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Carlsbad Area Office
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Statistical Summary of the Radiological Baseline Program for the WIPP

STATISTICAL SUMMARY OF THE RADIOLOGICAL BASELINE PROGRAM FOR THE WASTE ISOLATION PILOT PLANT

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Executive Summary

The report presents summary statistics and probability models for data collected during the Radiological Baseline Program (RBP) at the Waste Isolation Pilot Plant (WIPP). This program was designed to provide preoperational measurements of radioactivity in environmental samples that will serve as a basis for evaluating similar data collected during the WIPP Operational Environmental Monitoring Program. The RBP data analyzed in this report cover the period from 1985 through 1989. Sample types included in this report are airborne particulates, soil, surface water, groundwater, sediments, and six types of biotic tissue sample.

Airborne particulate samples were measured for gross beta activity, gross alpha activity, and concentrations of 22 individual radionuclides. Soil samples were analyzed for 19 radionuclides. Surface and groundwater samples were analyzed for 18 radionuclides. Sediment and biotic tissue samples were analyzed for 17 radionuclides.

Statistical summaries for these data bases include estimation of the mean, standard deviation, standard error, and coefficient of variation. Probability modeling was conducted on those data sets that exhibited random behavior. The normal and 2- or 3-parameter lognormal distributions were found to provide good models for most data bases. Critical values at the 0.80, 0.90, 0.95, and 0.99 probability levels were estimated for each data base. These values are appropriate for establishing warning and action levels for control charts during the Operational Environmental Monitoring Program.

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) is a U.S. Department of Energy (DOE) research and development project to demonstrate the safe disposal of waste materials contaminated with transuranic (TRU) radionuclides from defense programs. From 1986 through 1989, the WIPP Radiological Baseline Program (RBP) was dedicated to characterizing the radiological environment in the vicinity of WIPP prior to the start of waste handling operations. The preoperational data collected during the RBP, along with operational data collected at control locations, will serve as a basis for evaluating the results of the WIPP Operational Environmental Monitoring Program (OEMP). This report presents statistical summaries of the RBP data bases in a form that will facilitate their use in the OEMP.

1.1 WIPP Site Description

The WIPP Site is in a remote location in southeastern New Mexico, approximately 40 kilometers east southeast of Carlsbad, New Mexico. This area, called Los Medanos ("the dunes"), is a flat, sandy plain on the western edge of the Llano Estacado. The site is underlain with thick beds of Permian-aged sediments and evaporites. The halite-dominated Salado Formation, which is approximately 600 meters thick at the WIPP Site, will be the medium for isolating the waste material.

The climate of the Los Medanos area is warm-temperate and semiarid. Weather parameters have been monitored at the WIPP facility since 1985 and have been summarized yearly in the WIPP Annual Site Environmental Monitoring Reports (Reith et al., 1986; Banz et al., 1987; Flynn, 1988 and 1989; DOE, 1990). Summer high and winter low extremes in temperature are typically near 40 degrees and -10 degrees centigrade, respectively. Annual precipitation averages about 30 centimeters, with most falling in the summer. The prevailing wind in the area is from the southeast. Due to the midcontinental location of the site, however, most weather parameters are prone to extremes and rapid change.

The soils of the Los Medanos area are dominated by eolian sand of the Berino and Kermit Series (Soil Conservation Service, 1971). These soils are susceptible to wind erosion but are typically stabilized by vegetation. Shrubs, especially shinnery oak (*Quercus havardii*) and mesquite (*Prosopis glandulosus*), form coppice dunes that dominate the area. Perennial grasses, such as giant dropseed (*Sporobolus giganteus*), sand dropseed (*S. cryptandrus*), and fall witchgrass

(*Leptoloma cognata*), and sandbur (*Cenchrus insertus*), are important elements in the vegetation and aid in stabilizing the soil.

Due to the sandy nature of the soil and the undulating surface created by the coppice dunes, surface runoff is minimal, and effective precipitation is high. The soils are underlain (typically at a depth of about 2 meters) by a well-developed, Pleistocene-aged caliche (the Mescalero caliche), which impedes the percolation of water and leaves it available to evapotranspiration.

Wildlife in the area shows influences from both the Great Plains and the Chihuahuan desert. High densities of breeding birds of prey, especially Swainson's hawks (*Buteo swainsoni*), Harris's hawks (*Parabuteo unicinctus*), and great horned owls (*Bubo virginianus*), have been recorded in the Los Medanos (Bednarz and Hayden, 1988). These populations are supported by a small-mammal prey-base of cottontail rabbit (*Sylvilagus* sp.), ground squirrel (*Spermophilus* sp.), and nocturnal rodents, chiefly Ord's kangaroo rat (*Dipodomys ordii*). Game animals in the area include scaled quail (*Callipepla squamata*), northern bobwhite (*Colinus virginianus*), and mule deer (*Odocoileus hemionus*).

The principal land uses in the Los Medanos area are livestock (cattle) grazing and hydrocarbon (oil and gas) production. The three nearest residences to the WIPP Site are the Mill's ranch, approximately 6 kilometers south of the facility; the Smith ranch, approximately 9 kilometers west of the facility; and the Mobley Ranch, approximately 10 kilometers southwest of the facility.

Seven kilometers to the northwest of WIPP, the Los Medanos surface abruptly drops approximately 30 meters into Nash Draw, a wide depression containing several playa lakes, the largest of which is Laguna Grande de la Sal. Several potash mines and associated refining plants and outlying shaft facilities are located in Nash Draw.

The Pecos River is approximately 22 kilometers southwest of the WIPP Site at its nearest point. The Pecos flows from north to south through the city of Carlsbad. Several other municipalities in southeastern New Mexico, including Artesia and Loving, border its west bank. The river is used primarily for irrigation and recreation (fishing and boating) and has several flood-control and diversion dams along its course, the largest of which is Brantley Dam (constructed during the course of the RBP), McMillan Dam (replaced by Brantley and now breached), Avalon Dam, and Red Bluff Dam (immediately south of the New Mexico-Texas border).

An important event in the radiological history of the WIPP area is Project Gnome (see Mercer et al., 1989). In 1961, the U.S. Atomic Energy Commission detonated a 3-kiloton nuclear device in the Salado Formation approximately 12 kilometers southwest of the present WIPP Site. This test, which was part of the Plowshares Project, and subsequent experiments in radionuclide mobility resulted in radioactive surface and groundwater contamination in that area. Decontamination efforts have since reduced the surface radioactivity to approximately background levels (DOE, 1981; EG&G, 1988), although local groundwater radioactivity is still elevated (AEC, 1973).

1.2 WIPP Project Description

The WIPP repository is being mined at a level of 655 meters below the ground surface in the Salado Formation. The repository is accessed through four shafts: the Waste Handling Shaft, which is covered at the surface by the Waste Handling Building; the Salt Handling Shaft, through which mined salt is brought to the surface for placement and storage on a stockpile; the Air Intake Shaft, which provides a supplemental source of surface air to ventilate the repository; and the Exhaust Shaft, through which outgoing air is conducted and, if necessary, diverted through high-efficiency particulate air (HEPA) filters contained in the Exhaust Filter Building.

The projected 25-year operational period of the WIPP Project will be preceded by a 5-year Test Phase in which limited quantities of Contact-Handled (CH) TRU waste will be emplaced within instrumented bins and alcoves to test repository performance parameters. Based on the results of these tests, a decision will be made as to whether the operational phase will proceed. If it does, waste emplacement will proceed for both CH and Remote-Handled (RH) TRU waste. If the repository is found to be unsuitable, the experimental waste will be retrieved and the facility closed.

The CH waste will be shipped to WIPP in specially designed Transuranic Package Transporters, called TRUPACT-IIs. The RH waste will be transported in shielded casks. Transport containers will only be opened inside of the Waste Handling Building, where air flow is controlled through HEPA filter systems. A variety of on-site systems are in place that will monitor personnel and work areas for airborne radioactive contamination.

1.3 Environmental Monitoring Programs

The goal of the WIPP environmental monitoring programs is to verify that the waste handling operations are not contaminating the surrounding accessible environment. The design of the monitoring programs follows the two-phase approach described by Green (1979). In this approach, the existing (unimpacted) environment is characterized in a baseline study (the RBP). During the time of potential impact, an environmental monitoring program (the OEMP) is directed at detecting the impact, should it occur. The baseline data provide the standards against which the changes are detected. Non-WIPP-related changes in environmental parameters during the operational period will be accounted for through the use of control sites.

The designs of the RBP and OEMP are described in detail in Mercer et al. (1989). The RBP is divided into five subprograms, as follows:

- The Airborne Particulate Baseline (air sampling)
- The Ambient Radiation Baseline (penetrating radiation monitoring)
- The Terrestrial Baseline (soil sampling)
- The Hydrologic Baseline (groundwater and surface water sampling)
- The Biotic Tissue Baseline (animal and vegetation sampling).

The ambient radiation baseline, which consists of three elements (environmental dosimetry, aerial gamma survey, and high-pressure ionization chamber [HPIC] gamma radiation monitoring), are not summarized in this report. Environmental dosimetry will not be continued in the OEMP, while the aerial gamma survey, which represents continuous spatial coverage at a single point in time, and HPIC monitoring, which represents continuous temporal coverage at a single point in space, are not amenable to the type of statistical summarization presented here. The HPIC data are presented in the Annual Site Environmental Monitoring Reports (Banz et al., 1987; Flynn, 1988 and 1989; DOE, 1990). Descriptions of the other RBP subprograms are presented in the respective summary sections of this report (Sections 3.0 through 7.0).

1.4 RBP Data Collection and Quality Assurance

All data summarized in this report are from samples of environmental media collected in accordance with the WIPP Environmental Procedures Manual, WP02-3. Sample preparation, such as preservation, weighing, drying, ashing, and packaging, was conducted either in the field or at the WIPP Sample Preparation Laboratory, as required. Chain-of-custody documentation was maintained for all samples.

Sample analysis was contracted to the Waltz Mill laboratory of the Westinghouse Advanced Energy Systems Division (WAESD). Laboratory quality control was maintained through routine calibration of instruments, routine yield determinations for radiochemical procedures, frequent source and background counts, reagent purity checks, routine duplicate analyses, and participation in inter-laboratory cross-checks (Flynn, 1989). The minimum detection limits (MDL) presented in this report are from Flynn (1989), with units converted to match the data analyses.

Analytical results that are less than the MDL (including negative results) are reported by the laboratory and have been included in these analyses as reported. Due to analytical methods, some radionuclides are commonly reported as being less than a maximum value. When such maximum values represent a small proportion of the data set, or when they are themselves random in behavior, statistical analyses may be performed on them (Gilbert, 1987). In this report, data sets with more than 10 percent "less than" values were not statistically analyzed unless the maxima were found to simulate a random process.

The Environmental Evaluation Group (EEG) conducts parallel and independent environmental monitoring at WIPP, including air, soil, water (surface, groundwater, and public drinking water), sediment, and biotic tissues. Splits of some RBP samples (soil, water, sediment, and tissues) have been provided to the EEG for independent analysis. The results and summary of the EEG preoperation environmental monitoring program are reported in Kenney et al. (1990). In general, the measurements of radioactivity and radionuclide concentrations in the EEG program are consistent with those of the RBP.

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2.0 Methods

The purpose of this analysis is to derive probability models of the analytical results of the RBP that can be used for the future evaluation of similar data derived from the OEMP. This purpose is distinct from presenting a radiological characterization of the environment at and about the WIPP Site. The distinction between these two sampling objectives, i.e., descriptive sampling versus sampling for modeling (Eberhardt and Gilbert, 1980), must be clearly understood. The reader is cautioned that assumptions about the underlying precision and accuracy of the data and decisions about the statistical methodology used to analyze the data are not based on the goal of finding the most accurate single approximation of each parameter (e.g., the mean or a confidence range for the mean) as would be the case for a descriptive study. Rather, they are based on the goal of finding predictive probability models for evaluating each individual datapoint as it is generated during the OEMP.

Statistical analyses in this report were performed using Lotus® 1-2-3® Version 2.1 and Statgraphics®* Version 2.6. The methodology followed five steps:

- The individual RBP data bases were compiled from laboratory data reports onto Lotus 1-2-3 spreadsheets. Where appropriate, the data were scaled to minimize the use of large (positive or negative) exponents. The Lotus 1-2-3 spreadsheets were imported into Statgraphics file format.

- The data bases were evaluated, both subjectively (based on observable patterns or site knowledge) and statistically, for homogeneous subgroups. The data were stratified in accordance with these evaluations.

- Summary statistics were calculated for each subgroup.

- Where possible, probability distribution models were fitted to the data in each group.

- Critical values were estimated for each subgroup for four probability levels, 0.80, 0.90, 0.95, and 0.99.

The following sections describe the statistical methods used in these analyses.

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2.1 Probability Model

In its simplest form, the probabilistic model that describes each RBP parameter is:

$$x_{ij} = E(X) + r_{ij} \tag{2.1}$$

where x_{ij} is the measured value of the parameter X at location i and at time j, E(X) is the expected value of the parameter, and r_{ij} is an element of the random variable R, with mean zero. Both the value of E(X) and the shape of the probability distribution of R are determined by number of factors related to sampling. For the purposes of discussion, these are classified into two groups, environmental factors and procedural factors.

The environmental factors consist of three basic elements—the regional expected value of the parameter as it exists in the environment (not its measured value), the spatial variability of the parameter over the region, and the temporal variability of the parameter over a specified time. This may be written:

$$u_{ij} = E(U) + s_i + t_{ij} \tag{2.2}$$

where u_{ij} is the actual value (e.g., concentration of a radionuclide) of the parameter at location i and time j. E(U) is the expected value of the random variable U over all locations and times in the study. s_i and t_{ij} are random variables with mean zero that describe the spatial and temporal variability of the parameter. The variability with time is considered to be location-dependent, although this dependence may be weak in many cases.

The procedural factors consist of all sources of sampling and measurement error, whether systematic or random. Depending upon the degree of scrutiny with which the sampling and measurement activities are assessed, the number of identifiable factors can be large or small. Some of the more important general factors include counting error associated with both sample and background counts, self-shielding, error due to extraction processes, sample-handling techniques, and sample-collection techniques, including variability in sampling equipment.

Each factor may be seen as contributing two quantities to the final measurement of x_{ij} —a constant, or bias quantity, and a random quantity with mean zero. Thus, assuming that these factors are independent, the total effect of the procedural factors is:

$$p = \sum_{i=1}^{n} (b_i + e_i) \tag{2.3}$$

where p is the total error associated with the n procedural factors, b_i is the bias contributed by the i^{th} factor, and e_i is the random contribution of the i^{th} factor. This may be rewritten:

$$p = \sum_{i=1}^{n} b_i + \sum_{i=1}^{n} e_i$$

or,

$$p = b_p + e_p \tag{2.4}$$

where

$$b_p = \sum_{i=1}^{n} b_i$$

and

$$e_p = \sum_{i=1}^{n} e_i$$

Thus, b_p is the total amount of procedural bias expected in each measurement. Insufficient data are available to accurately quantify b_p, although some elements of bias, such as background counts within the sample count, have been estimated and corrected for in the data. In this report, it is assumed that bias is minimized and/or controlled through adherence to sample-collection procedures, analytical procedures, quality control procedures, and the participation in interlaboratory cross-checking (Flynn, 1989). The gross alpha counts on airborne particulate samples provides an example where a known change in analytical instrumentation resulted in a significant change in bias and required special consideration in the evaluation of the data (see Section 3.2).

The random element of the procedural factors, e_p, is independent of bias and will remain even if bias is completely eliminated or corrected for. As a sum of random variables with mean zero, e_p is also a random variable with mean zero. If all e_i's are independent, the variance of e_p will be the sum of their variances; however, the probability distribution of e_p will be a convolution of the probability distributions of the e_i's and thus is not readily predictable, although the Central Limit Theorem dictates that e_p will converge on a normal distribution as n increases (Mood et al., 1974).

The measured value of the parameter is composed of the actual value of the parameter in the environment (or the sampled environmental medium) at the time and location of sample collection plus the total effect (precision and bias) of sampling and measurement on that value, or:

$$x_{ij} = u_{ij} + p = E(U) + s_i + t_{ij} + b_p + e_p \qquad (2.5)$$

This is equivalent to Equation 2.1 when:

$$E(X) = E(U) + b_p$$

and

$$r_{ij} = s_i + t_{ij} + e_p$$

In this model, p is assumed to be independent of sample location and time. In the following analyses, b_p and e_p are considered inseparable parts of E(X) and r_{ij}, respectively. The emphasis of the data analyses in this report is the characterization of E(X) and r_{ij} through the probabilistic assessment of x_{ij}'s. As discussed in the following section, data stratification has been used to account for the effects of s_i and t_{ij}. Correlation analysis is used to quantify precision on replicate samples and duplicate counts of gross alpha and beta activities in airborne particulate samples.

2.2 Data Stratification

In the probability model described above, the random nature of r_{ij} is dependent on location i and time j being randomly selected from their respective domains, which are continuous. In reality, this is not the case. Sampling locations are fixed and strategically sited to maximize the probability of detecting radionuclide releases from the WIPP facility. Further, sampling times are usually at (approximately) regular intervals. Thus, s_i may in fact be considered a discrete random variable, with the domain of i being limited to the set of sample locations, and t_{ij} and r_{ij} are definable as finite mixtures (Titterington et al., 1985). The resulting complexity in the probability model is ameliorated by *a posteriori* stratification of the data into approximately homogeneous spatial and temporal groups (Gilbert, 1987; Eberhardt and Thomas, 1991).

The data within each individual data base were classified on spatial or temporal criteria specific to that data set. These are described separately in the subsequent sections. Depending on the distribution of sampling locations, the objective of the spatial classification is to either identify nonoverlapping geographic areas (e.g., Los Medanos, Nash Draw, and the Pecos River valley) that exhibit distinct probability characteristics for the parameter in question or to analyze the data for varying geographic scales. The surface water data base is an example of the former case. The airborne particulate data base and soil data base are examples of the latter.

In addition to spatial classification according to surface location, the soil and groundwater data bases were also stratigraphically divided. The three depths from which soil samples were collected were analyzed for differences in means. The groundwater samples collected from three geologic strata were also analyzed for differences in means.

Temporal divisions within each data base, where applicable, are limited to quarters within the calendar year. Differences between quarters in the probabilistic behavior of some parameters are assumed to be predictable, and separate modeling of the quarters would be of value to the operational monitoring program. Differences between years, on the other hand, are not considered to be predictable; thus, year was not used as a criterion for temporal classification.

Differences between means of the data groups were analyzed using one-way analysis-of-variance (ANOVA) or, for more than one classification factor, multifactor ANOVA (MANOVA). Differences in means were considered significant at the 0.05 probability level. Where differences were found, Tukey's Honestly Significant Difference (HSD) multiple range test was used to identify homogeneous groups at the 95 percent confidence level. This is an *a posteriori* test with experimentwise significance (Steel and Torrie, 1960). Prior to performance of ANOVA or MANOVA, the data were inspected for normality through normal probability plots. Where the data were found to be right-skewed, they were log-transformed to improve symmetry. Based on the results of these analyses, stratified data sets were either combined into homogeneous groups or modeled independently.

2.3 Summary Statistics

Four statistics are calculated for most data bases. The sample mean and standard deviation are calculated using the maximum likelihood estimators. The standard error is estimated as the standard deviation divided by the square root of the sample size and is, by definition, the maximum likelihood estimator of the standard deviation of the mean. The coefficient of variation is the ratio of the standard deviation and the mean.

Data sets in which more than 10 percent of the data points are reported as being less than a maximum value are not summarized with these four statistics. Instead, only the mean is estimated for these data sets. Since maximum values were included in the calculation, this will overestimate the true value. Therefore, these estimates are presented with "less than" symbols.

The coefficient of variation provides a way of assessing the magnitude of variability within the data set with respect to its mean (Sokal and Rohlf, 1981). Conversely, it is also way of assessing the nearness of the mean to zero with respect to the standard deviation. A high coefficient of variation value (e.g., greater than 3.0) indicates that the mean is small relative to its variability. Measurements of transuranics in environmental media typically exhibit high coefficients of variation (Pinder and Paine, 1980).

2.4 Probability Distribution Modeling

Probability distribution modeling on the final data sets followed a sequence of model testing. In all cases, the normal distribution was tested first, followed by the two-parameter lognormal distribution. These two families of probability distributions will provide the most accessible basis for evaluating the operational data due to the ready availability of tables, tests, and parametric procedures based on the normal distribution and the simple transformation of data from the lognormal to the normal distribution.

Data were initially evaluated for normality or lognormality by the use of normal probability plots of the raw and log-transformed data (Gilbert, 1987). If a reasonable fit to a straight line was observed on this plot, the model was tested using the maximum likelihood estimates of the mean and standard deviation as model parameters. The Kolmogorov-Smirnov goodness-of-fit test on the Statgraphics software package was used to test the null hypothesis that the model fits the data. Statgraphics calculates the D statistic and returns its significance level based on the sample size. A significance of 0.05 or less was used as the criterion for rejecting the null hypothesis and proceeding to the next model. In some cases, no model was found to produce an acceptable D value. In these cases, the data model is presented as the normal distribution with the mean and standard deviation as parameters.

When the data were observed to be right-skewed, but a good fit to the two-parameter lognormal was not found, or more important, some of the data were less than or equal to zero and therefore invalid for log-transformation, a scalar constant, t, was added to the data points and the lognormal distribution was retested. The resulting model is a three-parameter lognormal distribution. The application of this family of distributions to environmental monitoring data is discussed in detail by Gilbert (1987). The value of the constant was estimated by an iterative process by which the Kolmogorov-Smirnov D statistic was minimized.

Data sets with high proportions of "less than" values were not modeled. In rare cases, neither the normal nor the lognormal distributions were found to satisfy the Kolnogorov-Smirnov goodness-of-fit test. Other distributions were also tested (gamma, Weibull, beta), but in no case was this successful. In these cases, a close visual fit of the normal or lognormal distribution is presented.

2.5 Critical Values

A critical value, X_p, is the upper limit of the p^{th} quantile of the random variable X. Based on the probability distribution model determined for each RBP data set, four critical values were determined: p = 0.80, 0.90, 0.95, and 0.99. In the cases where no model was determined, the critical values were determined directly from the order statistics of the data set. These are reported with "less than" symbols when more than 10 percent of the data are reported as being less than a maximum value.

3.0 Airborne Particulate Samples

3.1 Gross Beta Activity

Weekly samples of airborne particulates were counted for gross beta radioactivity. Duplicate counts were performed on 191 filters to assess error resulting from counting technique. Total error resulting from sample collection, handling, and analysis was assessed through the collection of replicate samples, i.e., samples collected at the same location over the same time period but by different samplers. Eighty-three replicate samples were collected at the WIPP East location by two side-by-side samplers on the same base. Twenty-two replicate samples were collected at the WIPP Northwest location with the second sampler elevated approximately 1.5 meters above the primary sampler.

Correlation analysis on the duplicate counts indicated a high degree of precision in the gross beta counts (r^2 = 93.7 percent). The total sample precision, as indicated by the correlation of replicate samples from the WIPP East location, was only slightly less than that of the duplicate counts (r^2 = 93.2 percent). The correlation between the parallel samplers at WIPP Northwest, where the second sampler was elevated above the first, was further reduced (r^2 = 82.3 percent). A t-test on the log-transform of the WIPP Northwest data indicated no difference in the means at 95 percent confidence.

The Chernobyl accident caused significant increases in gross beta activity on all filter samples collected during weeks 19, 20, and 21 of 1986. These weeks were deleted from the data base prior to statistical analysis, since they represent known artificially induced elevations in activity over the natural background. The question of a long-term effect of Chernobyl on the background levels was explored through an ANOVA on the first 18 weeks of (log-transformed) data from each of the four years.

The means of the first 18 weeks of beta activity increase sequentially with year, from the low in 1986 of 8.1×10^{-10} Becquerels per milliliter to a high in 1989 of 1.0×10^{-9} Becquerels per milliliter, with the ANOVA indicating significant differences existing between means at 95 percent confidence. However, Tukey's HSD multiple range test showed 1986 and 1987 formed a homogeneous group, with 1988 and 1989 being significantly greater than their respective previous years. These results refute the hypothesis that the Chernobyl accident produced a sudden, statistically significant shift in background beta activity.

