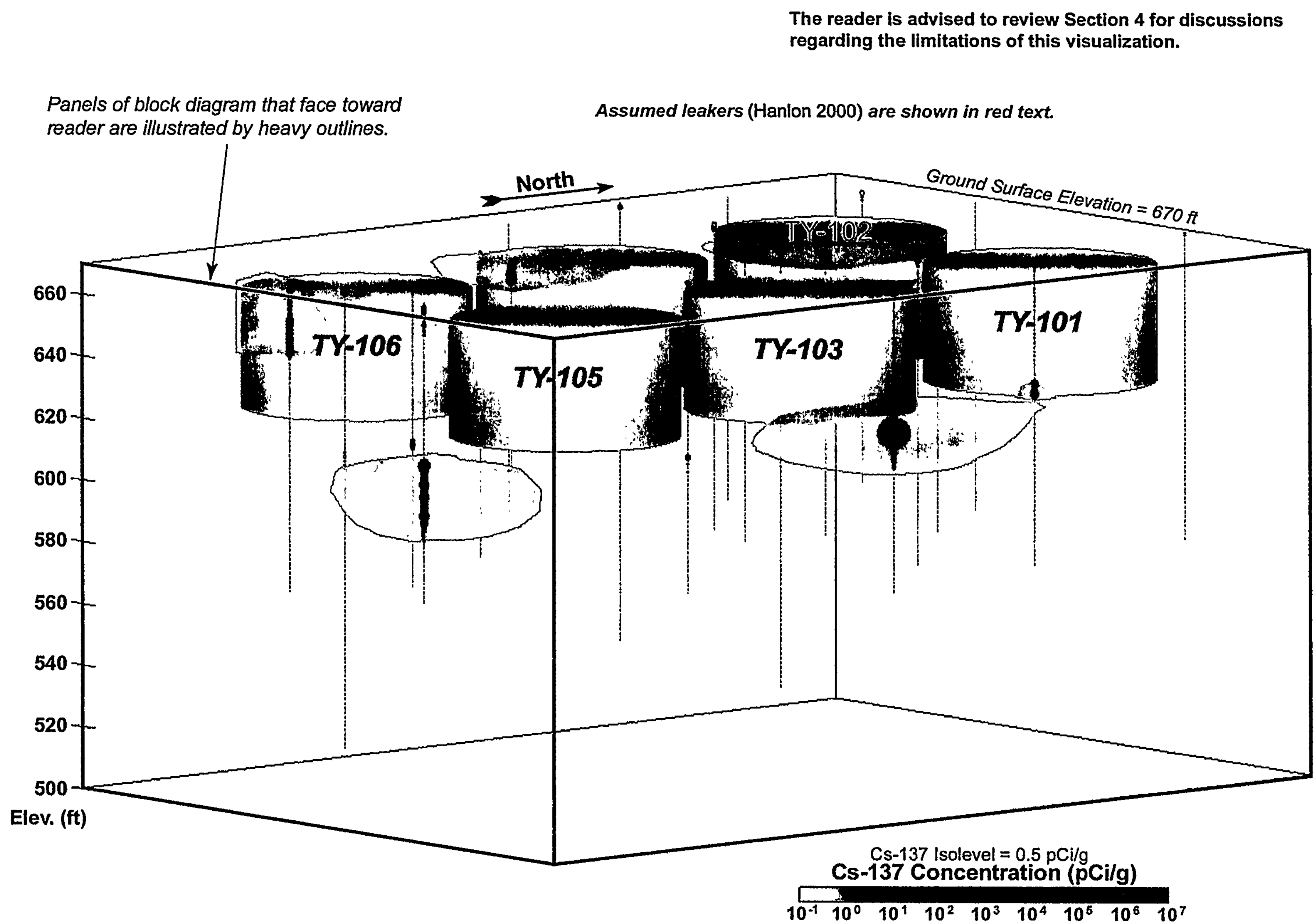


Figure D-13. TY Tank Farm Visualization

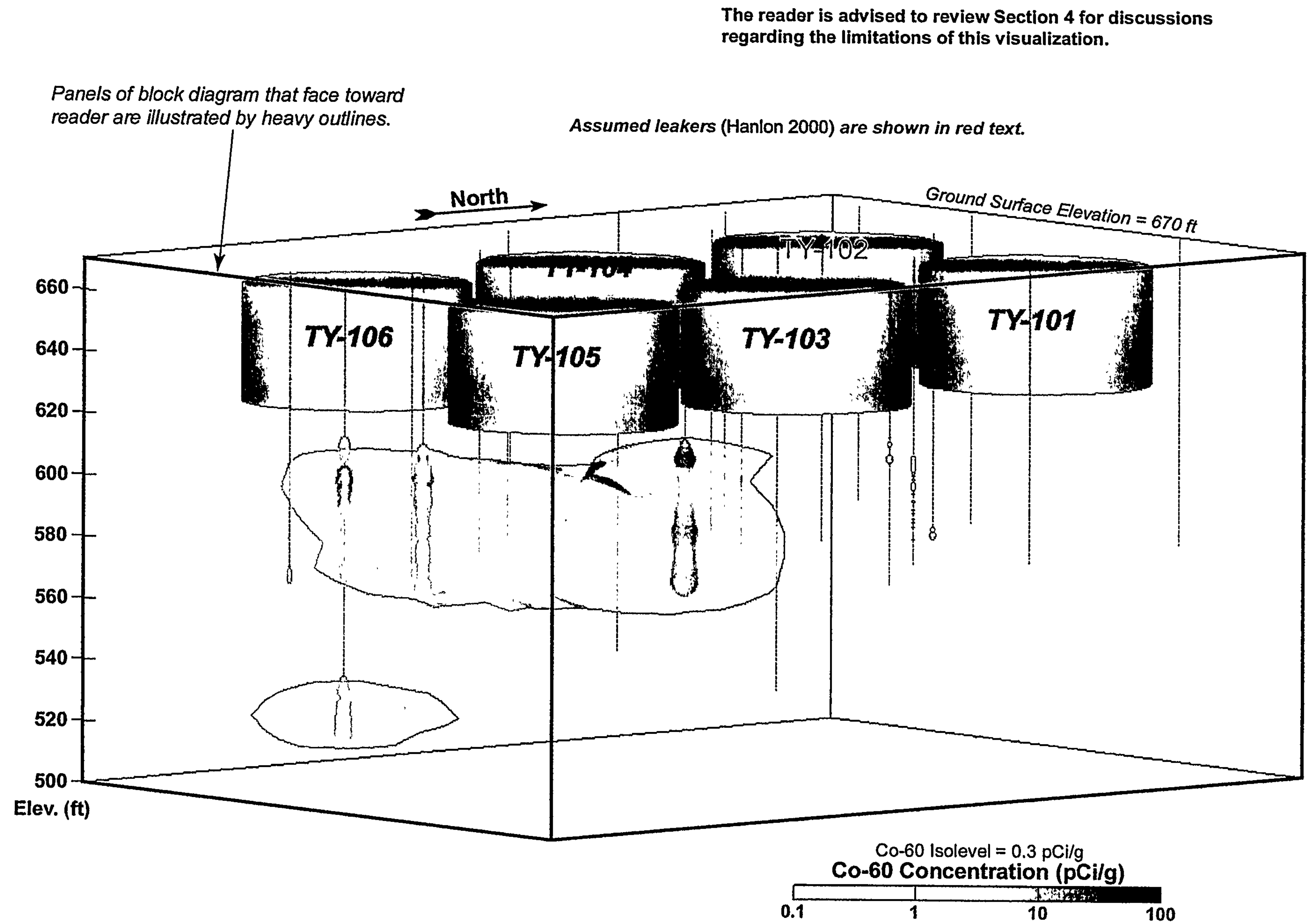


Figure D-14. TY Tank Farm Visualization

The reader is advised to review Section 4 for discussions regarding the limitations of this visualization.