Prior to statistical analysis, the large data base (1506 data points) was stratified into two geographical groups to avert biasing the analyses by the greater concentration of sampling locations near the WIPP facility. Due to a right-skew of the data, the data were also log-transformed before analyses that assume normally distributed data were performed.

The first sampler group, the Regional Transect, consists of the four off-site sampler locations—Carlsbad, Smith Ranch, Mills Ranch, and Eunice. These locations comprise a west-east cross-section of southeastern New Mexico with representation of the Pecos River valley, Nash Draw, Los Medanos, and the Llano Estacado, respectively. The group also consists of two urban locations and two rural residences.

The second sampler group, the WIPP Site, consists of the four WIPP locations—WIPP East, WIPP South, WIPP Northwest, and WIPP Far Field. The latter sampler was installed in week 38 of 1986 to eventually replace the WIPP Northwest sampler, which was located too close to the air intake shaft for downwind monitoring during the operational period. The WIPP Northwest sampler was removed after week 50 of 1988. All samplers in the WIPP Site group are within one kilometer of the WIPP facility.

A MANOVA was applied to each of the transformed data sets, with location and quarter as the independent factors. Where significant differences were found between groups (with p less than or equal to 0.05), Tukey's HSD multiple range test was used to identify homogeneous groups.

No significant differences were found between the means of the Regional Transect locations. Among the WIPP Site locations, WIPP Northwest was found to be significantly different from WIPP South and WIPP East, while WIPP Far Field was homogeneous with all WIPP locations. This result substantiated the comparability of the WIPP Northwest and Far-Field locations but also dictated the deletion of the WIPP Northwest data over the period of parallel sample collection so as not to bias the results toward that direction.

For both the Regional Transect and the WIPP Site, the same pattern of differences was observed between quarters: fourth quarter greater than first quarter greater than second and third quarters, which are equal. The data were subdivided temporally to reflect this pattern prior to the analysis of distributions.

Tables 3-1 through 3-3 present the results of the statistical characterization of the six temporal/spatial groups identified within the gross beta activity data base. All except one group (fourth quarter of the Regional Transect) were fitted to the lognormal distribution. The exception was fitted to the normal distribution. For all three temporal groups, the mean of the WIPP group is approximately 6 percent less than that of the Regional Transect. The coefficients of variation are small and relatively uniform across all groups, indicating good control of random error in this data base.

3.2 Gross Alpha Activity

Weekly airborne particulate samples were counted for gross alpha radioactivity. As with the gross beta counts, duplicate counts on individual samples and replicate counts on samples collected in parallel were performed to quantify error resulting from sample collection, handling, and analysis. An important aspect of the statistical analysis of the gross alpha data base is a change in the configuration of the counter at the start of 1989 that reduced the amount of shielding and, consequentially, improved the precision and accuracy of the data. The 1989 data are therefore analyzed separately.

Correlation analysis of the 141 duplicate gross alpha counts performed prior to 1989 and the 52 duplicate counts performed during 1989 showed a large improvement in precision, with r^2 increasing from 27.3 to 83.7 percent. Correlation between replicate samples also improved, with r^2 increasing from 42.8 prior to 1989 ($n = 36$) to 78.3 percent in 1989 ($n = 49$). The set of parallel samplers at the WIPP Northwest location (pre-1989) showed very poor correlation for gross alpha counts ($r^2 = 23.7$ percent, $n = 25$).

The Chernobyl accident caused no discernible effect on the gross alpha activity, although it is acknowledged that a small effect would have been masked by the poor precision in the data during that time period.

As with the gross beta data base, the gross alpha data base was stratified into two geographic groups, the Regional Transect and the WIPP Site (see previous section for descriptions). A MANOVA of the (log-transformed) 1989 data did not reveal significant differences between locations within either group (at 95 percent confidence), although differences were found between quarters. For this data set, the third quarter had the lowest mean alpha activity and the first quarter had the highest. The second and fourth quarters were intermediate and indistinguishable from each other at this confidence level. The data base was further subdivided into three temporal groups based on this result.

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Table 3-1

**Gross Beta Activity in Air Samples:
Summary Statistics**

Quarter	Group	n	Mean		s.e.	s	c.v.
1	REGION	206	0.97	+/-	0.02	0.29	0.30
1	WIPP	150	0.91	+/-	0.02	0.27	0.30
2 & 3	REGION	399	0.82	+/-	0.01	0.22	0.27
2 & 3	WIPP	291	0.77	+/-	0.01	0.25	0.33
4	REGION	198	1.21	+/-	0.02	0.34	0.28
4	WIPP	147	1.15	+/-	0.03	0.38	0.33

Abbreviations:
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation

Units are in Becquerels per milliliter x 10^{-9}

Table 3-2

Gross Beta Activity in Air Samples: Probability Distribution Functions

Quarter	Group	Type	Mean	s	K-S Signif.
1	REGION	LOGNORM.	0.97	0.28	0.28
1	WIPP	LOGNORM.	0.91	0.27	0.06
2 & 3	REGION	LOGNORM.	0.82	0.22	0.10
2 & 3	WIPP	LOGNORM.	0.77	0.23	0.18
4	REGION	NORMAL	1.21	0.34	1.00
4	WIPP	LOGNORM.	1.15	0.38	1.00

Abbreviations:
s - Standard deviation
K-S Signif.- Kolmogorov-Smirnov significance level

Units are in Becquerels per milliliter x 10^{-9}

Table 3-3

Gross Beta Activity in Air Samples:
Critical Values

Quarter	Group	Probability 0.80	0.90	0.95	0.99
1	REGION	1.18	1.34	1.48	1.80
1	WIPP	1.11	1.26	1.40	1.71
2 & 3	REGION	0.99	1.11	1.22	1.46
2 & 3	WIPP	0.94	1.07	1.19	1.46
4	REGION	1.50	1.64	1.77	2.00
4	WIPP	1.43	1.65	1.85	2.31

Units are in Becquerels per milliliter x 10^{-9}

Tables 3-4 through 3-6 present the results of the statistical characterization of the six temporal/spatial groups of the 1989 gross alpha data. An interesting pattern of distribution models emerge from these results. The maximum and minimum quarters (first and third quarters, respectively) showed symmetrical distributions about the mean and were fitted to the normal distribution for both the Regional Transect and the WIPP Site. The combined second and fourth quarter data were right-skewed and fit the lognormal distribution, perhaps reflecting an intermediate distribution between the two extremes.

As with the gross beta activity, the 1989 gross alpha means of the WIPP Site are consistently about 10 percent less than the Regional Transect. Coefficients of variation have a wider range and are typically larger than those of the gross beta data, indicating less precision in the analyses.

An attempt was made to find a linear transformation function to apply to the pre-1989 data in order to bring it to a level comparable to the 1989 data. The pre-1989 data were stratified geographically and temporally to match the subdivisions of the 1989 data base. It was noted that the third quarter again had the lowest gross alpha activity and that the third quarter WIPP Site data was also normally distributed. Assuming that the data group with the lowest mean activity and the smallest geographic range will be most comparable between years and therefore reflect the differences resulting from analytical methods most accurately, a transformation function was derived to give the pre-1989 third quarter WIPP data the same mean and standard deviation as the 1989 third quarter WIPP data.

The resulting transformation function is:

$$y = \frac{x + 0.03}{0.22} \tag{3.1}$$

where x is the pre-1989 datum and y is the transformed datum.

Tables 3-7 through 3-9 present the results of the statistical analysis of the transformed data. The MANOVA and Tukey's multiple range test verify the third quarter data set as being significantly less than the other quarters at 95 percent confidence but failed to find a

Table 3-4

1989 Gross Alpha Activity in Air Samples: Summary Statistics

Quarter	Group	n	Mean		s.e.	s	c.v.
1	REGION	50	0.82	+/-	0.04	0.27	0.33
1	WIPP	38	0.75	+/-	0.04	0.25	0.33
2 & 4	REGION	102	0.54	+/-	0.01	0.14	0.26
2 & 4	WIPP	75	0.49	+/-	0.02	0.14	0.28
3	REGION	50	0.44	+/-	0.02	0.13	0.30
3	WIPP	38	0.38	+/-	0.02	0.14	0.37

Abbreviations:
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation

Units are in Becquerels per milliliter x 10^{-9}

Table 3-5

1989 Gross Alpha Activity in Air Samples: Probability Distribution Functions

Quarter	Group	Type	Mean	s	K-S Signif.
1	REGION	NORMAL	0.82	0.27	0.50
1	WIPP	NORMAL	0.75	0.25	0.37
2 & 4	REGION	LOGNORM.	0.54	0.14	1.00
2 & 4	WIPP	LOGNORM.	0.49	0.15	0.41
3	REGION	NORMAL	0.44	0.13	0.14
3	WIPP	NORMAL	0.37	0.14	1.00

Abbreviations:
s - Standard deviation
K-S Signif.- Kolmogorov-Smirnov significance level

Units are in Becquerels per milliliter x 10^{-9}

Table 3-6

1989 Gross Alpha Activity in Air Samples: Critical Values

		Probability			
Quarter	Group	0.80	0.90	0.95	0.99
1	REGION	1.05	1.17	1.26	1.45
1	WIPP	0.96	1.07	1.16	1.33
2 & 4	REGION	0.65	0.72	0.80	0.95
2 & 4	WIPP	0.60	0.69	0.77	0.94
3	REGION	0.55	0.61	0.65	0.74
3	WIPP	0.49	0.55	0.60	0.70

Units are in Becquerels per milliliter x 10^{-9}

Table 3-7

Pre-1989 Gross Alpha Activity in Air Samples:
Summary Statistics

Quarter	Group	n	Mean		s.e.	s	c.v.
1	REGION	156	0.42	+/-	0.01	0.15	0.36
1	WIPP	138	0.41	+/-	0.01	0.15	0.36
2 & 4	REGION	312	0.45	+/-	0.01	0.17	0.38
2 & 4	WIPP	283	0.42	+/-	0.01	0.17	0.40
3	REGION	153	0.40	+/-	0.02	0.23	0.58
3	WIPP	145	0.37	+/-	0.01	0.14	0.38

Original data have been linearly transformed by the function:
$y = (x + 0.03)/0.22$

Abbreviations:
n - Sample size
s.e. - Standard error
s - Standard deviation
c.v. - Coefficient of variation

Units are in Becquerels per milliliter x 10^{-9}

Table 3-8

Pre-1989 Gross Alpha Activity in Air Samples: Probability Distribution Functions

Quarter	Group	Type	Mean	s	K-S Signif.
1	REGION	NORMAL	0.42	0.15	1.00
1	WIPP	LOGNORM.	0.41	0.16	1.00
2 & 4	REGION	LOGNORM.	0.46	0.17	0.37
2 & 4	WIPP	LOGNORM.	0.43	0.17	0.37
3	REGION	LOGNORM.	0.40	0.18	0.54
3	WIPP	NORMAL	0.36	0.14	0.40

Original data have been linearly transformed by the function:

$$y = (x + 0.03)/0.22$$

Abbreviations:

s - Standard deviation

K-S Signif.- Kolmogorov-Smirnov significance level

Units are in Becquerels per milliliter x 10^{-9}

Table 3-9

Pre-1989 Gross Alpha Activity in Air Samples: Critical Values

		Probability			
Quarter	Group	0.80	0.90	0.95	0.99
1	REGION	0.55	0.61	0.67	0.77
1	WIPP	0.52	0.62	0.71	0.92
2 & 4	REGION	0.58	0.68	0.78	0.99
2 & 4	WIPP	0.55	0.65	0.75	0.97
3	REGION	0.52	0.63	0.74	0.99
3	WIPP	0.48	0.54	0.59	0.68

Original data have been linearly transformed by the function:

$$y = (x + 0.03)/0.22$$

Units are in Becquerels per milliliter x 10^{-9}

difference between the other three quarters. Again, the means of the WIPP Site are about 6 percent less those of the Regional Transect. The coefficients of variation are greater than those of the 1989 data.

3.3 Quarterly Radionuclide Analysis

Weekly samples of airborne particulates from each sampler location were composited over each quarter and analyzed for specific radionuclides. Statistical analysis of these data consisted of a normal probability plotting to determine symmetry and normality (or lognormality) of the data sets, ANOVA to determine homogeneity of the data across sampler locations and quarters, and statistical distribution fitting.

The latter analysis was not performed on five radionuclides (^{60}Co, ^{137}Cs, ^{226}Ra, ^{228}Ra, and ^{228}Th), since more than 10 percent of these data sets are reported as being less than a maximum value. Although this type of data is an unavoidable consequence of the analytical method for these radionuclides and unfortunately precludes the identification of the underlying probability distribution function through parametric techniques, maximum critical percentiles were estimated directly from the cumulative distribution of the raw data.

No radionuclides were found to differ significantly (95 percent confidence level) between sampler locations. Only ^{230}Th was found to differ between quarters. The data for this radionuclide were divided between two temporal groups, accordingly (quarters 1 and 4; quarters 2 and 3). This grouping reflects the temporal pattern found in the gross beta activity.

Tables 3-10 through 3-12 present the results of the statistical analyses performed on these data. Because the MDL for the quarterly composited samples are determined in Becquerels (Bq)/composite sample, they are not directly comparable to the mean radionuclide concentrations, which are expressed in Bq/mL of air. A minimum detectable average (MDA) was therefore calculated from each MDL, which expresses the minimum average concentration (in Bq/mL) that would have to be maintained over the entire quarter to obtain the MDL on the quarterly sample. The MDA calculation is based on the assumptions of a quarter equaling a 91-day sampling period and an average sampling rate of 2 cubic feet per minute. This gives a total of 262,080 cubic feet of air sampled per composite, or 7.42×10^9 milliliters per composite sample. Therefore, the MDA, in Bq/mL, is the MDL multiplied by the inverse of 7.42×10^9 mL/composite sample.

Table 3-10

Quarterly Airborne Particulate Samples: Summary Statistics

Radio-nuclide	Group	MDA	n	Mean		s.e.	s	c.v.
^{7}Be	ALL	---	106	5700	+/-	100	900	0.16
^{40}K	ALL	---	106	160	+/-	10	70	0.44
^{60}Co	ALL	0.015	106	< 12		N/A	N/A	N/A
^{90}Sr	ALL	0.150	92	6	+/-	4	35	5.83
^{137}Cs	ALL	0.010	100	< 5.8		N/A	N/A	N/A
^{210}Pb	ALL	0.100	99	760	+/-	28	280	0.37
^{210}Po	ALL	---	53	700	+/-	28	210	0.30
^{226}Ra	ALL	0.025	107	< 16		N/A	N/A	N/A
^{228}Ra	ALL	---	107	< 30		N/A	N/A	N/A
^{228}Th	ALL	0.015	107	< 11		N/A	N/A	N/A
^{230}Th	Q1&4	0.010	43	9.6	+/-	1.4	9.2	0.96
	Q2&3	0.010	40	5.4	+/-	1.0	6.7	1.24
^{232}Th	ALL	0.010	83	5.3	+/-	0.7	6.7	1.26
^{233}U	ALL	0.005	98	-1.0	+/-	0.5	4.6	4.60
^{234}U	ALL	0.005	98	3.2	+/-	0.3	2.8	0.88
^{235}U	ALL	---	98	0.2	+/-	0.1	1.0	5.00
^{238}U	ALL	0.005	98	2.4	+/-	0.2	1.5	0.62
^{237}Np	ALL	0.010	79	-0.3	+/-	0.2	1.4	4.67
^{238}Pu	ALL	0.020	100	-1.5	+/-	0.8	7.7	5.13
$^{239/240}Pu$	ALL	0.010	100	0.3	+/-	0.3	3.3	11.00
^{241}Pu	ALL	0.499	100	900	+/-	600	6100	6.78
^{241}Am	ALL	0.005	37	2.6	+/-	1.6	9.7	3.73
^{244}Cm	ALL	0.005	37	-0.6	+/-	1.4	8.2	13.67

Abbreviations:

MDA - Minimum Detectable Average
n - Sample size
s - Standard deviation
s.e. - Standard error
c.v. - Coefficient of variation
N/A - Not Applicable
Q1&4 - Quarters 1 and 4
Q2&3 - Quarters 2 and 3

Units are in Becquerels per milliliter x 10^{-12}

Table 3-11

Quarterly Airborne Particulate Samples:
Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter Mean	s	t	K-S Signif.
^{7}Be	ALL	LOGNORM.	5660	930	--	0.16
^{40}K	ALL	NORMAL	155	70	--	1.00
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	NORMAL	6.5	35	--	1.00
^{137}Cs	ALL	N/A	N/A	N/A	N/A	N/A
^{210}Pb	ALL	LOGNORM.	750	270	--	1.00
^{210}Po	ALL	LOGNORM.	703	207	--	0.41
^{226}Ra	ALL	N/A	N/A	N/A	N/A	N/A
^{228}Ra	ALL	N/A	N/A	N/A	N/A	N/A
^{228}Th	ALL	N/A	N/A	N/A	N/A	N/A
^{230}Th	Q1&4	LOGNORM.	20.8	9.1	11.1	1.00
	Q2&3	NORMAL	5.4	6.7	--	0.40
^{232}Th	ALL	LOGNORM.	12	6.4	6.7	0.35
^{233}U	ALL	NORMAL	-1.0	4.6	--	0.00
^{234}U	ALL	LOGNORM.	8.4	1.7	5.2	0.50
^{235}U	ALL	NORMAL	0.25	1.0	--	0.23
^{238}U	ALL	NORMAL	2.4	1.5	--	1.00
^{237}Np	ALL	NORMAL	-0.3	1.4	--	0.38
^{238}Pu	ALL	NORMAL	-1.5	7.7	--	0.00
$^{239/240}Pu$	ALL	NORMAL	0.29	3.3	--	0.00
^{241}Pu	ALL	NORMAL	910	6100	--	0.00
^{241}Am	ALL	LOGNORM.	19.4	9.9	16.7	1.00
^{244}Cm	ALL	NORMAL	-0.6	8.2	--	0.00

Abbreviations:
- s - Standard Deviation
- t - Scalar Constant (3-Parameter Lognormal)
- K-S Signif. - Kolmogorov-Smirnov significance level
- N/A - Not Applicable
- Q1&4 - Quarters 1 and 4 Q2&3 - Quarters 2 and 3

Units are in Becquerels per milliliter x 10^{-12}

Table 3-12

Quarterly Airborne Particulate Samples: Critical Values

Radio-nuclide	Group	Probability 0.80	0.90	0.95	0.99
^{7}Be	ALL	6400	6900	7300	8200
^{40}K	ALL	210	240	270	320
^{60}Co	ALL	< 14	< 16	< 24	< 27
^{90}Sr	ALL	36	51	64	88
^{137}Cs	ALL	< 8	< 10	< 11	< 17
^{210}Pb	ALL	950	1100	1200	1600
^{210}Po	ALL	860	980	1100	1300
^{226}Ra	ALL	< 20	< 30	< 40	< 120
^{228}Ra	ALL	< 41	< 56	< 63	< 74
^{228}Th	ALL	< 19	< 27	< 30	< 44
^{230}Th	Q1&4	16	21	27	39
	Q2&3	11	14	16	21
^{232}Th	ALL	9	13	17	27
^{233}U	ALL	2.9	4.9	6.6	9.7
^{234}U	ALL	4.5	5.4	6.2	7.9
^{235}U	ALL	1.1	1.5	1.9	2.6
^{238}U	ALL	3.7	4.3	4.9	5.9
^{237}Np	ALL	0.8	1.4	2.0	2.9
^{238}Pu	ALL	5	8	11	16
$^{239/240}$Pu	ALL	3.1	4.5	5.7	8.0
^{241}Pu	ALL	6000	9000	11000	15000
^{241}Am	ALL	26	32	38	53
^{244}Cm	ALL	6	10	13	18

Abbreviations:
- Q1&4 - Quarters 1 and 4
- Q2&3 - Quarters 2 and 3

Units are in Becquerels per milliliter x 10^{-12}

4.0 Soil Samples

Soil samples were collected and analyzed from a total of 37 locations within an 80-kilometer radius of the WIPP facility. At each location, samples from three depths were collected, although not all depths were analyzed from every location. The three depths are denoted as surface (0 to 2 centimeters), intermediate (2 to 5 centimeters), and deep (5 to 10 centimeters). Two sampling times are represented in the data base—December 1985 and July 1987. These were considered replicate samples from each location and were not distinguished in the statistical analysis. The samples were analyzed for 19 radionuclides.

Due to the wide geographic scope of the soil sampling program, the data base was divided into three geographic groups, each representing a different regional scale. The WIPP Site group, which has the smallest scale (covering the smallest area), consists of the eight locations at the cardinal compass directions from the center of the WIPP facility along the Secured Area Boundary fence. All sampling locations in this group are within 1 kilometer of the Waste Handling Building and Exhaust Shaft.

The next group in increasing scale is the Five-Mile Ring, which consists of 16 locations forming a ring with a radius of approximately 5 miles (8 kilometers) and centered at the WIPP facility. The sampling locations are at the 16 principal compass directions around the ring. All are within the Los Medanos region and represent an area of approximately 200 square kilometers.

The third group, the Outer Sites, consists of 13 locations, representing a variety of habitats, soil types, and land uses in southeastern New Mexico, from Artesia and Loving on the west to Hobbs and Jal on the east and including the Gnome Site, a potash mine, and an oil production area. The area of coverage of approximately 10,000 square kilometers.

The data for each parameter were graphically checked for normal and lognormal distribution using a normal probability plot. When the latter was indicated, the data were log-transformed prior to analysis. ANOVA, with a 95 percent confidence limit, was used to test each parameter for homogeneity between geographic groups and between depths. Only those sampling locations with all three depths represented in the data base were used for the latter. Where differences were found, Tukey's multiple range test was used to identify homogeneous groups at 95 percent confidence.

^{40}K, ^{234}U, ^{235}U, and ^{238}U exhibited significant differences between all three geographic groups, while ^{137}Cs, ^{226}Ra, ^{228}Th, and ^{230}Th exhibited differences between the Outer Sites and the other two groups, which were indistinguishable. No significant differences were found between depths.

The data base was subdivided according to the result of the ANOVAs. Each of the subsequent data sets was tested and fit to a probability distribution model. The results are presented in Tables 4-1 through 4-3. ^{60}Co and ^{228}Ra were not fitted to probability models, because more than 10 percent of the data were reported as being less than a maximum value. Data fits to either the normal or lognormal distributions were generally good. ^{241}Am, ^{230}Th, ^{232}Th, and ^{235}U were fitted to three-parameter lognormal distributions.

^{233}U, ^{237}Np, and all isotopes of plutonium exhibited poor fits to all models tested. These data sets generally shared a pattern of being symmetrical about zero, with a high frequency of data points near zero, but with a relatively wide spread of data points on either side. In these cases, the critical values were derived from the normal distribution, with parameters equal to the maximum-likelihood estimators of the mean and standard deviation calculated from the data.

Table 4-1

Soil Samples: Summary Statistics

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{40}K	O	---	35	340	+/-	20	130	0.38
	R	---	79	180	+/-	10	60	0.33
	W	---	33	200	+/-	10	30	0.15
^{60}Co	ALL	3.7	114	< 2.4		N/A	N/A	N/A
^{90}Sr	ALL	74	145	0.06	+/-	0.06	0.78	13
^{137}Cs	O	3.7	24	8.1	+/-	1.3	6.3	0.78
	R/W	3.7	121	4.7	+/-	0.4	4.9	1.04
^{226}Ra	O	7.4	35	20	+/-	2	10	0.50
	R/W	7.4	111	9.6	+/-	0.2	2.2	0.23
^{228}Ra	ALL	---	144	< 80		N/A	N/A	N/A
^{228}Th	O	3.7	35	18	+/-	2	9	0.50
	R/W	3.7	112	7.8	+/-	0.2	2.5	0.32
^{230}Th	O	3.7	24	19	+/-	5	26	1.37
	R/W	3.7	129	9.1	+/-	0.8	9.1	1.00
^{232}Th	ALL	3.7	154	11	+/-	1	13	1.18
^{233}U	ALL	3.7	145	0.02	+/-	0.04	0.55	27.50
^{234}U	O	3.7	25	12	+/-	1	7	0.58
	R	3.7	96	6.8	+/-	0.5	5.3	0.78
	W	3.7	32	5.4	+/-	0.2	1.4	0.26
^{235}U	O	---	17	0.63	+/-	0.17	0.70	1.11
	R	---	96	0.40	+/-	0.04	0.41	1.02
	W	---	32	0.16	+/-	0.06	0.34	2.12
^{238}U	O	3.7	25	11	+/-	1	6	0.54
	R	3.7	96	5.9	+/-	0.2	2.4	0.41
	W	3.7	33	5.7	+/-	0.3	1.6	0.28
^{237}Np	ALL	3.7	154	-0.03	+/-	0.03	0.35	11.67

Table 4-1

(Continued)

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{238}Pu	ALL	15	145	-0.1	+/-	0.1	1.1	11.00
$^{239/240}Pu$	ALL	7.4	145	0.20	+/-	0.06	0.73	3.65
^{241}Pu	ALL	370	145	160	+/-	50	560	3.50
^{241}Am	ALL	3.7	58	1.7	+/-	0.3	2.0	1.18
^{244}Cm	ALL	3.7	58	0.21	+/-	0.11	0.83	3.95

Abbreviations:
Groups: O - Outer Sites; R - Five-mile Ring; W - WIPP Site
MDL - Minimum Detection Limit
n - Sample size
s.e. - Standard error
s - Standard deviation
c.v. - Coefficient of variation
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-3}

Table 4-2

Soil Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter Mean	Parameter s	Parameter t	K-S Signif.
^{40}K	O	LOGNORM.	340	140	---	1.00
	R	LOGNORM.	180	50	---	0.39
	W	NORMAL	200	30	---	1.00
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	NORMAL	0.06	0.78	---	0.38
^{137}Cs	O	LOGNORM.	8.4	8.2	---	1.00
	R/W	LOGNORM.	4.8	4.8	---	0.52
^{226}Ra	O	LOGNORM.	20	12	---	1.00
	R/W	LOGNORM.	9.6	2.1	---	0.36
^{228}Ra	ALL	N/A	N/A	N/A	N/A	N/A
^{228}Th	O	LOGNORM.	18	9.7	---	1.00
	R/W	LOGNORM.	7.7	2.4	---	0.47
^{230}Th	O	LOGNORM.	32	120	2.2	1.00
	R/W	LOGNORM.	12	12	2.2	1.00
^{232}Th	ALL	LOGNORM.	13	18	1.0	1.00
^{233}U	ALL	NORMAL	0.02	0.54	---	0.00
^{234}U	O	LOGNORM.	12	7.1	---	1.00
	R	LOGNORM.	6.7	4.2	---	0.16
	W	NORMAL	5.4	1.4	---	1.00
^{235}U	O	LOGNORM.	1.2	0.83	0.5	1.00
	R	LOGNORM.	0.91	0.40	0.5	1.00
	W	NORMAL	0.16	0.34	---	1.00
^{238}U	O	LOGNORM.	11	6	---	1.00
	R	LOGNORM.	5.9	2.3	---	0.51
	W	LOGNORM.	5.8	1.7	---	1.00
^{237}Np	ALL	NORMAL	-0.03	0.35	---	0.02

Table 4-2

(Continued)

Radio-nuclide	Group	Type	Parameter Mean	s	t	K-S Signif.
^{238}Pu	ALL	NORMAL	-0.1	1.1	---	0.00
$^{239/240}$Pu	ALL	NORMAL	0.20	0.73	---	0.01
^{241}Pu	ALL	NORMAL	160	560	---	0.00
^{241}Am	ALL	LOGNORM.	6.7	2.1	5.0	0.32
^{244}Cm	ALL	NORMAL	0.21	0.83	---	0.35

Abbreviations:
s - Standard Deviation
t - Scalar Constant (3-Parameter Lognormal)
Groups: O - Outer Sites; R - Five-mile Ring; W - WIPP Site
K-S Signif. - Kolmogorov-Smirnov significance level
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-3}

Table 4-3

Soil Samples: Critical Values

Radio-nuclide	Group	MDL	Probability			
			0.80	0.90	0.95	0.99
^{40}K	O	---	430	520	600	780
	R	---	220	250	280	340
	W	---	230	240	260	280
^{60}Co	ALL	3.7	< 3.3	< 3.7	< 4.4	< 5.2
^{90}Sr	ALL	74	0.7	1.0	1.3	1.9
^{137}Cs	O	3.7	12	17	23	40
	R/W	3.7	7	10	13	24
^{226}Ra	O	7.4	28	35	42	61
	R/W	7.4	11	12	13	16
^{228}Ra	ALL	---	< 120	< 170	< 180	< 400
^{228}Th	O	3.7	24	30	36	51
	R/W	3.7	9	11	12	15
^{230}Th	O	3.7	30	70	120	380
	R/W	3.7	15	22	31	57
^{232}Th	ALL	3.7	17	28	41	83
^{233}U	ALL	3.7	0.5	0.7	0.9	1.3
^{234}U	O	3.7	16	21	25	37
	R	3.7	9	12	15	22
	W	3.7	6.6	7.2	7.7	8.6
^{235}U	O	---	1.2	1.7	2.3	3.7
	R	---	0.7	0.9	1.2	1.7
	W	---	0.45	0.60	0.72	0.95
^{238}U	O	3.7	15	18	22	32
	R	3.7	8	9	10	13
	W	3.7	7	8	9	11
^{237}Np	ALL	3.7	0.26	0.42	0.54	0.78

Table 4-3

(Continued)

Radio-nuclide	Group	MDL	Probability 0.80	0.90	0.95	0.99
^{238}Pu	ALL	15	0.8	1.3	1.7	2.4
$^{239/240}Pu$	ALL	7.4	0.8	1.1	1.4	1.9
^{241}Pu	ALL	370	600	900	1100	1500
^{241}Am	ALL	3.7	3.3	4.5	5.6	8.0
^{244}Cm	ALL	3.7	0.9	1.2	1.5	2.1

Abbreviations:
Groups: O - Outer Sites; R - Five-mile Ring; W - WIPP Site
MDL - Minimum Detection Limit

Units are in Becquerels per gram x 10^{-3}

5.0 Water Samples

Both surface-water and groundwater samples were collected during the RBP. These samples were analyzed for 18 radionuclides, including tritium (^{3}H). The resulting data from the surface-water and groundwater sampling programs were analyzed independently.

5.1 Surface Water Samples

Samples of surface water were collected from 12 locations over the course of the RBP. A total of five sampling rounds were performed. The separate rounds are considered replicate samples for the statistical analyses. Not all locations were sampled during each round, giving a maximum sample size of 44 data points for each parameter.

Sampling locations were divided into three groups for an initial analysis of geographic variability. Stock tanks represented the largest group, with five locations, and they are the locations closest to the WIPP facility. Stock tanks in this area are typically man-made earthen catchment basins with no surface outflow, except by rare overflow events. Three of the tank samples are within the Los Medanos area and two are in Nash Draw, to the west. Also included in this group is a single sample of WIPP influent water and a single sample of water from the WIPP primary wastewater treatment lagoon.

The Pecos River represents the next major surface water group. Four sampling locations were used along the Pecos, from a northern (up-river) point near the town of Artesia, New Mexico, to a southern (down-river) point near the town of Malaga, New Mexico. The Pecos River locations were sampled four times during the RBP.

The third group, called Laguna Grande de la Sal, represents water from a series of playa lakes at the lower (southwestern) end of Nash Draw. These lakes are fed by both surface flow and springs. The water in these lakes is highly saline, often at or near saturation level for sodium chloride and other salts. The sediments of Laguna Grande de la Sal, the largest of the lakes, are rich enough in crystalline sodium chloride that they are commercially mined.

Laguna Grande de la Sal was sampled five times during the RBP, with each sample consisting of a composite of one or two aliquots from separate locations along the lake shoreline and an aliquot from Laguna Tres, northeast of Laguna Grande. The sampling location on the south shore of Laguna Grande was twice excluded from the composite sample due to drying of that part of the lake.

ANOVA was performed on each data base to identify significant differences between these groups (at 95 percent confidence). As a result of these analyses, ^{40}K data from Laguna Grande de la Sal were separated from the other locations, and all four isotopes of uranium were segregated among the three geographic groups prior to statistical analysis.

Summary statistics for the surface water data base are presented in Table 5-1. The means for most radionuclides are below their respective detection limit. Due to its saline nature, the concentration of ^{40}K is significantly higher in Laguna Grande than the freshwater sites. Laguna Grande also has the highest concentrations of uranium (all four radioisotopes). The concentrations of uranium are consistently higher in the Pecos River than the stock tanks near the WIPP Site.

Table 5-2 presents the results of probability distribution modeling of the various data bases. These results generally show a good fit for the normal and lognormal distributions. Three-parameter lognormal distributions were used for seven isotopes. ^{60}Co and ^{137}Cs were not modeled, due to the large proportion of data reported as less than a maximum value. Table 5-3 presents critical values for each parameter based on the probability model or, in the cases of ^{60}Co and ^{137}Cs, the actual data.

5.2 Groundwater Samples

During the RBP, samples of groundwater were collected from 37 wells, including 23 water monitoring wells in the Culebra unit of the Rustler Formation, 4 in the Magenta unit of the Rustler, and 10 privately owned wells. Replicate sampling of these wells range from one to four independent samples.

The groundwater data were initially stratified into three groups—Culebra wells, Magenta wells, and private wells—and ANOVA was applied to determine whether significant differences (at 95 percent confidence) exist among these groups for each parameter. The elevated ^{40}K concentrations are expected owing to the briny nature of the Culebra water and its proximity to the Salado Formation.

^{226}Ra was found to have a distinct geographic pattern in the Culebra. Means from individual wells show this radionuclide increases in concentration from west to east. Because this

Table 5-1

Surface Water Samples: Summary Statistics

Radionuclide	Group	MDL	n	Mean	s.e.	s	c.v.
^{3}H	ALL	56	41	-26	+/- 7	43	1.65
^{40}K	TANKS/PECOS	---	39	< 100	+/- 10	80	0.80
	LGS	---	5	10000	+/- 1000	2000	0.20
^{60}Co	ALL	3.0	44	< 13	N/A	N/A	N/A
^{90}Sr	ALL	7.4	43	0.28	+/- 0.08	0.52	1.86
^{137}Cs	ALL	1.9	44	< 6.9	N/A	N/A	N/A
^{226}Ra	ALL	5.6	40	< 4.8	+/- 1.1	7.2	1.5
^{228}Ra	ALL	---	40	< 8.4	+/- 0.6	3.9	0.46
^{228}Th	ALL	3.7	40	< 2.3	+/- 0.3	2.2	0.96
^{230}Th	ALL	0.37	44	0.10	+/- 0.04	0.29	2.9
^{232}Th	ALL	0.37	44	0.032	+/- 0.013	0.087	2.72
^{233}U	TANKS	0.37	23	-0.016	+/- 0.008	0.040	2.5
	LGS	0.37	5	0.07	+/- 0.06	0.12	1.71
	PECOS	0.37	16	0.001	+/- 0.013	0.053	53.00
^{234}U	TANKS	0.37	23	0.11	+/- 0.04	0.19	1.73
	LGS	0.37	5	5.7	+/- 1.5	3.3	0.58
	PECOS	0.37	16	1.2	+/- 0.2	0.7	0.58
^{235}U	TANKS	---	22	0.006	+/- 0.004	0.020	3.33
	LGS	---	5	0.13	+/- 0.04	0.09	0.69
	PECOS	---	15	0.045	+/- 0.009	0.036	0.80
^{238}U	TANKS	0.37	22	0.046	+/- 0.012	0.054	1.17
	LGS	0.37	5	2.8	+/- 0.7	1.6	0.57
	PECOS	0.37	16	0.56	+/- 0.06	0.22	0.39
^{237}Np	ALL	0.37	41	0.003	+/- 0.005	0.035	11.67
^{238}Pu	ALL	0.11	44	-0.004	+/- 0.013	0.085	21.25
$^{239/240}Pu$	ALL	0.74	44	-0.006	+/- 0.006	0.041	6.83
^{241}Pu	ALL	37	44	9	+/- 2	13	1.44

Abbreviations:
MDL - Minimum Detection Limit
s.e. - Standard error
c.v. - Coefficient of variation
N/A - Not Applicable
n - Sample size
s - Standard deviation
LGS - Laguna Grande de la Sal

Units are in Becquerels per gram x 10^{-4}

Table 5-2

Surface Water Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter Mean	s	t	K-S Signif.
^{3}H	ALL	NORMAL	-26	43	---	1.00
^{40}K	TANKS/PECOS	LOGNORM.	120	160	---	1.00
	LGS	NORMAL	10000	2500	---	1.00
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	LOGNORM.	0.91	0.65	0.60	1.00
^{137}Cs	ALL	N/A	N/A	N/A	N/A	N/A
^{226}Ra	ALL	LOGNORM.	4.5	5.0	---	1.00
^{228}Ra	ALL	NORMAL	8.4	3.9	---	0.21
^{228}Th	ALL	LOGNORM.	2.5	4.0	---	0.44
^{230}Th	ALL	LOGNORM.	0.57	0.10	0.5	1.00
^{232}Th	ALL	LOGNORM.	0.24	0.10	0.2	0.50
^{233}U	TANKS	NORMAL	-0.01	0.04	---	0.11
	LGS	LOGNORM.	0.13	0.50	0.01	1.00
	PECOS	NORMAL	0.00	0.053	---	0.27
^{234}U	TANKS	LOGNORM.	0.13	0.23	0.012	1.00
	LGS	LOGNORM.	6.1	4.4	---	1.00
	PECOS	LOGNORM.	1.2	0.61	---	1.00
^{235}U	TANKS	NORMAL	0.006	0.020	---	1.00
	LGS	LOGNORM.	0.14	0.12	---	1.00
	PECOS	LOGNORM.	0.044	0.027	---	1.00
^{238}U	TANKS	LOGNORM.	0.09	0.071	0.04	1.00
	LGS	LOGNORM.	3.0	2.1	---	1.00
	PECOS	NORMAL	0.56	0.22	---	1.00
^{237}Np	ALL	LOGNORM.	0.044	0.032	0.04	1.00
^{238}Pu	ALL	NORMAL	0.004	0.085	---	1.00
$^{239,240}Pu$	ALL	NORMAL	-0.009	0.037	---	1.00
^{241}Pu	ALL	NORMAL	8.3	13	---	1.00

Abbreviations:
s - Standard Deviation   t - Scalar Constant (3-Parameter Lognormal)
K-S Signif. - Kolmogorov-Smirnov significance level
LGS - Laguna Grande de la Sal   N/A - Not Applicable

Units are in Becquerels per gram x 10^{-4}

Table 5-3

Surface Water Samples: Critical Values

Radio-nuclide	Group	MDL	Probability			
			0.80	0.90	0.95	0.99
^{3}H	ALL	56	10	29	45	74
^{40}K	TANKS/PECOS	---	170	260	380	760
	LGS	---	12000	13000	14000	16000
^{60}Co	ALL	3.0	< 24	< 24	< 27	< 30
^{90}Sr	ALL	7.4	0.7	1.1	1.5	2.7
^{137}Cs	ALL	1.9	< 12	< 17	< 19	< 21
^{226}Ra	ALL	5.6	6	9	13	24
^{228}Ra	ALL	---	12	13	15	17
^{228}Th	ALL	3.7	3	6	8	18
^{230}Th	ALL	0.37	0.15	0.20	0.25	0.34
^{232}Th	ALL	0.37	0.11	0.17	0.23	0.36
^{233}U	TANKS	0.37	0.024	0.041	0.056	0.083
	LGS	0.37	0.1	0.3	0.5	1.5
	PECOS	0.37	0.04	0.07	0.09	0.12
^{234}U	TANKS	0.37	0.2	0.3	0.4	1.0
	LGS	0.37	8	11	14	22
	PECOS	0.37	1.6	2.0	2.4	3.3
^{235}U	TANKS	---	0.023	0.032	0.039	0.052
	LGS	---	0.20	0.28	0.36	0.60
	PECOS	---	0.06	0.08	0.10	0.14
^{238}U	TANKS	0.37	0.09	0.13	0.18	0.32
	LGS	0.37	4	6	7	11
	PECOS	0.37	0.7	0.8	0.9	1.1
^{237}Np	ALL	0.37	0.02	0.04	0.06	0.12
^{238}Pu	ALL	0.11	0.07	0.10	0.14	0.19
$^{239/240}Pu$	ALL	0.74	0.022	0.039	0.052	0.077
^{241}Pu	ALL	37	19	25	30	38

Abbreviations:
- MDL - Minimum Detection Limit
- LGS - Laguna Grande de la Sal
- N/A - Not Applicable

Units are in Becquerels per gram x 10^{-4}

increase forms a continuous gradient across the landscape, criteria for subdivision of the data base were selected to optimize statistical and spatial uniformity within each group while maintaining large and comparable sample sizes.

The Culebra wells were divided into two groups based on whether the mean concentration of ^{226}Ra is greater or less than 1.66×10^{-3} Becquerels per gram, or three times the MDL. The low group, i.e., those having means less than this value, contains ten Culebra wells (all wells west of the WIPP Site boundary plus H-2A and H-9), as well as all Magenta wells and private wells. The high group, i.e., those wells having means greater than three times the MDL, contains 12 Culebra wells, all of which are east of the western boundary of the WIPP Site.

Table 5-4 presents the summary statistics for each radionuclide and subsequent well group. Table 5-5 presents the results of probability distribution modeling of these data bases. Table 5-6 presents the critical values resulting from these models. ^{40}K, ^{60}Co, ^{137}Cs, ^{228}Ra, and ^{228}Th all had more than 10 percent of their data reported as being less than a maximum value; however, for ^{40}K, ^{228}Ra, and ^{228}Th, probability models were found that provided a good fit to the data with these maximum values left in the data base. For ^{60}Co and ^{137}Cs, probability modeling was unsuccessful due to the nonrandom nature of the maximum values.

Of the remaining data bases that have reported MDL, only ^{226}Ra, ^{234}U, and ^{238}U have group means exceeding the MDL. Model fitting results are generally good using the normal or the two- or three-parameter lognormal distribution.

Table 5-4

Groundwater Samples: Summary Statistics

Radio-nuclide	Group	MDL	n	Mean		s.e.	s	c.v.
^{3}H	ALL	56	84	-38	+/-	4	33	0.87
^{40}K	M/P	---	33	< 73	+/-	11	65	0.89
	C	---	57	< 200	+/-	20	140	0.70
^{60}Co	ALL	3.0	92	< 12		N/A	N/A	N/A
^{90}Sr	ALL	7.4	83	0.30	+/-	0.08	0.69	2.30
^{137}Cs	ALL	1.9	92	< 7.2		N/A	N/A	N/A
^{226}Ra	LOW	5.6	39	6.9	+/-	0.8	4.7	0.68
	HIGH	5.6	32	52	+/-	5	26	0.50
^{228}Ra	ALL	---	84	< 9.6	+/-	0.4	4.2	0.44
^{228}Th	ALL	3.7	84	< 2.2	+/-	0.2	1.8	0.82
^{230}Th	ALL	0.37	87	0.14	+/-	0.05	0.47	3.36
^{232}Th	ALL	0.37	87	0.007	+/-	0.008	0.075	10.71
^{233}U	ALL	0.37	97	0.012	+/-	0.005	0.049	4.08
^{234}U	ALL	0.37	97	2.6	+/-	0.2	2.3	0.88
^{235}U	ALL	---	96	0.055	+/-	0.009	0.088	1.60
^{238}U	ALL	0.37	97	0.72	+/-	0.08	0.84	1.17
^{237}Np	ALL	0.37	87	0.001	+/-	0.004	0.041	41.00
^{238}Pu	ALL	0.11	91	0.03	+/-	0.02	0.18	6.00
$^{239/240}Pu$	ALL	0.74	91	0.007	+/-	0.008	0.080	11.43
^{241}Pu	ALL	37	91	9	+/-	3	32	3.56

Abbreviations:

MDL - Minimum Detection Limit
s.e. - Standard error
c.v. - Coefficient of variation
C - Culebra Formation
n - Sample size
s - Standard deviation
M/P - Magenta Formation and Private Wells
N/A - Not Applicable

Units are in Becquerels per gram x 10^{-4}

Table 5-5

Groundwater Samples: Probability Distribution Functions

Radio-nuclide	Group	Type	Parameter			K-S Signif.
			Mean	s	t	
^{3}H	ALL	NORMAL	-38	33	---	1.00
^{40}K	M/P	N/A	N/A	N/A	N/A	N/A
	C	N/A	N/A	N/A	N/A	N/A
^{60}Co	ALL	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	NORMAL	0.30	0.69	---	1.00
^{137}Cs	ALL	N/A	N/A	N/A	N/A	N/A
^{226}Ra	LOW	LOGNORM.	7.2	6.6	---	1.00
	HIGH	LOGNORM.	52	27	---	1.00
^{228}Ra	ALL	NORMAL	9.6	4.2	---	0.30
^{228}Th	ALL	LOGNORM.	2.3	2.9	---	1.00
^{230}Th	ALL	NORMAL	0.06	0.09	---	1.00
^{232}Th	ALL	NORMAL	0.007	0.075	---	0.10
^{233}U	ALL	LOGNORM.	0.11	0.03	0.1	0.03
^{234}U	ALL	LOGNORM.	3.6	2.7	1.0	1.00
^{235}U	ALL	LOGNORM.	0.10	0.07	0.05	0.36
^{238}U	ALL	LOGNORM.	1.1	0.70	0.4	1.00
^{237}Np	ALL	NORMAL	0.001	0.02	---	1.00
^{238}Pu	ALL	LOGNORM.	0.53	0.14	0.5	0.07
$^{239/240}Pu$	ALL	NORMAL	0.007	0.029	---	0.29
^{241}Pu	ALL	NORMAL	6.9	18	---	0.34

Abbreviations:
- s - Standard Deviation
- t - Scalar Constant (3-Parameter Lognormal)
- K-S Signif. - Kolmogorov-Smirnov significance level
- N/A - Not Applicable
- M/P - Magenta Formation and Private Wells
- C - Culebra Formation

Units are in Becquerels per gram x 10^{-4}

Table 5-6

Groundwater Samples: Critical Values

Radio-nuclide	Group	MDL	Probability 0.80	0.90	0.95	0.99
^{3}H	ALL	56	-10	4	16	39
^{40}K	M/P	---	< 120	< 180	< 200	< 210
	C	---	< 310	< 370	< 440	< 630
^{60}Co	ALL	3.0	< 16	< 18	< 25	< 28
^{90}Sr	ALL	7.4	0.9	1.2	1.4	1.9
^{137}Cs	ALL	1.9	< 12	< 13	< 17	< 23
^{226}Ra	LOW	5.6	10	14	19	33
	HIGH	5.6	70	90	100	140
^{228}Ra	ALL	---	< 13	< 15	< 16	< 19
^{228}Th	ALL	3.7	< 3	< 5	< 7	< 14
^{230}Th	ALL	0.37	0.14	0.18	0.21	0.27
^{232}Th	ALL	0.37	0.07	0.10	0.13	0.18
^{233}U	ALL	0.37	0.03	0.05	0.06	0.10
^{234}U	ALL	0.37	4	6	8	13
^{235}U	ALL	---	0.09	0.13	0.18	0.31
^{238}U	ALL	0.37	1.1	1.6	2.0	3.2
^{237}Np	ALL	0.37	0.018	0.026	0.034	0.047
^{238}Pu	ALL	0.11	0.14	0.21	0.28	0.44
$^{239/240}Pu$	ALL	0.74	0.031	0.044	0.054	0.074
^{241}Pu	ALL	37	22	30	36	49

Abbreviations:
- MDL - Minimum Detection Limit
- N/A - Not Applicable
- M/P - Magenta Formation and Private Wells
- C - Culebra Formation

Units are in Becquerels per gram x 10^{-4}

6.0 Bottom Sediment Samples

The analysis of bottom sediments is a crucial component to the WIPP environmental monitoring programs. A recent study of the ecological distribution of radionuclides in a contaminated reservoir at the Savannah River Site (Whicker et al., 1990) found nearly 99 percent of long-lived radionuclides (^{90}Sr, ^{137}Cs, and transuranics) remaining in the system were in the bottom sediments.