Panels of block diagram that face toward reader are illustrated by heavy outlines.

Assumed leakers (Hanlon 2000) ***are shown in red text.***

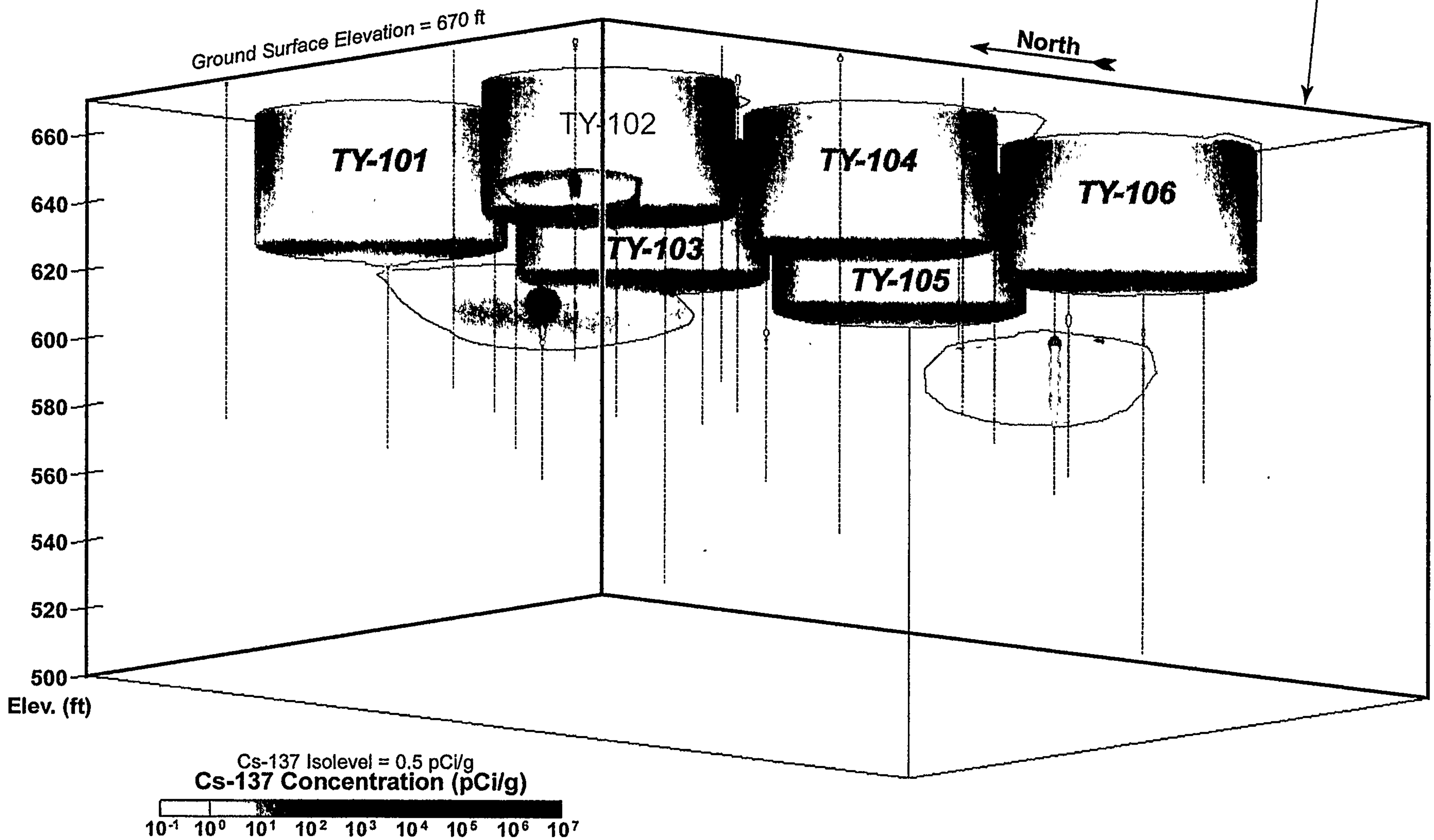


Figure D-15. TY Tank Farm Visualization

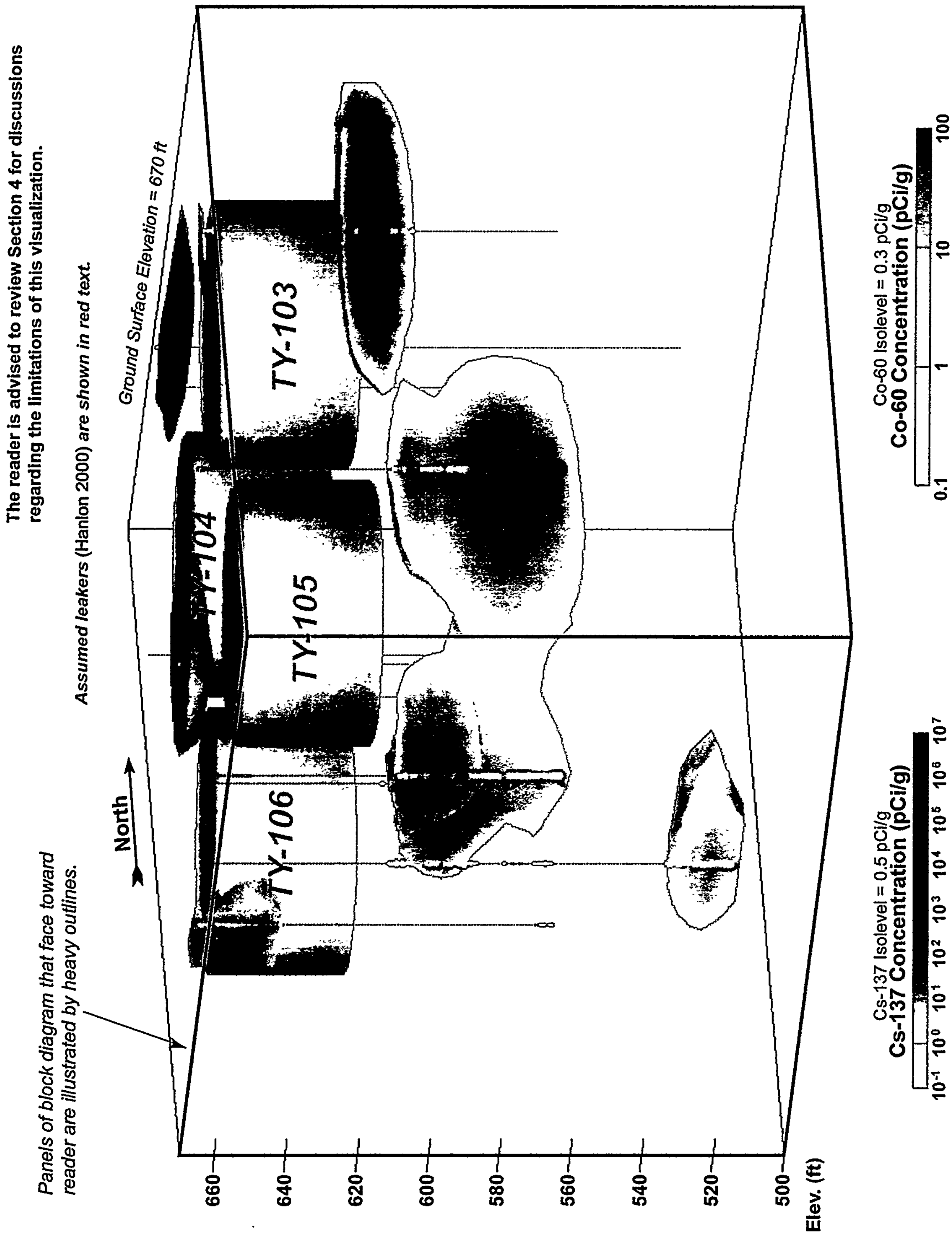


Figure D-16. TY Tank Farm Visualization