For the WIPP RBP, bottom sediments were collected from six locations—Hill Tank, Indian Tank, Noye Tank, Laguna Grande de la Sal, and two sites along the Pecos River in conjunction with surface-water sampling. These samples were analyzed for 17 radionuclides. As with the surface-water samples, samples collected at different times from the same location are considered replicate samples for that location.

The data were stratified into three geographic groups—stock tanks, the Pecos River, and Laguna Grande de la Sal. The latter is separated because of the atypical nature of the sediments; however, this location is represented in the data base with only three replicate samples.

Analysis of variance was used to determine whether significant differences exist between these groups (at 95 percent confidence). Where none was found, the data were combined. Because of the small sample size for Laguna Grande de la Sal, it was not analyzed independently but rather combined with the group to which it had closest affinities. Thus, for ^{40}K and ^{137}Cs Laguna Grande de la Sal was combined with the stock tanks and for ^{226}Ra, ^{228}Ra, and ^{228}Th it was combined with the Pecos River data.

Summary statistics for this data base are presented in Table 6-1. In all five of the cases where differences were found between location groups, the stock tanks had higher concentrations of the radionuclide, possibly indicating an accumulation effect from the closed nature of the tanks. Laguna Grande de la Sal sediments were found to contain significantly higher concentrations of ^{234}U than the stock tanks and the Pecos River, which were indistinguishable. In this case, the data were analyzed with Laguna Grande included and then reanalyzed with it excluded.

Table 6-1

Bottom Sediment Samples: Summary Statistics

Radio-nuclide	Group	LGS	MDL	n	Mean		s.e.	s	c.v.
^{40}K	TANKS	+	---	12	670	+/-	60	220	0.33
	PECOS	-	---	8	210	+/-	20	60	0.28
^{60}Co	ALL	+	3.7	20	< 2.6		N/A	N/A	N/A
^{90}Sr	ALL	+	74	20	1	+/-	5	23	23.00
^{137}Cs	TANKS	-	3.7	9	16	+/-	3	8	0.50
	PECOS	+	3.7	11	1.2	+/-	0.4	1.4	1.17
^{226}Ra	TANKS	-	7.4	9	30	+/-	2	6	0.20
	PECOS	+	7.4	11	17	+/-	2	6	0.35
^{228}Ra	TANKS	-	---	9	< 39		N/A	N/A	N/A
	PECOS	+	---	11	< 12		N/A	N/A	N/A
^{228}Th	TANKS	-	3.7	9	31	+/-	2	5	0.16
	PECOS	+	3.7	11	9.0	+/-	1.3	4.5	0.50
^{230}Th	ALL	+	3.7	20	1.7	+/-	0.4	2.0	1.18
^{232}Th	ALL	+	3.7	20	2.1	+/-	0.6	2.7	1.28
^{233}U	ALL	+	3.7	20	0.39	+/-	0.22	0.98	2.51
^{234}U	ALL	+	3.7	20	22	+/-	5	22	1.00
	ALL	-	3.7	17	16	+/-	1	4	0.25
^{235}U	ALL	+	---	20	0.97	+/-	0.21	0.97	1.00
^{238}U	ALL	+	3.7	20	17	+/-	2	10	0.59
^{237}Np	ALL	+	3.7	20	-0.04	+/-	0.06	0.27	6.75
^{238}Pu	ALL	+	15	20	0.1	+/-	0.3	1.2	12.00
$^{239/240}$Pu	ALL	+	7.4	20	0.36	+/-	0.15	0.66	1.83
^{241}Pu	ALL	+	370	20	50	+/-	60	280	5.60

Abbreviations:
- LGS - Laguna Grande de la Sal, data included (+) or excluded (-)
- MDL - Minimum Detection Limit
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation
- N/A - Not Applicable

Units are in Becquerels per gram x 10^{-3}

Fits to the normal or lognormal probability distributions were generally very high (Table 6-2). In four cases (^{40}K, ^{230}Th, ^{232}Th, and ^{233}U), the three-parameter lognormal distribution was used with good results. ^{90}Sr exhibits the poorest fit; however, these data are well below the MDL and tend to be clustered about zero. Critical values for all sediment data sets are presented in Table 6-3.

M

Table 6-2

Bottom Sediment Samples: Probability Distribution Functions

Radio-nuclide	Group	LGS	Type	Parameter Mean	s	t	K-S Signif.
^{40}K	TANKS	+	NORMAL	660	220	---	1.00
	PECOS	-	LOGNORM.	67	71	-150	1.00
^{60}Co	ALL	+	N/A	N/A	N/A	N/A	N/A
^{90}Sr	ALL	+	NORMAL	4.7	12	---	1.00
^{137}Cs	TANKS	-	NORMAL	16	8.1	---	1.00
	PECOS	+	LOGNORM.	1.2	1.0	---	1.00
^{226}Ra	TANKS	-	NORMAL	30	5.6	---	1.00
	PECOS	+	NORMAL	17	6.1	---	1.00
^{228}Ra	TANKS	-	N/A	N/A	N/A	N/A	N/A
	PECOS	+	N/A	N/A	N/A	N/A	N/A
^{228}Th	TANKS	-	NORMAL	31	5.2	---	1.00
	PECOS	+	NORMAL	9.0	4.5	---	1.00
^{230}Th	ALL	+	LOGNORM.	2.4	3.5	0.5	1.00
^{232}Th	ALL	+	LOGNORM.	3.5	3.0	1.0	1.00
^{233}U	ALL	+	LOGNORM.	2.0	1.1	1.5	1.00
^{234}U	ALL	+	LOGNORM.	22	22	---	0.16
	ALL	-	NORMAL	16	4.3	---	1.00
^{235}U	ALL	+	NORMAL	0.97	0.97	---	1.00
^{238}U	ALL	+	LOGNORM.	17	9.6	---	1.00
^{237}Np	ALL	+	NORMAL	-0.045	0.27	---	1.00
^{238}Pu	ALL	+	NORMAL	0.12	1.2	---	1.00
$^{239/240}Pu$	ALL	+	NORMAL	0.36	0.66	---	1.00
^{241}Pu	ALL	+	NORMAL	51	280	---	1.00

Abbreviations:
- s - Standard Deviation
- t - Scalar Constant (3-Parameter Lognormal)
- LGS - Laguna Grande de la Sal, data included (+) or excluded (-)
- K-S Signif. - Kolmogorov-Smirnov significance level

Units are in Becquerels per gram x 10^{-3}

Table 6-3

Bottom Sediment Samples: Critical Values

Radio-nuclide	Group	LGS	MDL	Probability 0.80	0.90	0.95	0.99
^{40}K	TANKS	+	---	800	900	1000	1200
	PECOS	-	---	240	290	340	500
^{60}Co	ALL	+	3.7	< 3.3	< 3.4	< 4.6	< 5.9
^{90}Sr	ALL	+	74	15	20	24	33
^{137}Cs	TANKS	-	3.7	23	26	29	35
	PECOS	+	3.7	1.7	2.3	3.0	5.0
^{226}Ra	TANKS	-	7.4	35	37	39	43
	PECOS	+	7.4	22	25	27	31
^{228}Ra	TANKS	-	---	< 44	< 48	< 48	< 48
	PECOS	+	---	< 12	< 24	< 24	< 24
^{228}Th	TANKS	-	3.7	35	38	40	43
	PECOS	+	3.7	13	15	16	19
^{230}Th	ALL	+	3.7	3	5	7	16
^{232}Th	ALL	+	3.7	4	6	8	14
^{233}U	ALL	+	3.7	1.2	1.9	2.6	4.3
^{234}U	ALL	+	3.7	30	40	60	110
	ALL	-	3.7	20	22	23	26
^{235}U	ALL	+	---	1.8	2.2	2.6	3.2
^{238}U	ALL	+	3.7	23	29	35	50
^{237}Np	ALL	+	3.7	0.18	0.30	0.40	0.58
^{238}Pu	ALL	+	15	1.1	1.6	2.1	2.9
$^{239/240}Pu$	ALL	+	7.4	0.9	1.2	1.4	1.9
^{241}Pu	ALL	+	370	290	410	510	700

Abbreviations:
LGS - Laguna Grande de la Sal, data included (+) or excluded (-)
MDL - Minimum Detection Limit

Units are in Becquerels per gram x 10^{-3}

7.0 Biotic Tissue Samples

Tissue samples were collected from five components of the biological environment—vegetation, quail, rabbit, catfish, and domestic cattle. Because of the small sample sizes in this subprogram, no attempt was made to further subdivide the samples, nor was probability distribution fitting attempted.

Vegetation samples included above-ground tissues of native vegetation, with species represented in approximately the same proportions (in biomass) as they occur at the sampling site. The samples were ashed prior to analysis. Three sites were sampled twice during the RBP. Summary statistics for 14 radionuclides are presented in Table 7-1. ^{7}Be and ^{60}Co were the only vegetation parameters with values reported as being less than a maximum.

Rabbit, quail, and catfish tissue samples have been analyzed for 17 radionuclides. Initially, the samples were ashed prior to analysis. This procedure was later changed to merely drying the samples. Summary statistics for each data set are presented in Table 7-1.

Both muscle and bone were independently sampled and analyzed from two locally grown beef cattle. Dried tissue samples have been analyzed for 17 radionuclides. The results are summarized in Table 7-1. The means of the bone samples slightly exceeded the MDL for ^{230}Th and ^{232}Th. Because there are only two data points for each radionuclide in these data sets, standard deviation, standard error, and coefficient of variation were not calculated for the beef samples.

Table 7-1

Biotic Tissue Samples: Summary Statistics

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{7}Be	VEGETATION (ASH)	---	5	< 2000		N/A	N/A	N/A
^{40}K	VEGETATION (ASH)	---	6	3200	+/-	400	900	0.28
	RABBIT (ASH)	---	1	1000		N/A	N/A	N/A
	RABBIT (DRY)	---	2	390		N/A	N/A	N/A
	QUAIL (ASH)	---	1	1100		N/A	N/A	N/A
	QUAIL (DRY)	---	2	410		N/A	N/A	N/A
	FISH (ASH)	---	1	1800		N/A	N/A	N/A
	FISH (DRY)	---	2	610		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	340		N/A	N/A	N/A
	BEEF (BONE)	---	2	25		N/A	N/A	N/A
^{60}Co	VEGETATION (ASH)	18	6	< 10		N/A	N/A	N/A
	RABBIT (ASH)	18	1	9.6		N/A	N/A	N/A
	RABBIT (DRY)	18	2	6.1		N/A	N/A	N/A
	QUAIL (ASH)	18	1	9.3		N/A	N/A	N/A
	QUAIL (DRY)	18	2	5.2		N/A	N/A	N/A
	FISH (ASH)	18	1	17		N/A	N/A	N/A
	FISH (DRY)	18	2	7.0		N/A	N/A	N/A
	BEEF (MUSCLE)	18	2	4.8		N/A	N/A	N/A
	BEEF (BONE)	18	2	3.8		N/A	N/A	N/A
^{90}Sr	RABBIT (ASH)	---	1	14		N/A	N/A	N/A
	RABBIT (DRY)	---	2	-3.5		N/A	N/A	N/A
	QUAIL (ASH)	---	1	28		N/A	N/A	N/A
	QUAIL (DRY)	---	2	16		N/A	N/A	N/A
	FISH (ASH)	---	1	26		N/A	N/A	N/A
	FISH (DRY)	---	2	-3.0		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	2.8		N/A	N/A	N/A
	BEEF (BONE)	---	2	12		N/A	N/A	N/A
^{137}Cs	VEGETATION (ASH)	7.4	6	10	+/-	3	6	0.60
	RABBIT (ASH)	7.4	1	2.1		N/A	N/A	N/A
	RABBIT (DRY)	7.4	2	2.2		N/A	N/A	N/A
	QUAIL (ASH)	7.4	1	7.4		N/A	N/A	N/A
	QUAIL (DRY)	7.4	2	2.6		N/A	N/A	N/A
	FISH (ASH)	7.4	1	10		N/A	N/A	N/A
	FISH (DRY)	7.4	2	1.2		N/A	N/A	N/A
	BEEF (MUSCLE)	7.4	2	3.1		N/A	N/A	N/A
	BEEF (BONE)	7.4	2	1.8		N/A	N/A	N/A

Table 7-1

(Continued)

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{226}Ra	VEGETATION (ASH)	37	6	59	+/-	8	20	0.34
	RABBIT (ASH)	37	1	20		N/A	N/A	N/A
	RABBIT (DRY)	37	2	6.1		N/A	N/A	N/A
	QUAIL (ASH)	37	1	5.2		N/A	N/A	N/A
	QUAIL (DRY)	37	2	8.1		N/A	N/A	N/A
	FISH (ASH)	37	1	16		N/A	N/A	N/A
	FISH (DRY)	37	2	3.6		N/A	N/A	N/A
	BEEF (MUSCLE)	37	2	2.1		N/A	N/A	N/A
	BEEF (BONE)	37	2	12		N/A	N/A	N/A
^{228}Ra	VEGETATION (ASH)	---	6	65	+/-	12	30	0.45
	RABBIT (ASH)	---	1	16		N/A	N/A	N/A
	RABBIT (DRY)	---	2	11		N/A	N/A	N/A
	QUAIL (ASH)	---	1	36		N/A	N/A	N/A
	QUAIL (DRY)	---	2	20		N/A	N/A	N/A
	FISH (ASH)	---	1	33		N/A	N/A	N/A
	FISH (DRY)	---	2	22		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	9.1		N/A	N/A	N/A
	BEEF (BONE)	---	2	14		N/A	N/A	N/A
^{228}Th	VEGETATION (ASH)	15	6	27	+/-	4	10	0.39
	RABBIT (ASH)	15	1	9.3		N/A	N/A	N/A
	RABBIT (DRY)	15	2	1.3		N/A	N/A	N/A
	QUAIL (ASH)	15	1	17		N/A	N/A	N/A
	QUAIL (DRY)	15	2	6.8		N/A	N/A	N/A
	FISH (ASH)	15	1	9.3		N/A	N/A	N/A
	FISH (DRY)	15	2	6.0		N/A	N/A	N/A
	BEEF (MUSCLE)	15	2	2.8		N/A	N/A	N/A
	BEEF (BONE)	15	2	6.8		N/A	N/A	N/A
^{230}Th	RABBIT (ASH)	3.7	1	0.056		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.34		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.44		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.54		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.59		N/A	N/A	N/A
	FISH (DRY)	3.7	2	0.30		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.037		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	3.84		N/A	N/A	N/A
^{232}Th	RABBIT (ASH)	3.7	1	1.5		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.18		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.56		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.31		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.14		N/A	N/A	N/A
	FISH (DRY)	3.7	2	0.19		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	1.0		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	4.1		N/A	N/A	N/A

Table 7-1

(Continued)

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{233}U	VEGETATION (ASH)	3.7	6	0.07	+/-	0.04	0.11	1.62
	RABBIT (ASH)	3.7	1	0.89		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.00		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.00		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.00		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.00		N/A	N/A	N/A
	FISH (DRY)	3.7	2	2.8		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.00		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	0.00		N/A	N/A	N/A
^{234}U	VEGETATION (ASH)	3.7	6	0.06	+/-	0.02	0.04	0.63
	RABBIT (ASH)	3.7	1	0.059		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.00		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.28		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.22		N/A	N/A	N/A
	FISH (ASH)	3.7	1	5.9		N/A	N/A	N/A
	FISH (DRY)	3.7	2	-0.055		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.23		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	0.58		N/A	N/A	N/A
^{235}U	VEGETATION (ASH)	---	6	0.09	+/-	0.08	0.21	2.43
	RABBIT (ASH)	---	1	0.41		N/A	N/A	N/A
	RABBIT (DRY)	---	2	-0.11		N/A	N/A	N/A
	QUAIL (ASH)	---	1	0.48		N/A	N/A	N/A
	QUAIL (DRY)	---	2	0.026		N/A	N/A	N/A
	FISH (ASH)	---	1	0.00		N/A	N/A	N/A
	FISH (DRY)	---	2	0.54		N/A	N/A	N/A
	BEEF (MUSCLE)	---	2	0.21		N/A	N/A	N/A
	BEEF (BONE)	---	2	0.22		N/A	N/A	N/A
^{238}U	VEGETATION (ASH)	3.7	6	0.69	+/-	0.21	0.51	0.74
	RABBIT (ASH)	3.7	1	0.00		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	1.7		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	0.00		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	0.35		N/A	N/A	N/A
	FISH (ASH)	3.7	1	5.6		N/A	N/A	N/A
	FISH (DRY)	3.7	2	1.2		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.56		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	0.19		N/A	N/A	N/A

M

Table 7-1

(Continued)

Radio-nuclide	Sample Type	MDL	n	Mean		s.e.	s	c.v.
^{237}Np	RABBIT (ASH)	3.7	1	-0.67		N/A	N/A	N/A
	RABBIT (DRY)	3.7	2	0.00		N/A	N/A	N/A
	QUAIL (ASH)	3.7	1	-0.14		N/A	N/A	N/A
	QUAIL (DRY)	3.7	2	-0.020		N/A	N/A	N/A
	FISH (ASH)	3.7	1	0.44		N/A	N/A	N/A
	FISH (DRY)	3.7	2	-0.091		N/A	N/A	N/A
	BEEF (MUSCLE)	3.7	2	0.21		N/A	N/A	N/A
	BEEF (BONE)	3.7	2	2.9		N/A	N/A	N/A
^{238}Pu	VEGETATION (ASH)	15	6	0.0	+/-	0.7	1.8	---
	RABBIT (ASH)	15	1	1.3		N/A	N/A	N/A
	RABBIT (DRY)	15	2	0.49		N/A	N/A	N/A
	QUAIL (DRY)	15	2	1.1		N/A	N/A	N/A
	FISH (ASH)	15	1	-3.6		N/A	N/A	N/A
	FISH (DRY)	15	2	0.91		N/A	N/A	N/A
	BEEF (MUSCLE)	15	2	-1.7		N/A	N/A	N/A
	BEEF (BONE)	15	2	-0.52		N/A	N/A	N/A
$^{239/240}Pu$	VEGETATION (ASH)	7.4	6	0.37	+/-	0.15	0.36	0.96
	RABBIT (ASH)	7.4	1	0.63		N/A	N/A	N/A
	RABBIT (DRY)	7.4	2	-0.20		N/A	N/A	N/A
	QUAIL (DRY)	7.4	2	0.35		N/A	N/A	N/A
	FISH (ASH)	7.4	1	-0.56		N/A	N/A	N/A
	FISH (DRY)	7.4	2	0.13		N/A	N/A	N/A
	BEEF (MUSCLE)	7.4	2	-0.059		N/A	N/A	N/A
	BEEF (BONE)	7.4	2	0.11		N/A	N/A	N/A
^{241}Pu	VEGETATION (ASH)	370	6	370	+/-	130	300	0.81
	RABBIT (ASH)	370	1	320		N/A	N/A	N/A
	RABBIT (DRY)	370	2	400		N/A	N/A	N/A
	QUAIL (DRY)	370	2	350		N/A	N/A	N/A
	FISH (ASH)	370	1	1700		N/A	N/A	N/A
	FISH (DRY)	370	2	510		N/A	N/A	N/A
	BEEF (MUSCLE)	370	2	-1300		N/A	N/A	N/A
	BEEF (BONE)	370	2	350		N/A	N/A	N/A

Abbreviations:
- MDL - Minimum Detection Limit
- n - Sample size
- s.e. - Standard error
- s - Standard deviation
- c.v. - Coefficient of variation
- N/A - Not Applicable

ASH and DRY indicates whether the analysis was performed on ashed tissue or dried tissue, respectively.

Beef muscle and bone samples are analyzed as dried tissue.

Units are in Becquerels per gram of ash or dried tissue x 10^{-3}

8.0 Summary

The WIPP RBP was designed to provide preoperational measurements of radioactivity in environmental samples that will serve as a basis for evaluating similar data collected during the WIPP operational period in order for the safe performance of the facility to be determined. The RBP data analyzed in this report cover the period from 1985 through 1989. These data include radionuclide concentrations in airborne particulates, soil, surface water, groundwater, sediments, and six types of biotic tissue samples.

Gross beta and alpha activities were also measured in weekly airborne particulate samples. The Chernobyl accident resulted in significant increases in gross beta counts on these samples for a three-week period, although no long-term effect was detected. The Chernobyl accident did not affect the alpha counts. Gross beta activity, gross alpha activity, and ^{230}Th all differed significantly with season (quarter). In general, radioactivity on these samples was higher over a regional transect than at the WIPP Site itself.

Soil samples were collected at three depths. No differences between depth were found. The data were stratified to represent three regional scales about the WIPP Site. Isotopes of uranium, thorium, radium, cesium, and potassium were all found to vary with regional scale, with the mean concentrations increasing with area covered. Transuranics were below the detection limits.

In surface waters, Laguna Grande de la Sal exhibited relatively high concentrations of ^{40}K, ^{234}U, and ^{238}U. The Pecos River had detectable levels of ^{234}U and ^{238}U, although the sediments in stock tanks were higher in ^{40}K, ^{137}Cs, ^{226}Ra, ^{228}Ra, and ^{238}Th than the Pecos River sediments. ^{226}Ra was found to form an east-west gradient in concentration in groundwater samples collected from the Culebra dolomite unit.

Most radionuclides were below the detection limits in biotic tissues. Vegetation samples showed detectable levels of ^{7}Be, ^{40}K, ^{137}Cs, ^{226}Ra, ^{228}Ra, ^{228}Th, and ^{241}Pu. The latter, however, exhibits wide ranges in measured values resulting from low precision in its measurement on tissue samples. Animal tissues showed detectable levels of ^{40}K. Beef bone samples exhibited detectable levels of ^{230}Th and ^{232}Th. Catfish exhibited ^{234}U in ashed samples.

The normal and two- or three-parameter lognormal distributions were found to provide good models for most data bases. Critical values at the 0.80, 0.90, 0.95, and 0.99 probability levels were estimated for each data base. These values are appropriate for establishing warning and action levels for control charts during the operational environmental monitoring program.

9.0 References

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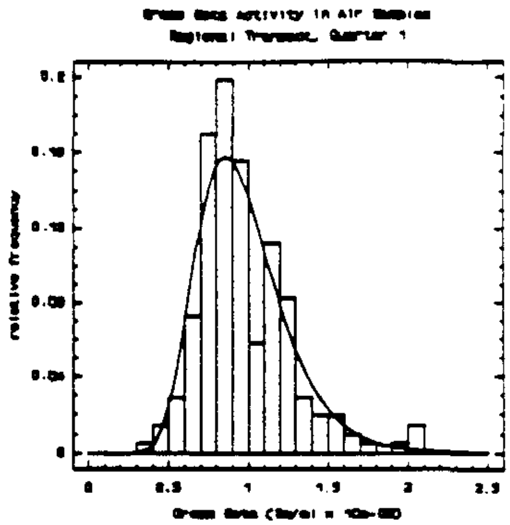
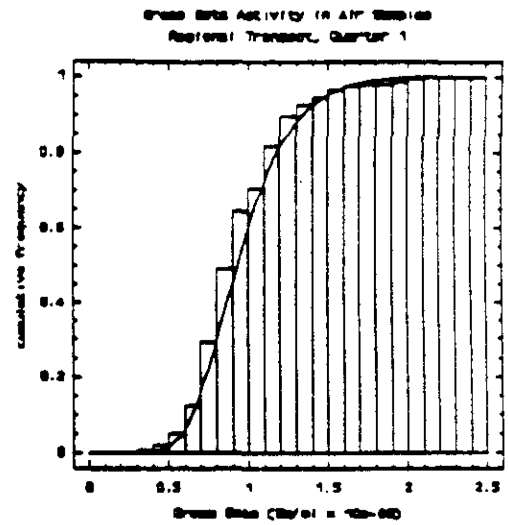
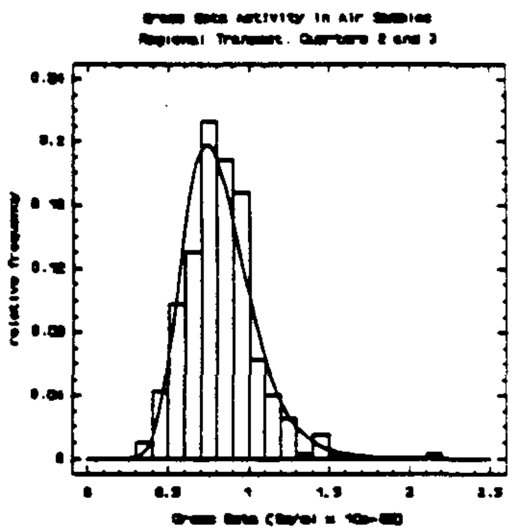
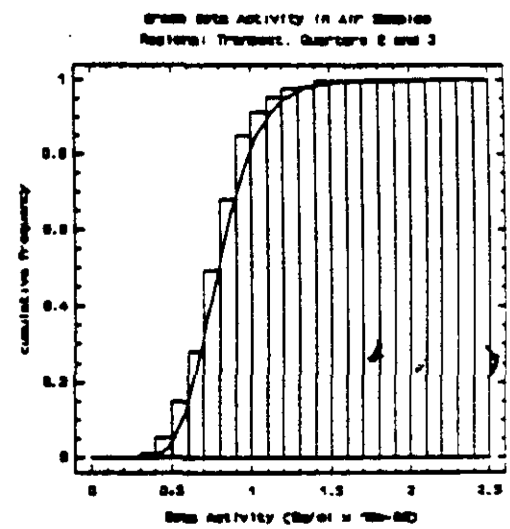
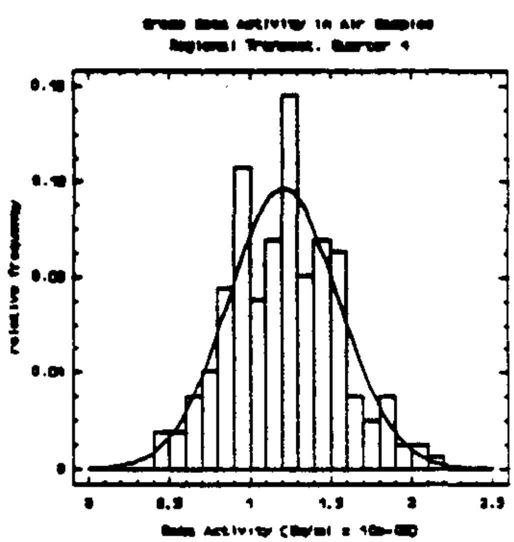
APPENDIX
DATA HISTOGRAMS AND PROBABILITY DISTRIBUTION MODELS

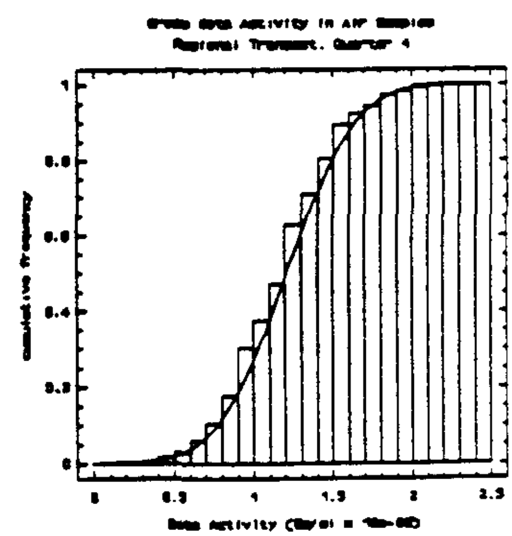


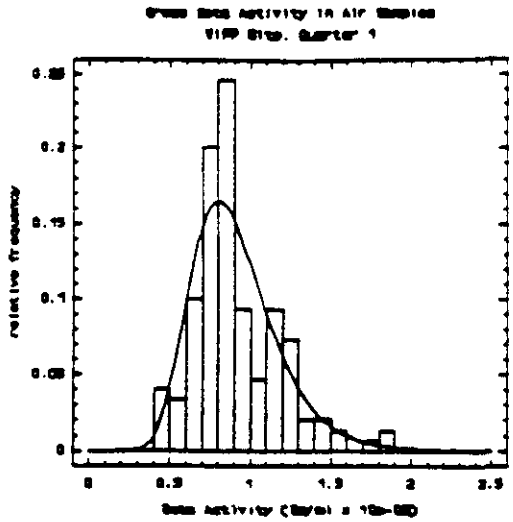


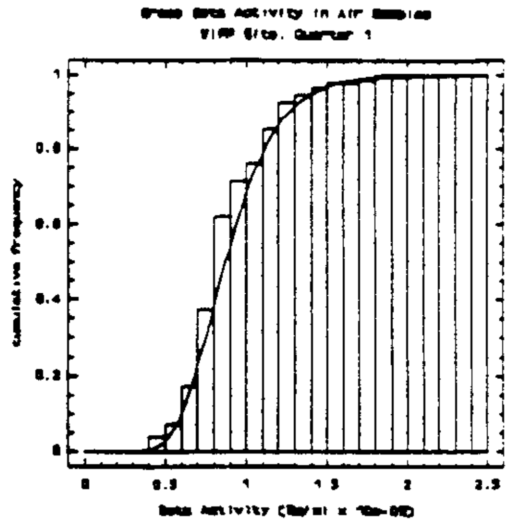


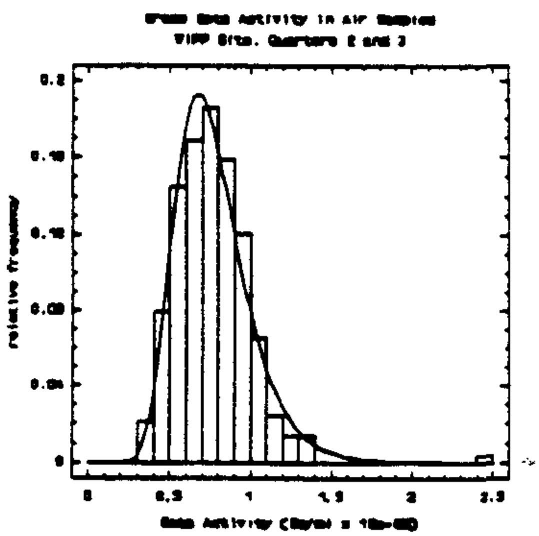


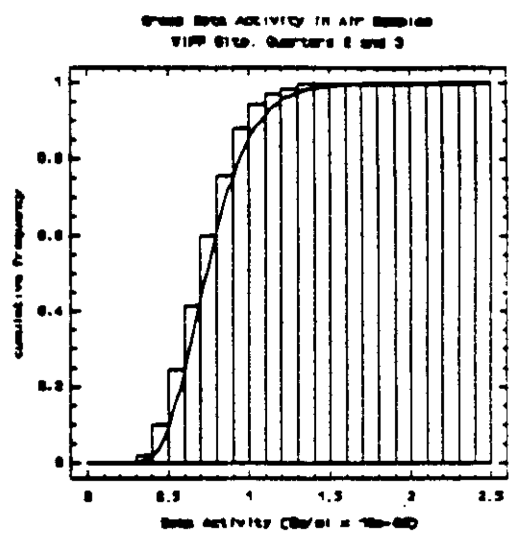


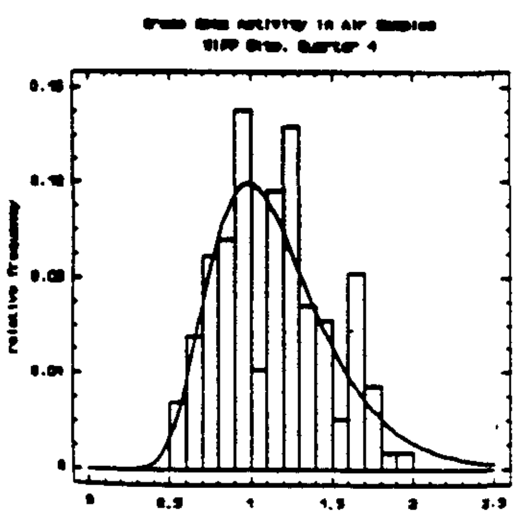


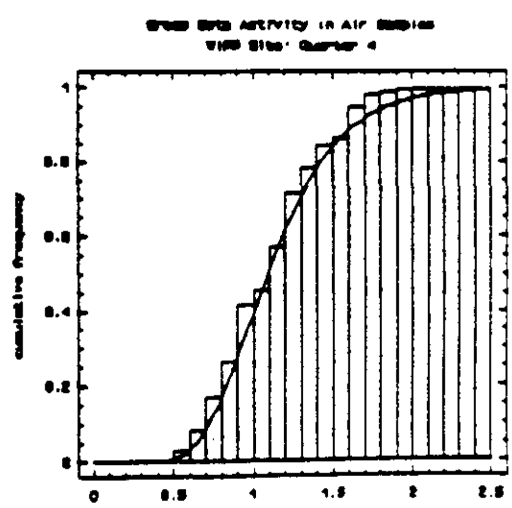


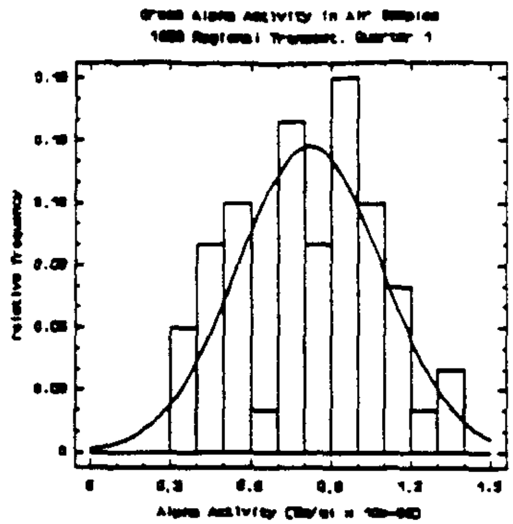


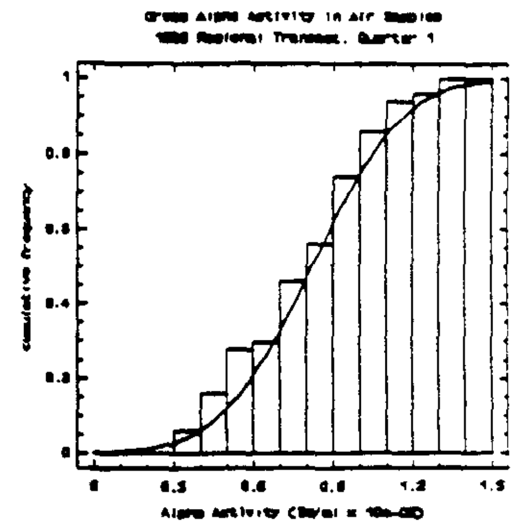


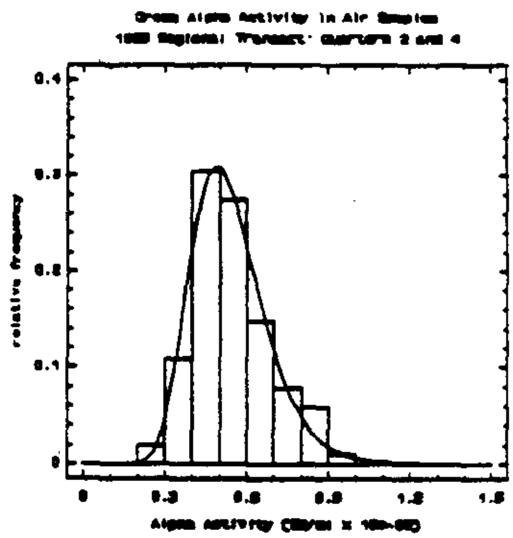


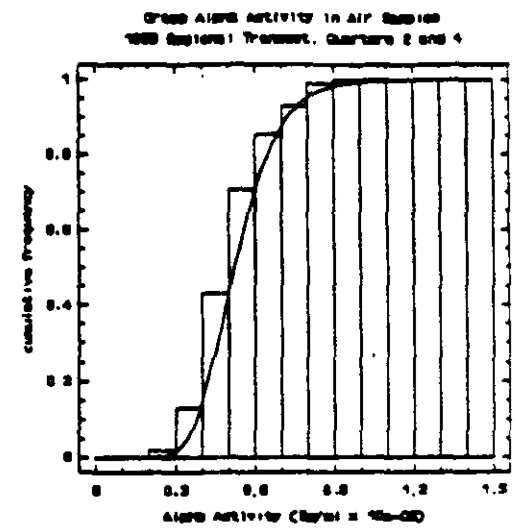


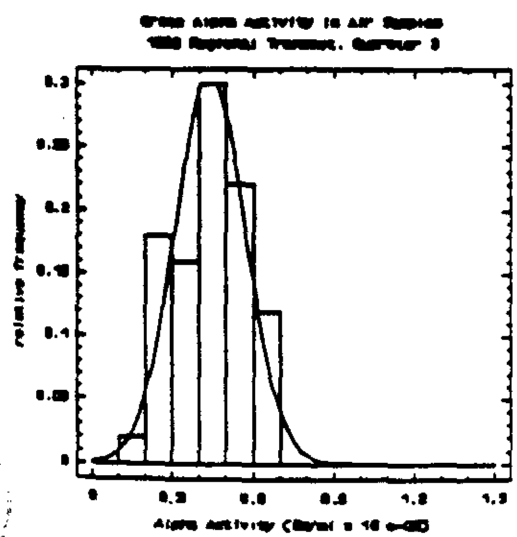


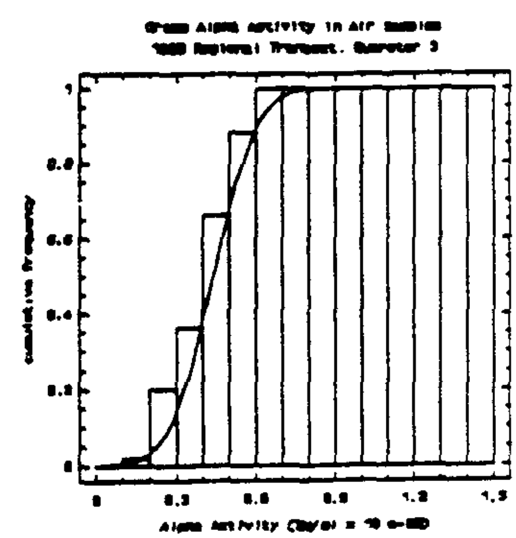












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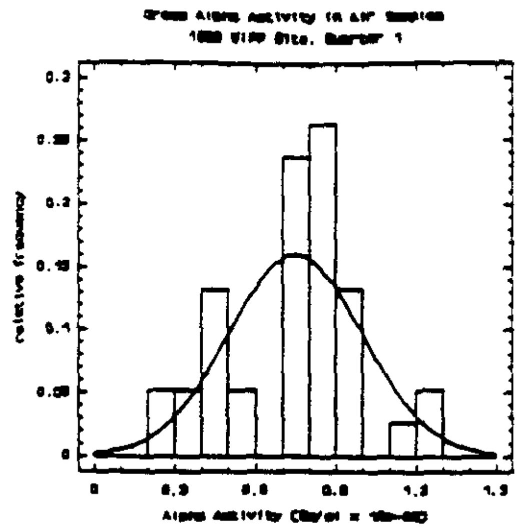
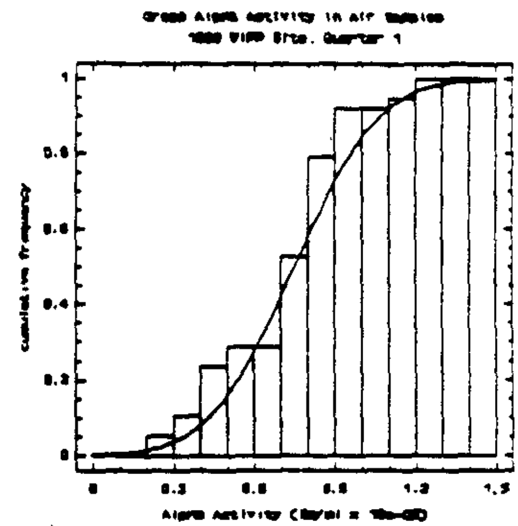
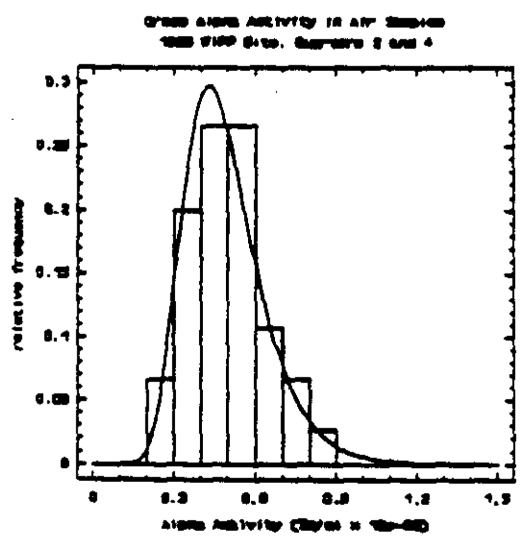
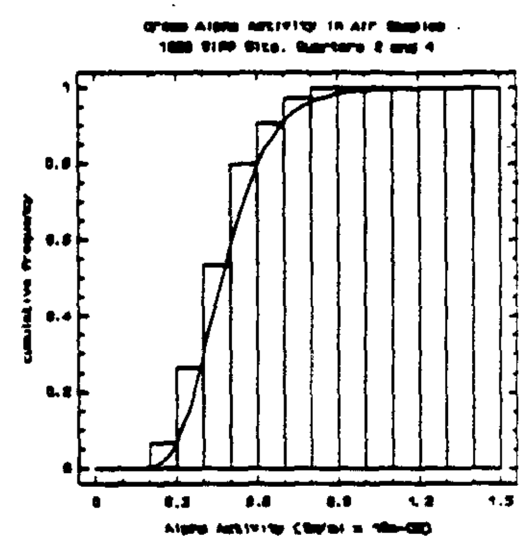
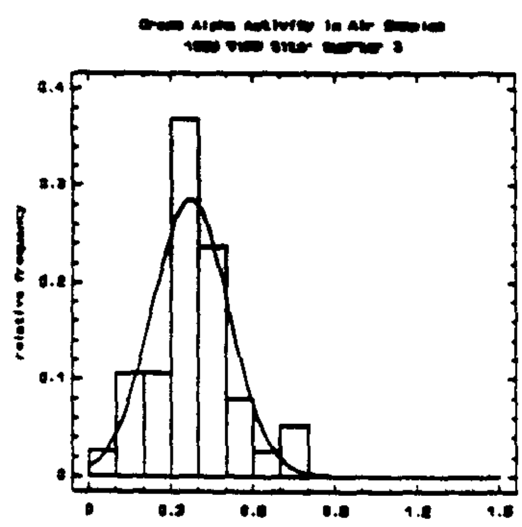
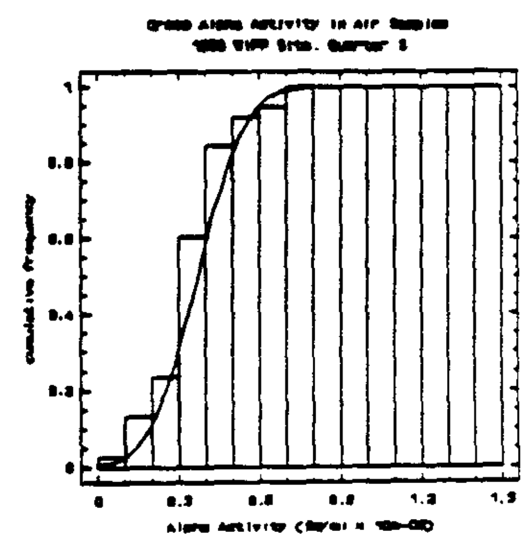


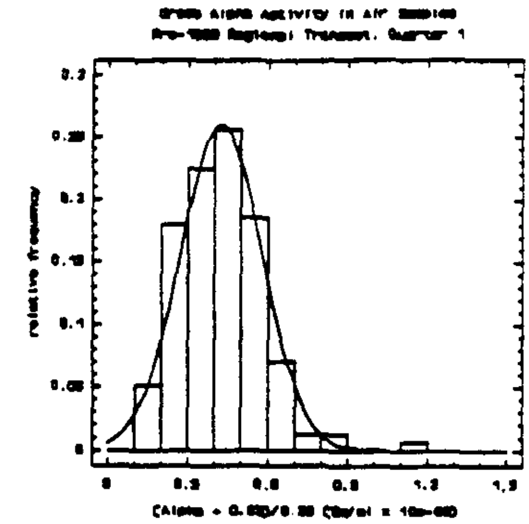


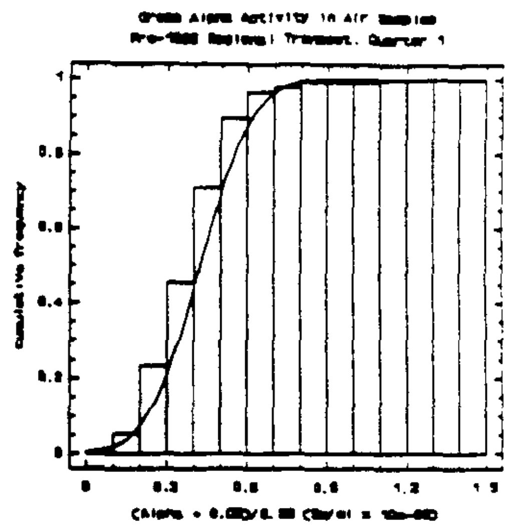


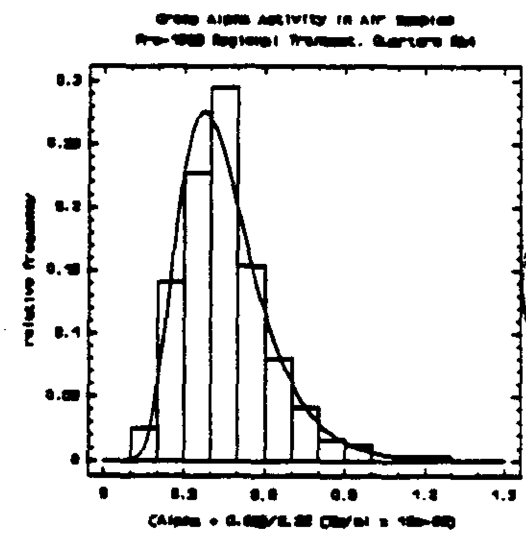


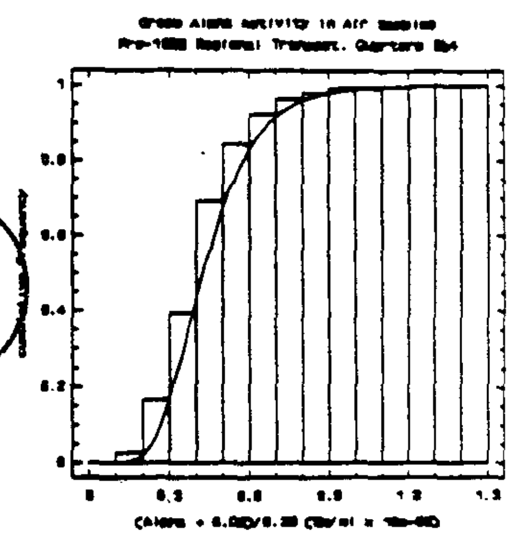


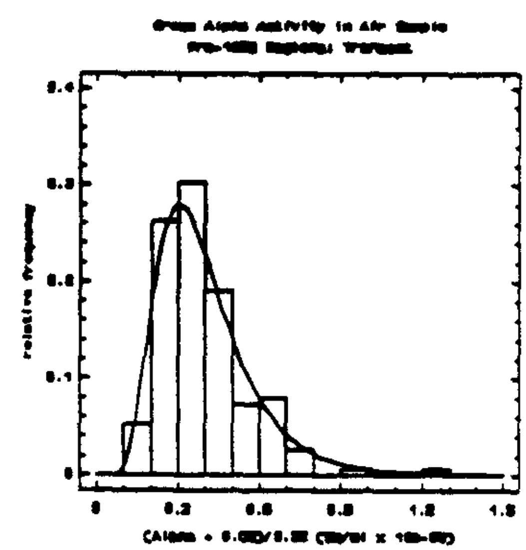


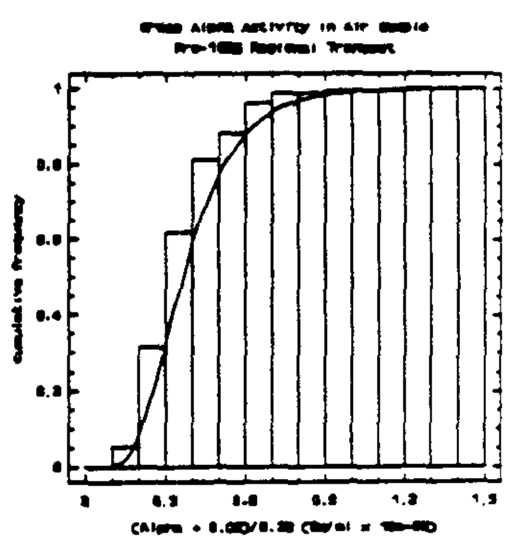


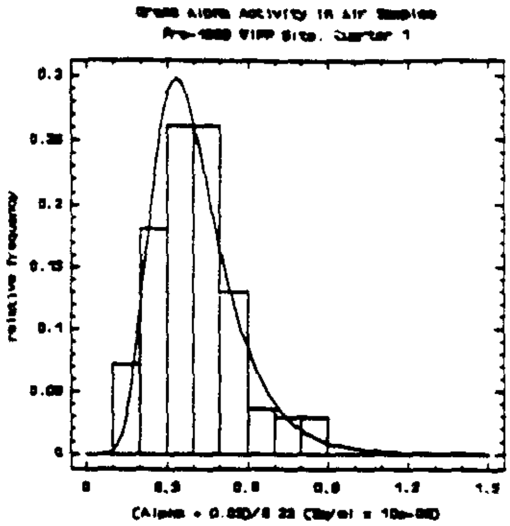


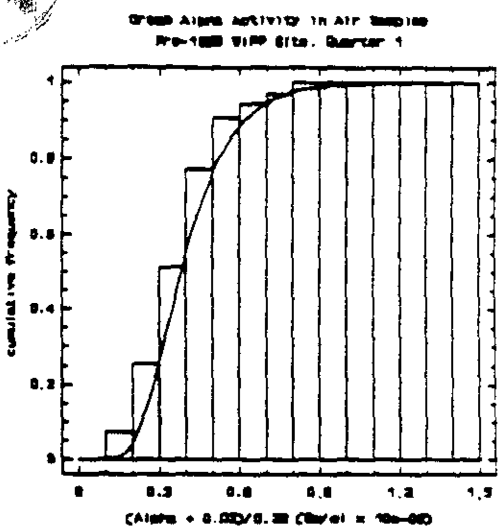


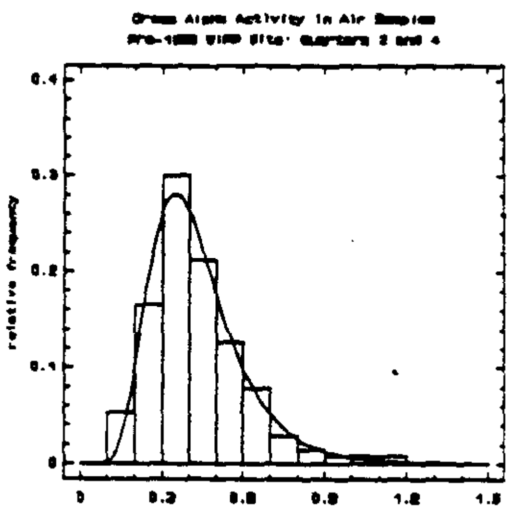


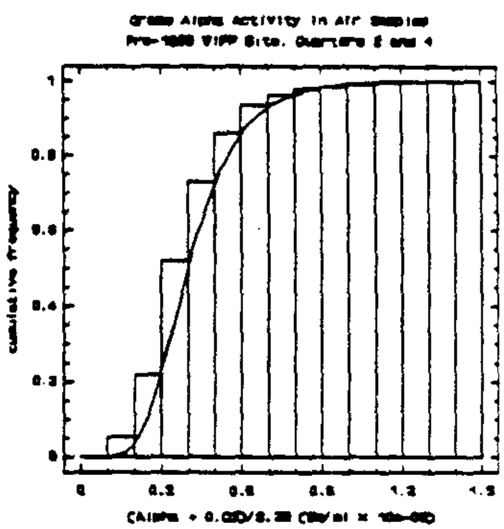





Gross Alpha Activity in Air Samples
WIPP Site, Quarter 1
relative frequency


Gross Alpha Activity in Air Samples
WIPP Site, Quarter 1
cumulative frequency


Gross Alpha Activity in Air Samples
WIPP Site, Quarters 2 and 4
relative frequency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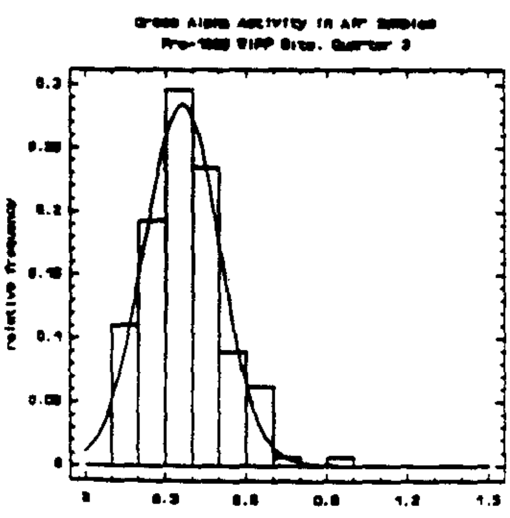
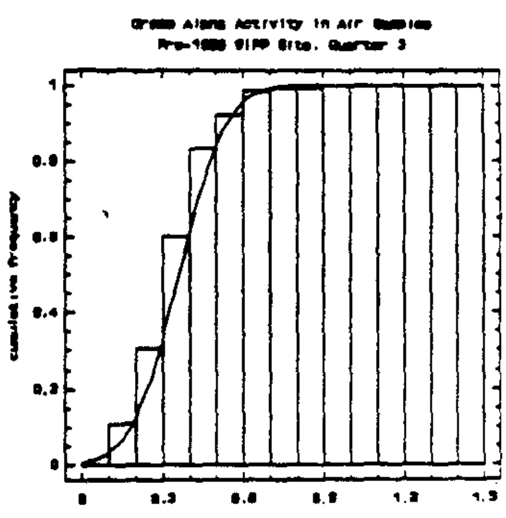
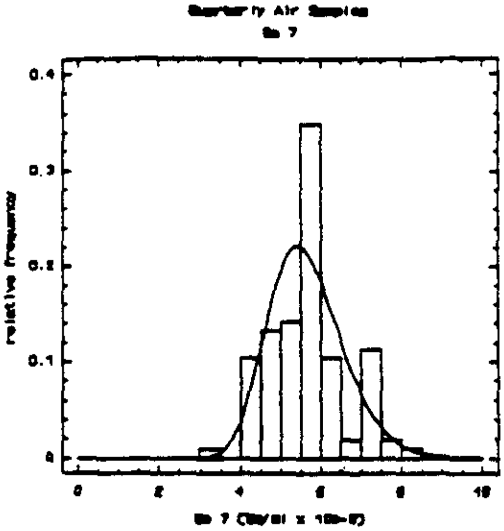
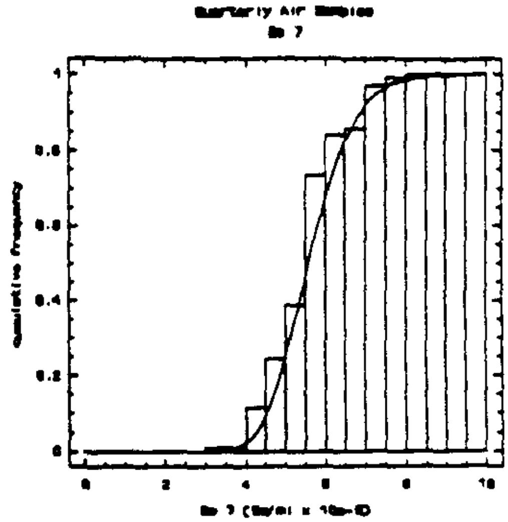
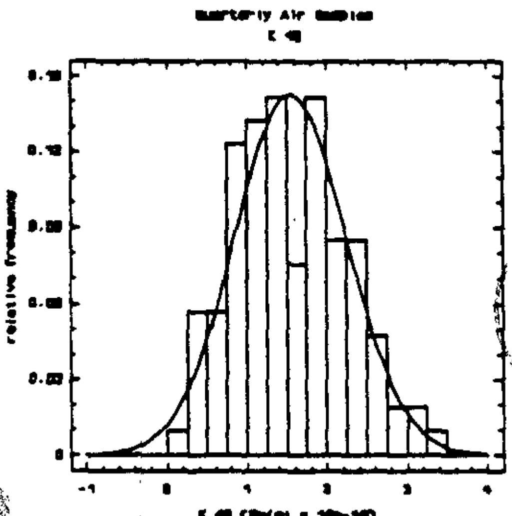

Gross Alpha Activity in Air Samples
WIPP Site, Quarter 3
relative frequency


Gross Alpha Activity in Air Samples
WIPP Site, Quarter 3
cumulative frequency



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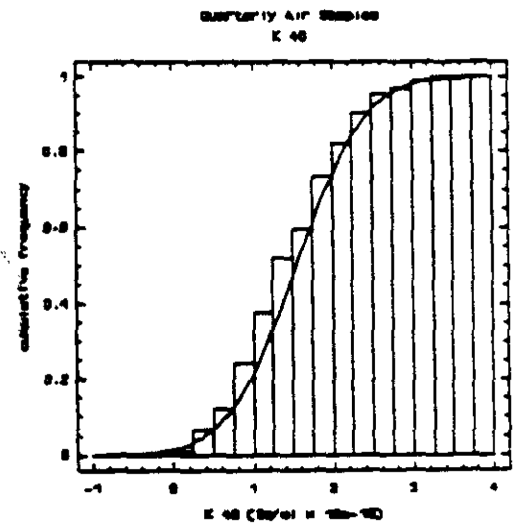
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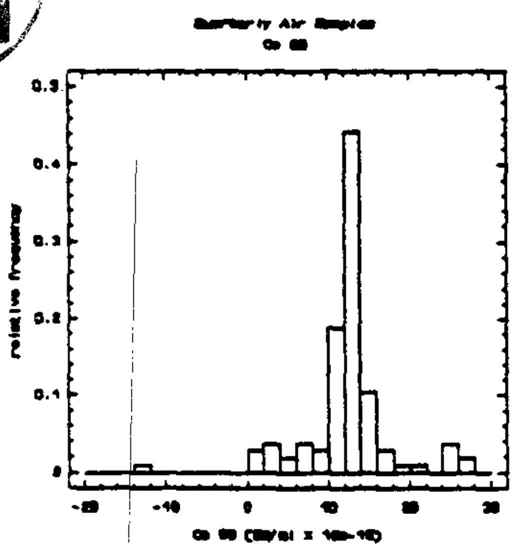
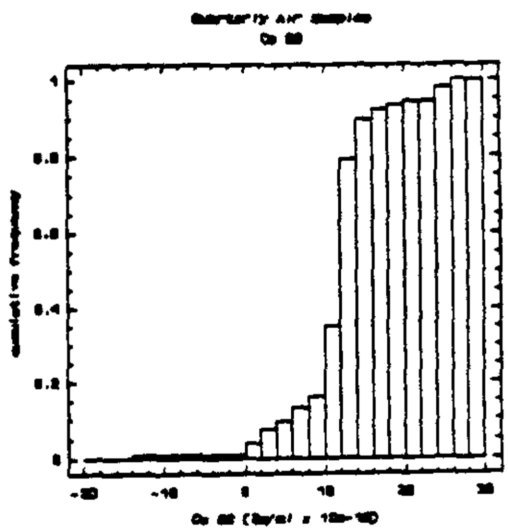
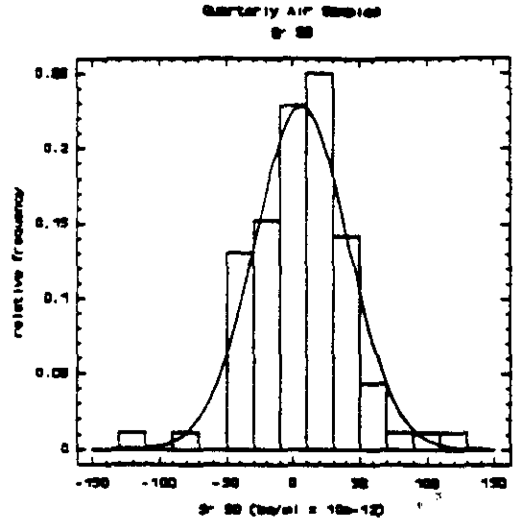
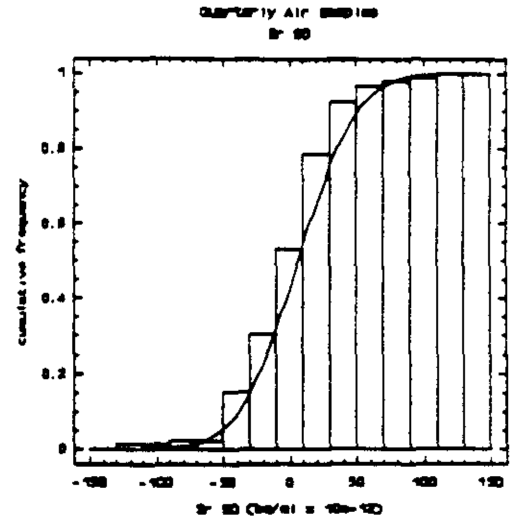
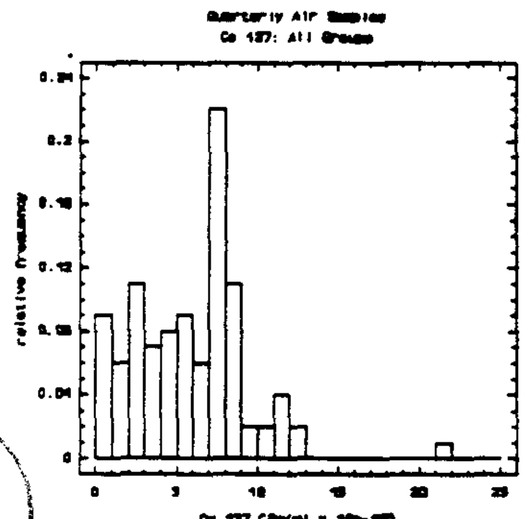
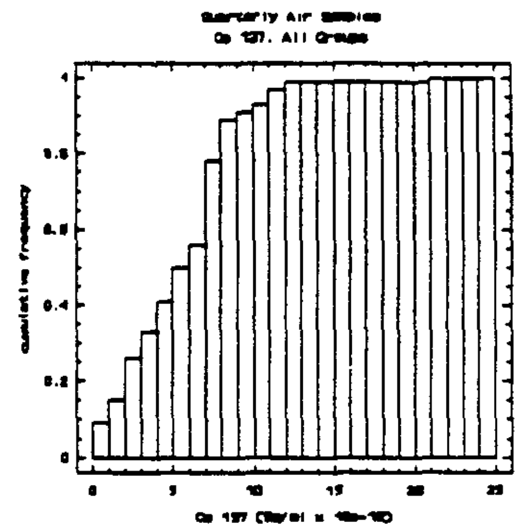


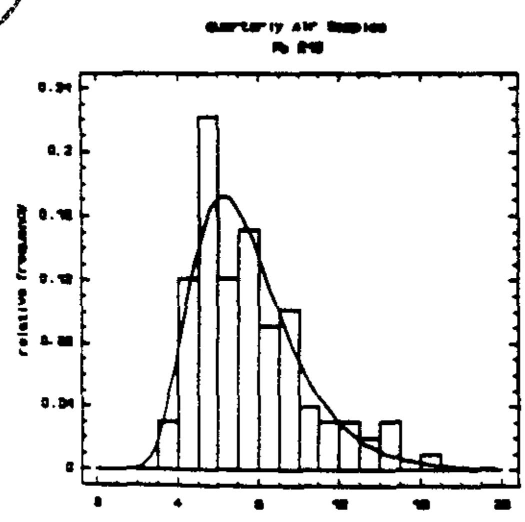


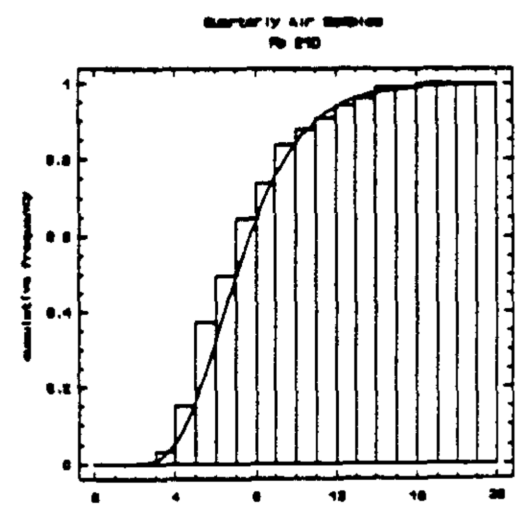


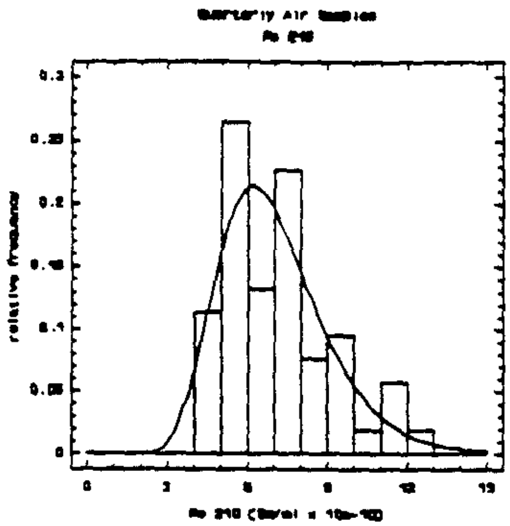
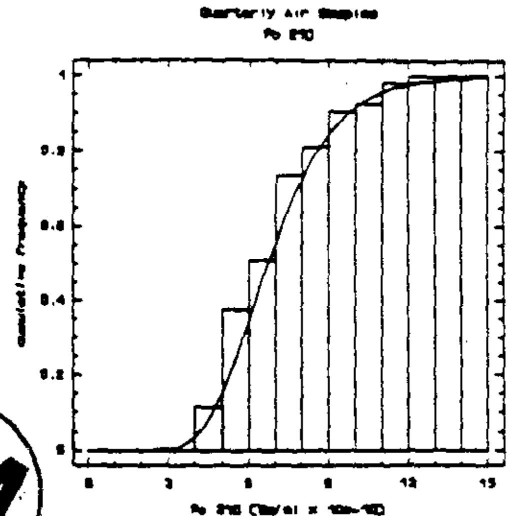
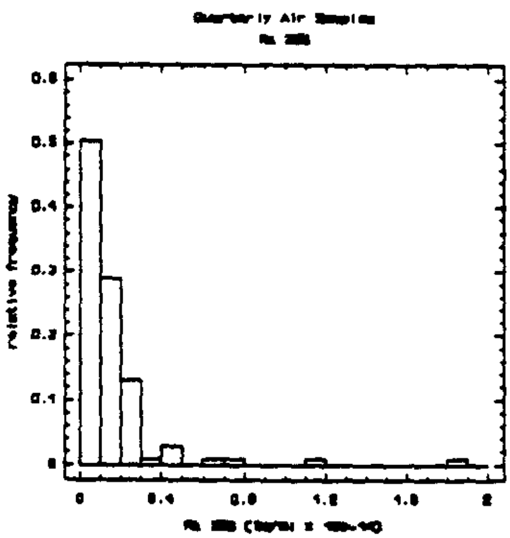
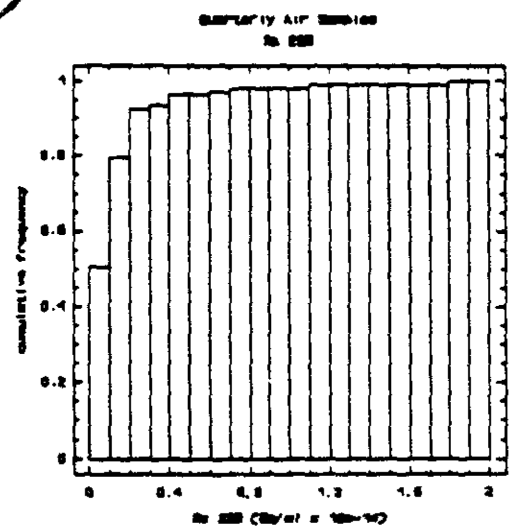
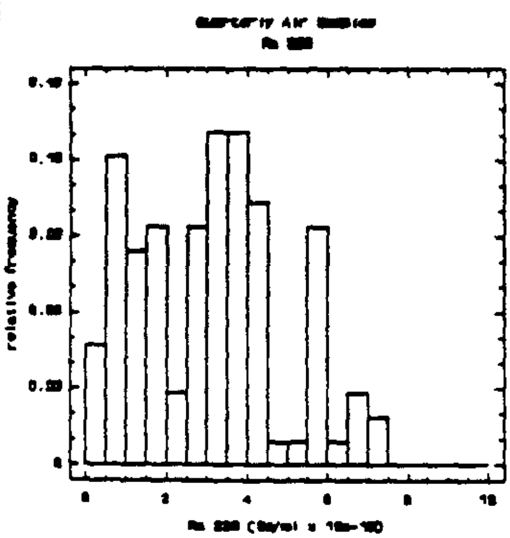
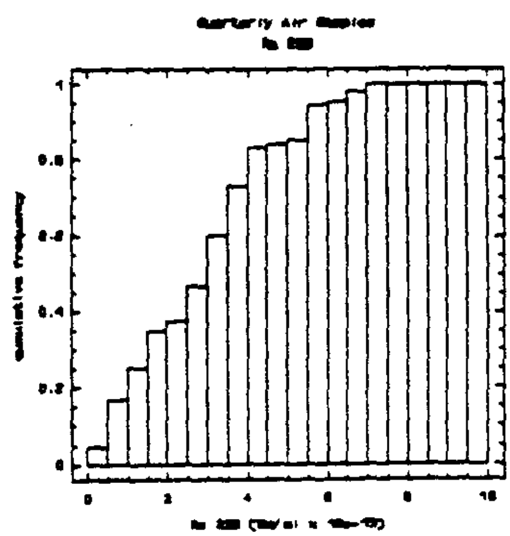


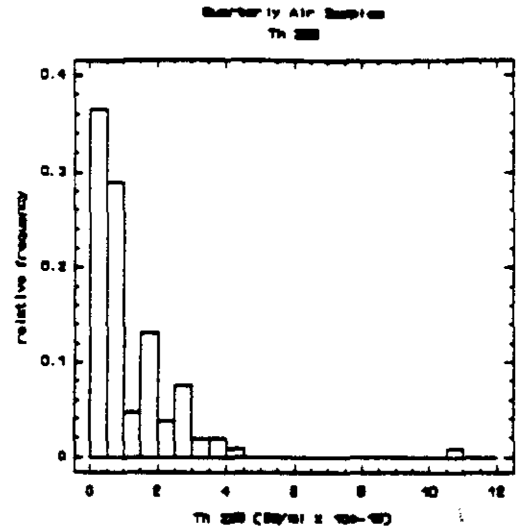


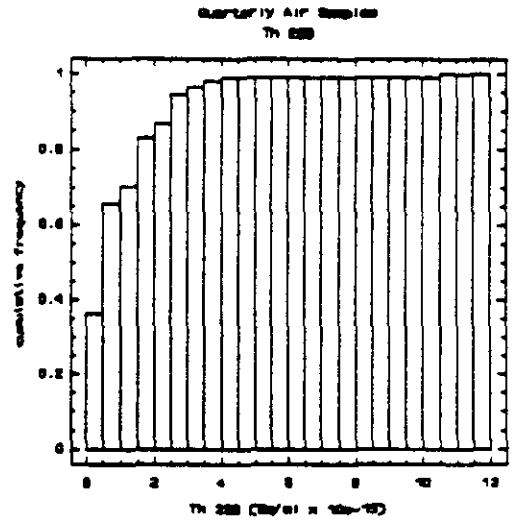


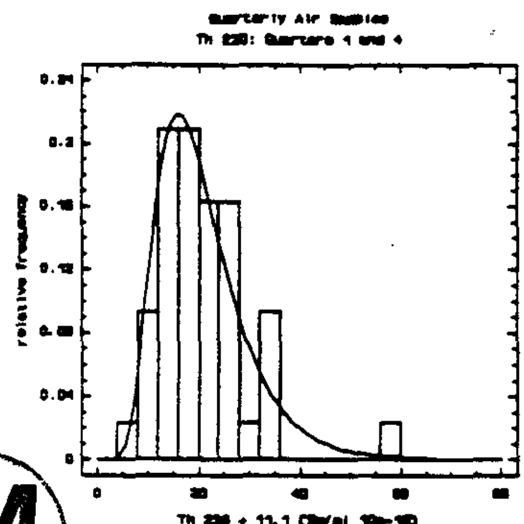


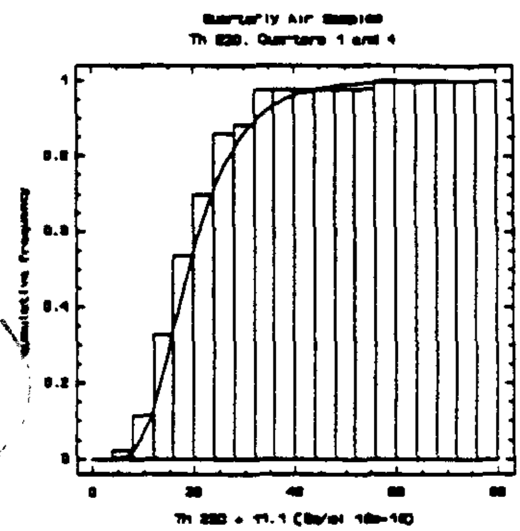


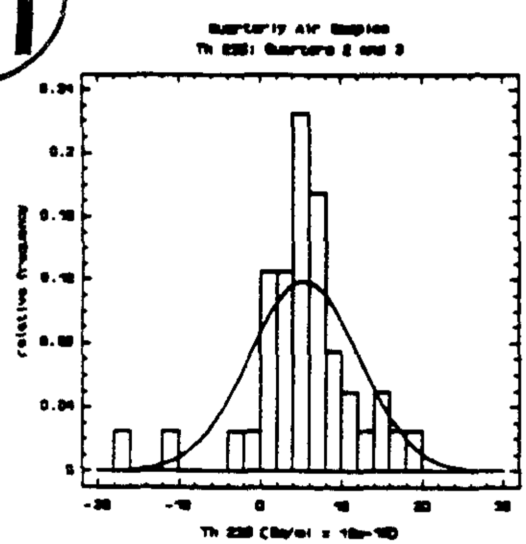







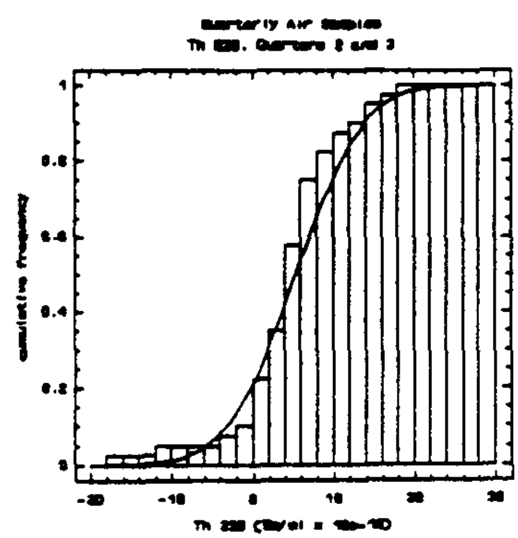


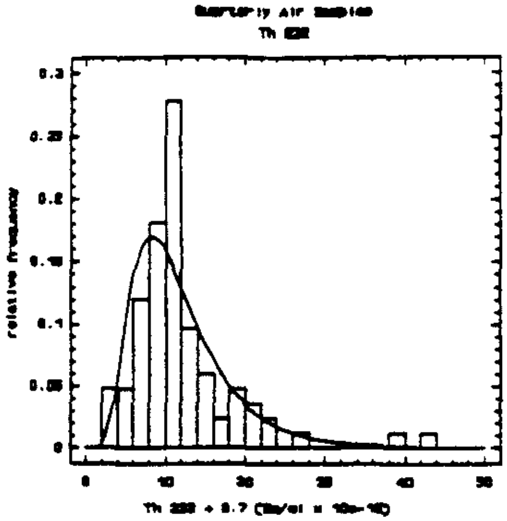


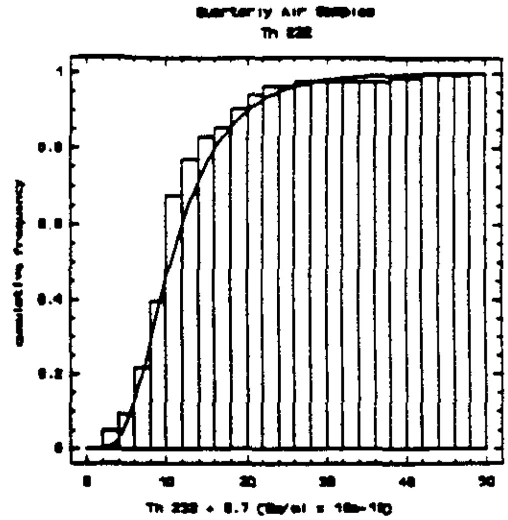









Quarterly Air Samples
Th 232
relative frequency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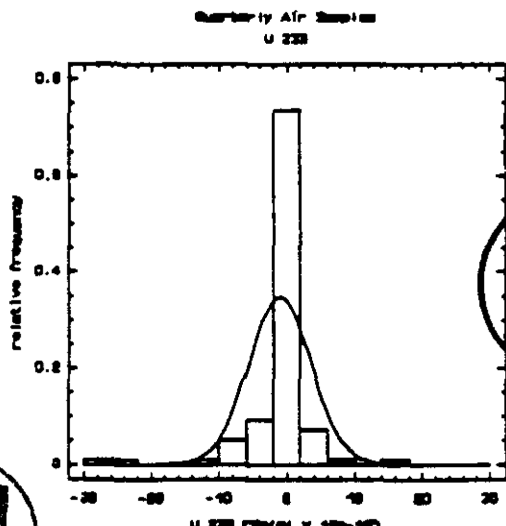
Th 232
cumulative frequency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U 238
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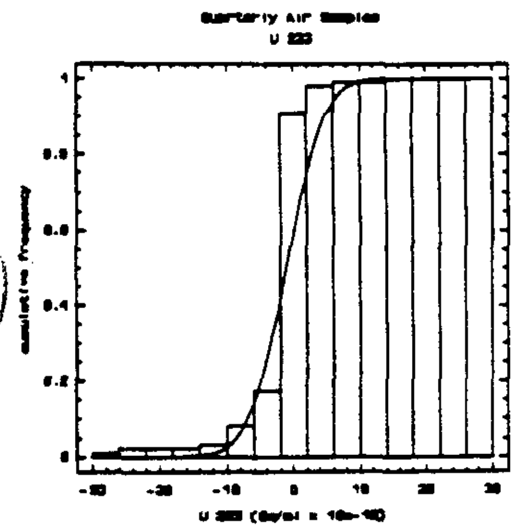
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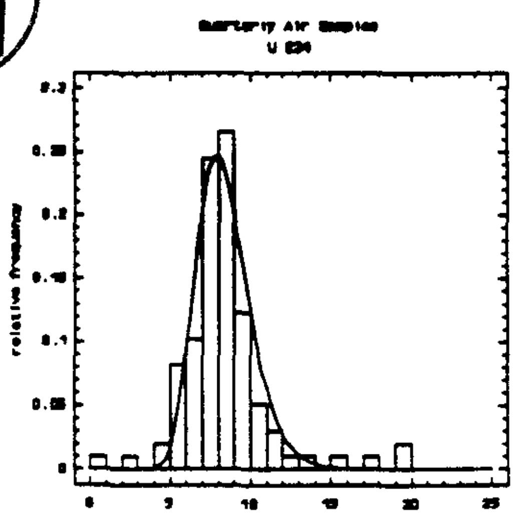
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U 234
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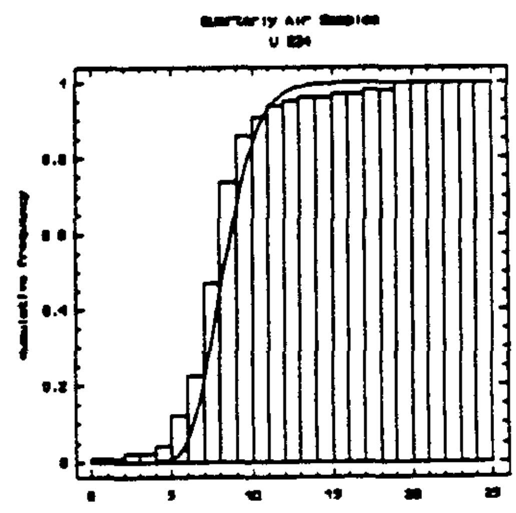
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U 234
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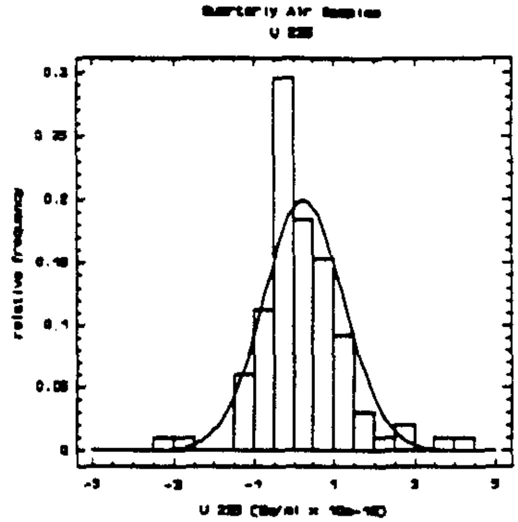
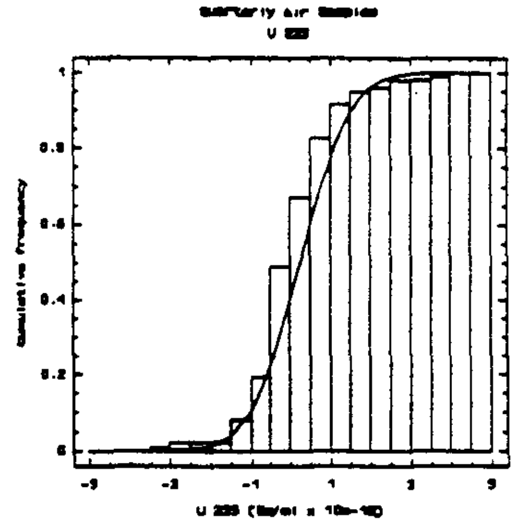
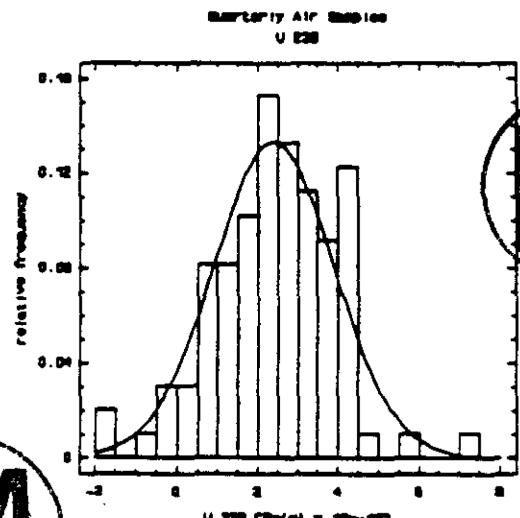
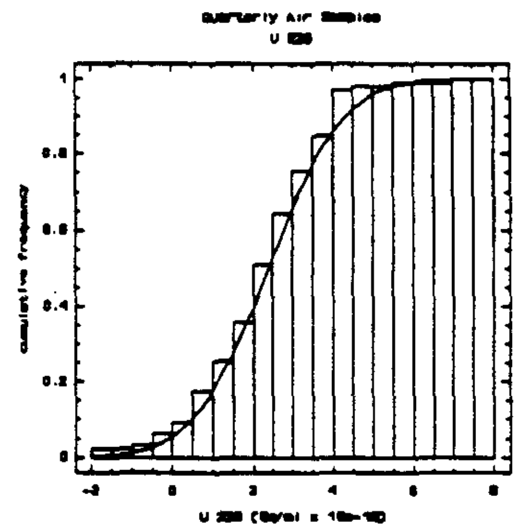
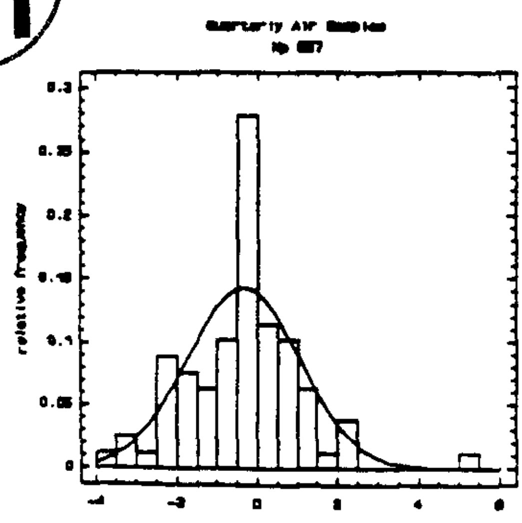
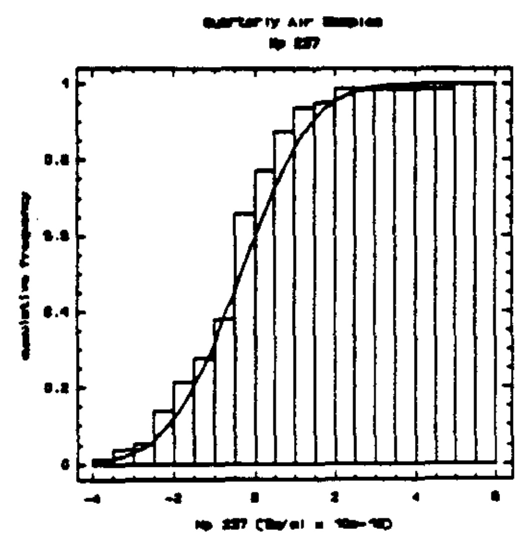


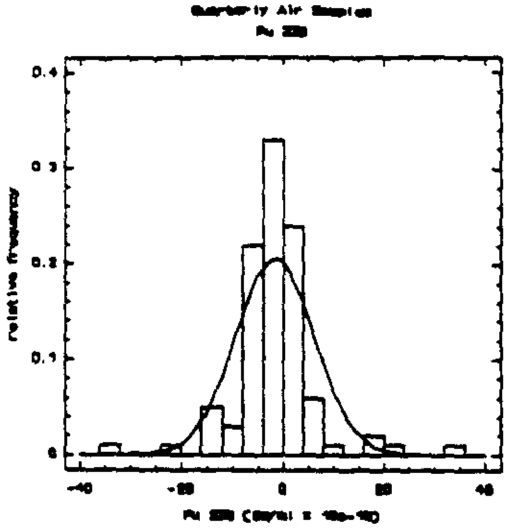


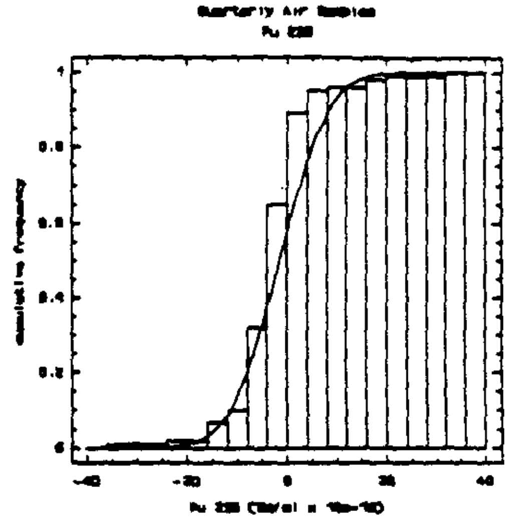


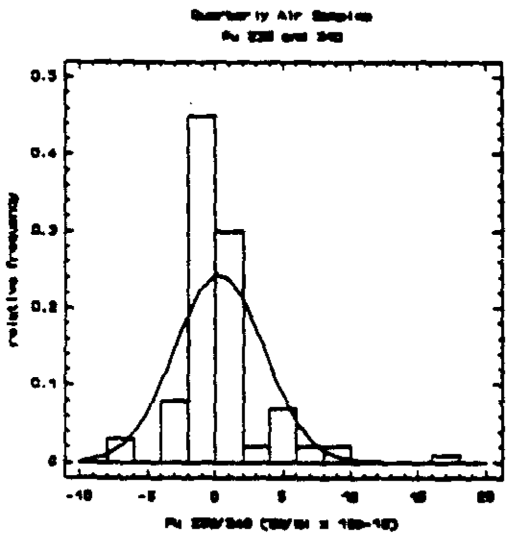


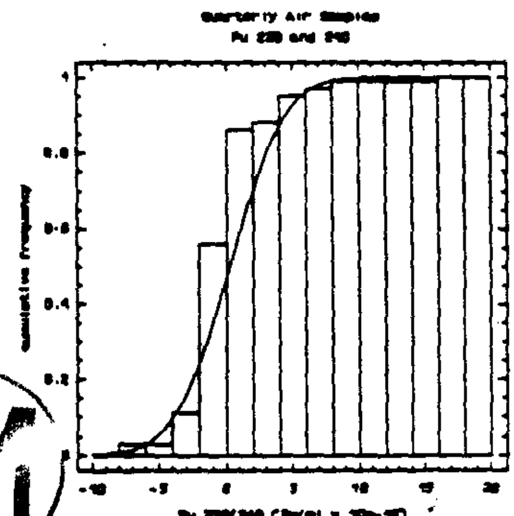


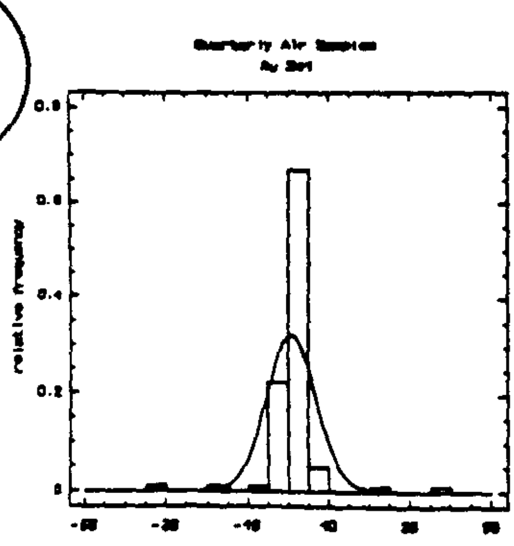


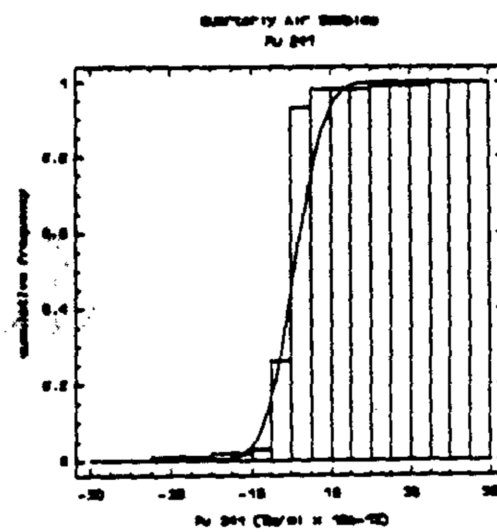


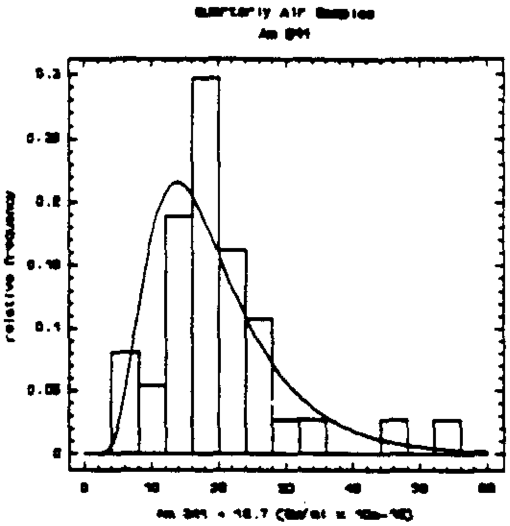


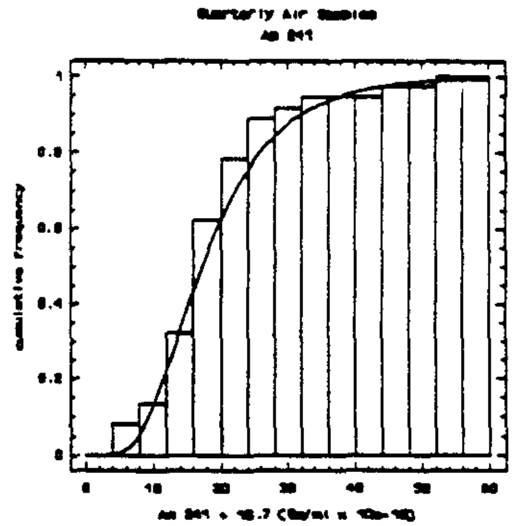


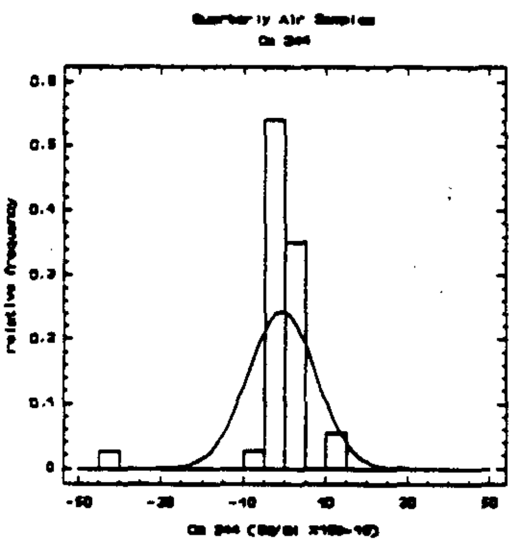


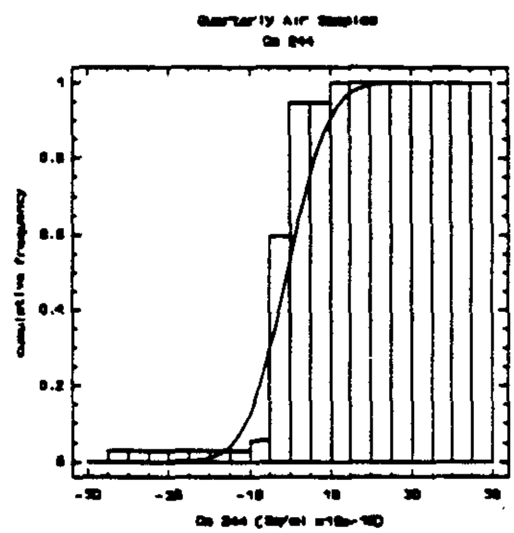


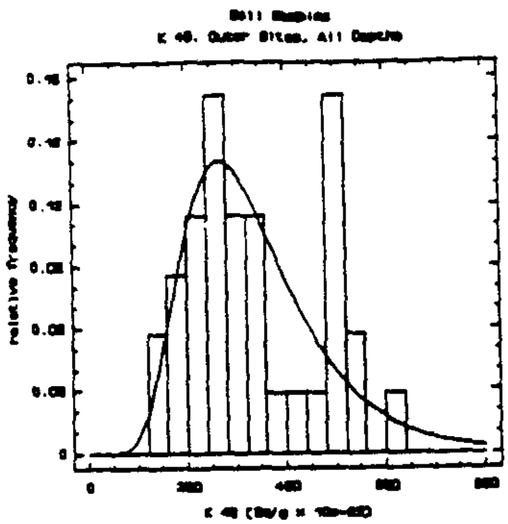


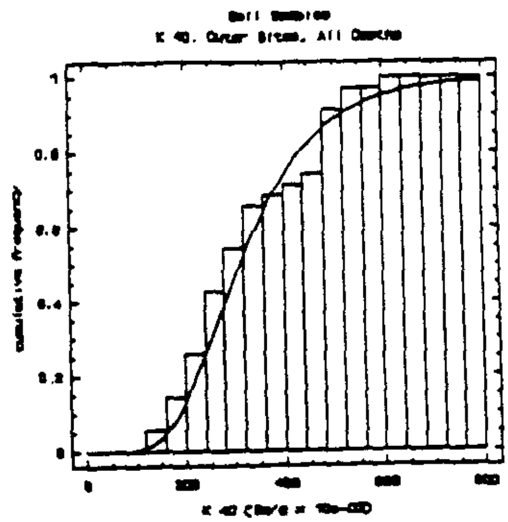

Quarterly Air Samples
Am 241
relative frequency

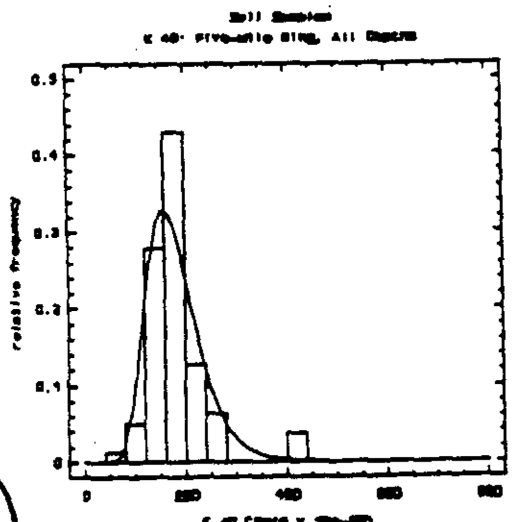

Quarterly Air Samples
Am 241
cumulative frequency

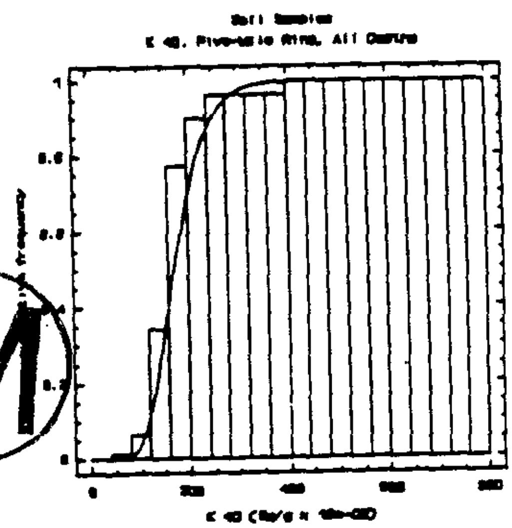

Quarterly Air Samples
Cm 244
relative frequency

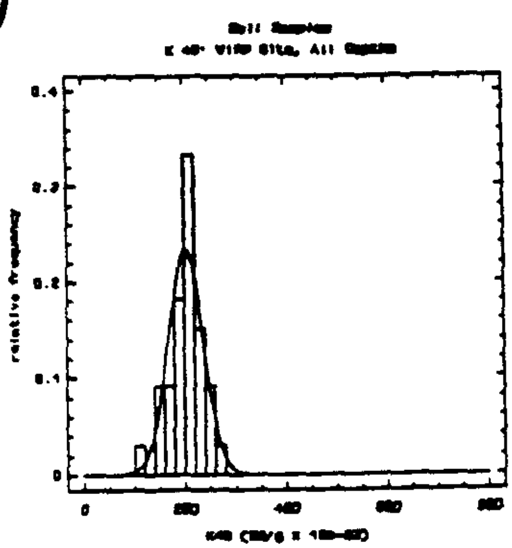

Quarterly Air Samples
Cm 244
cumulative frequency

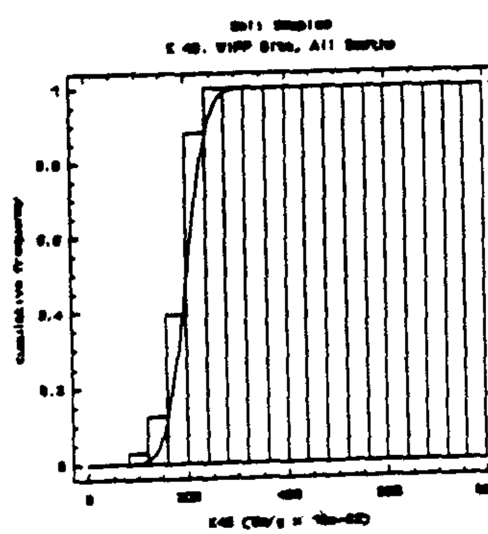


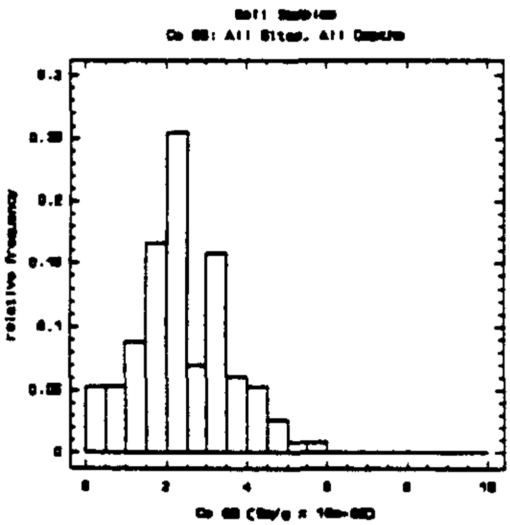


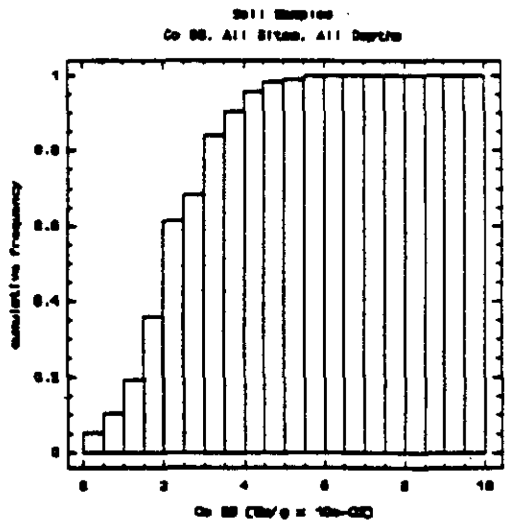


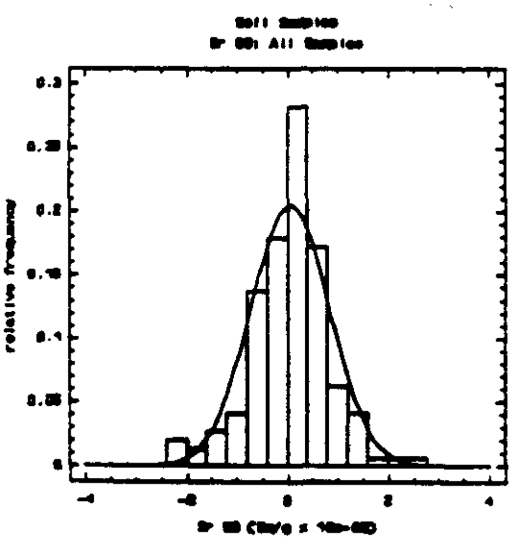


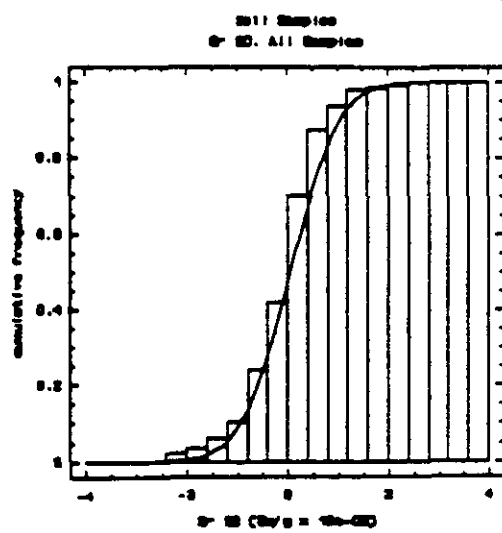


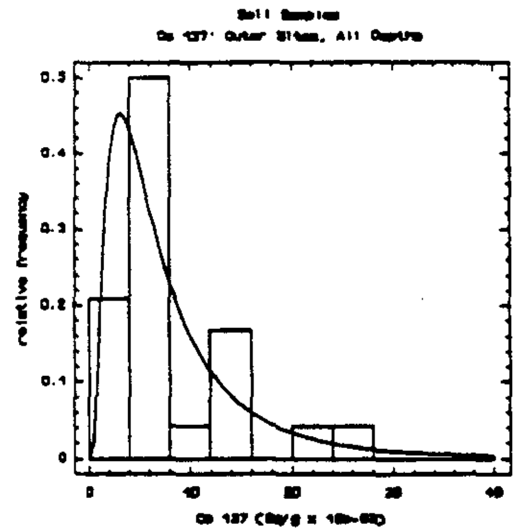


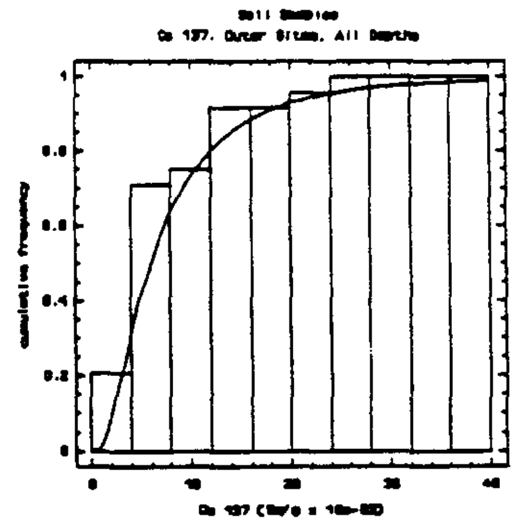

Soil Samples
relative frequency


Soil Samples
cumulative frequency


Soil Samples
relative frequency


Soil Samples
cumulative frequency


relative frequency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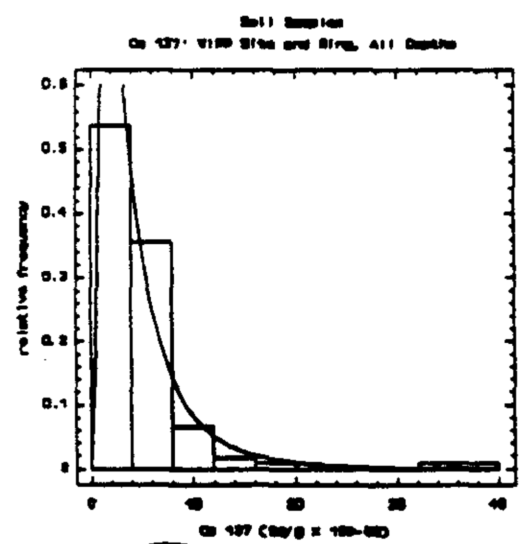
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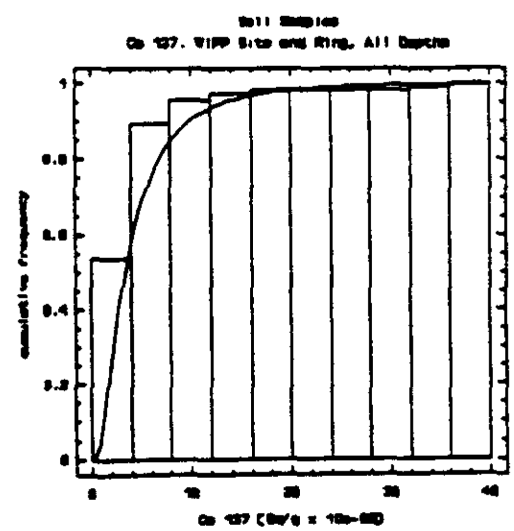
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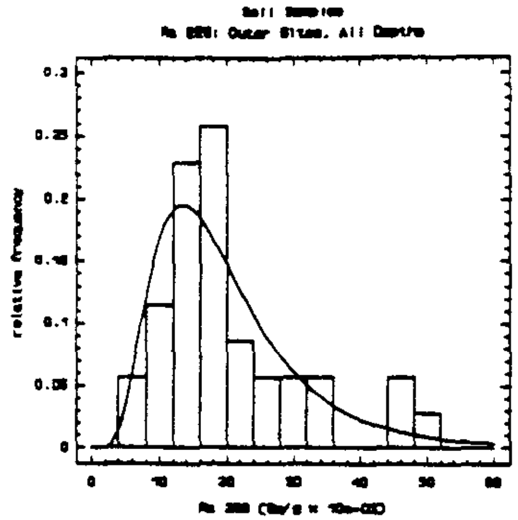
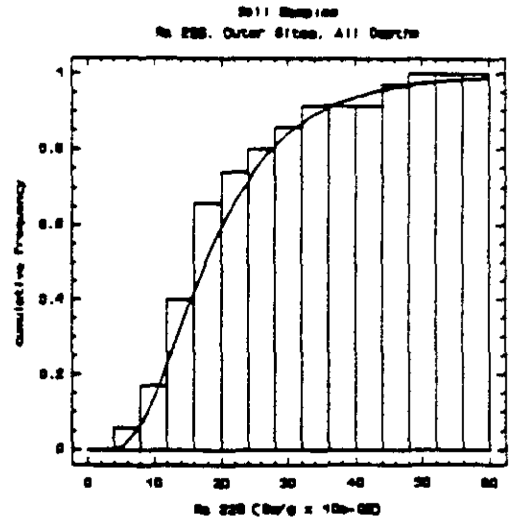

relative frequency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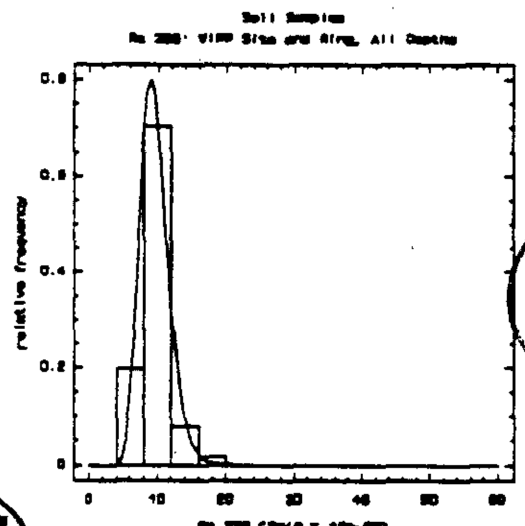
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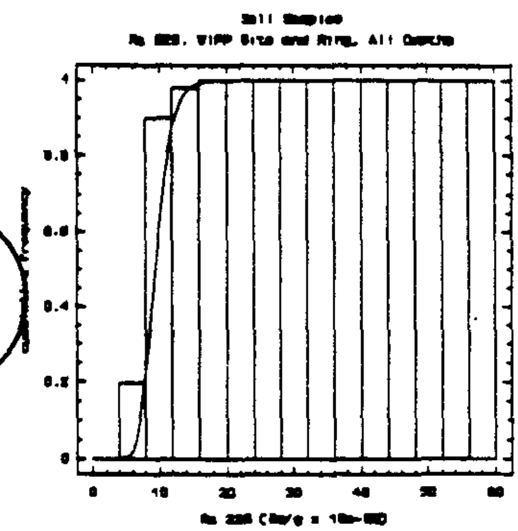

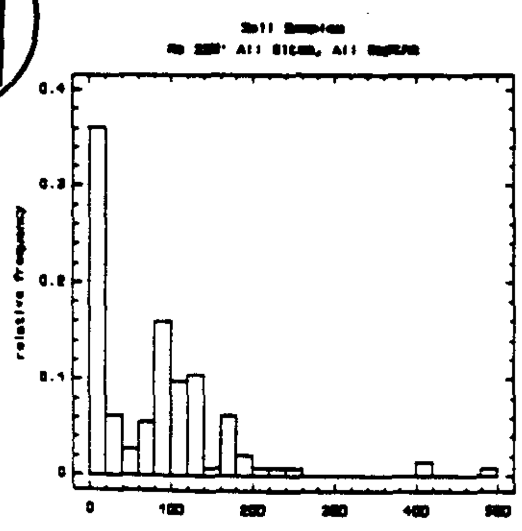
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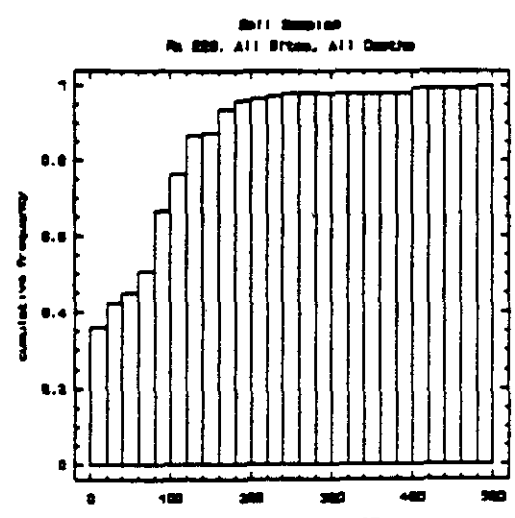
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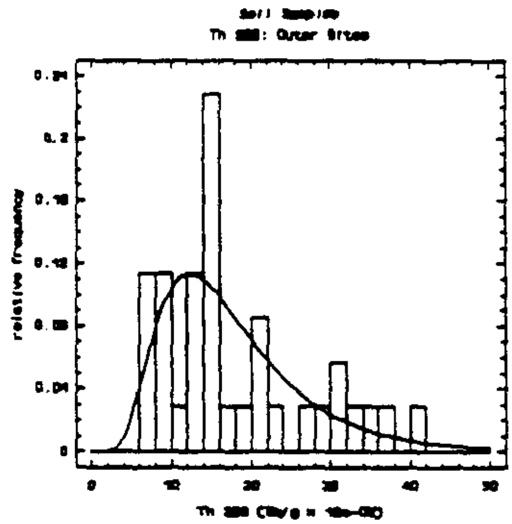
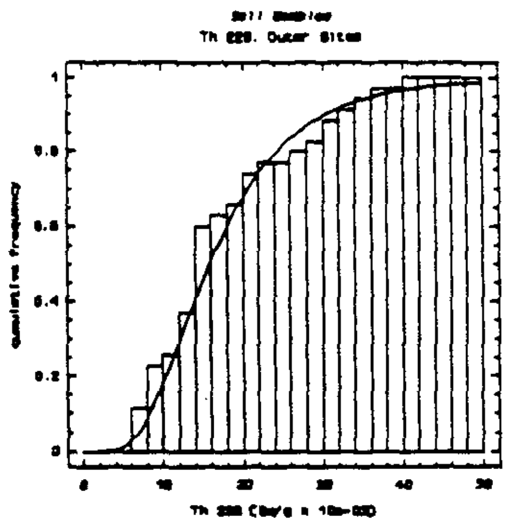
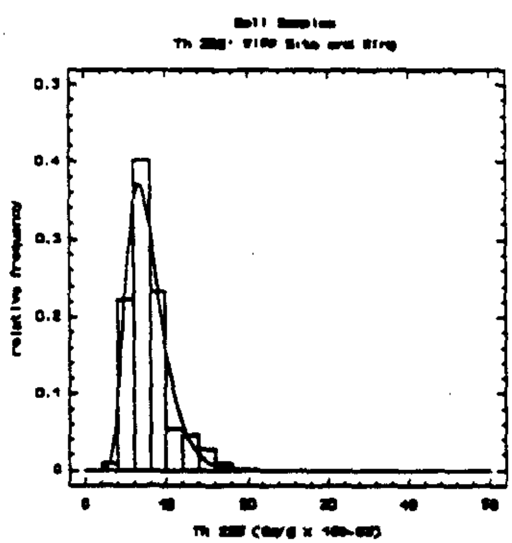
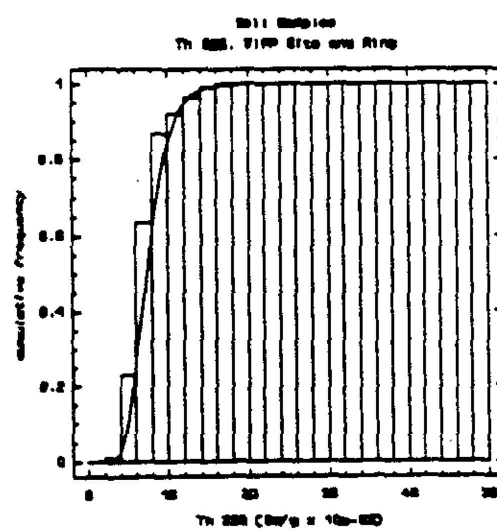
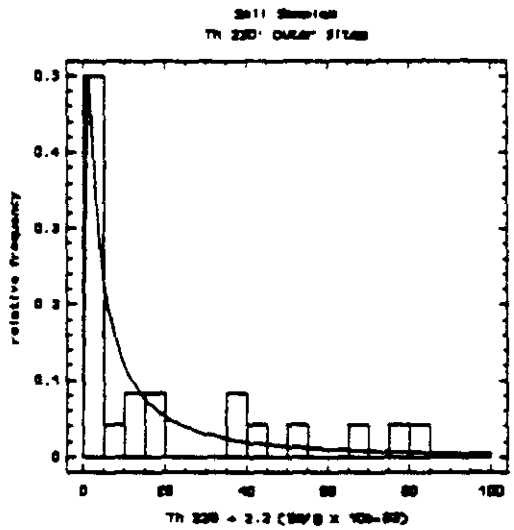
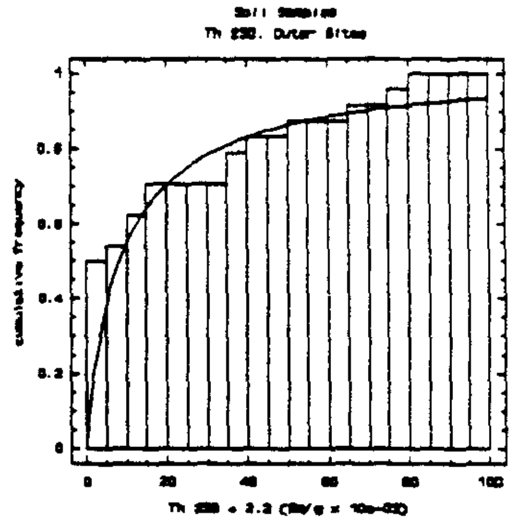


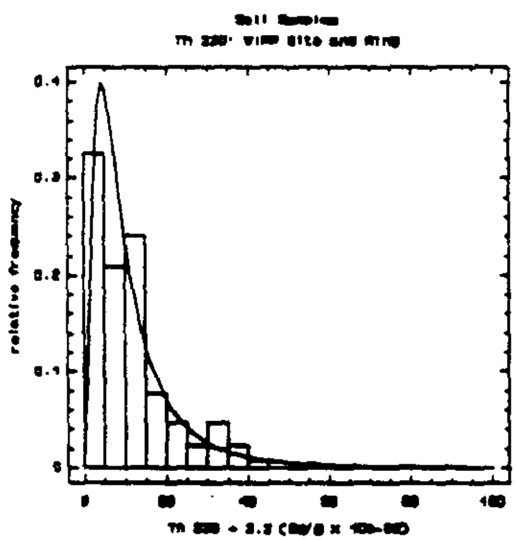


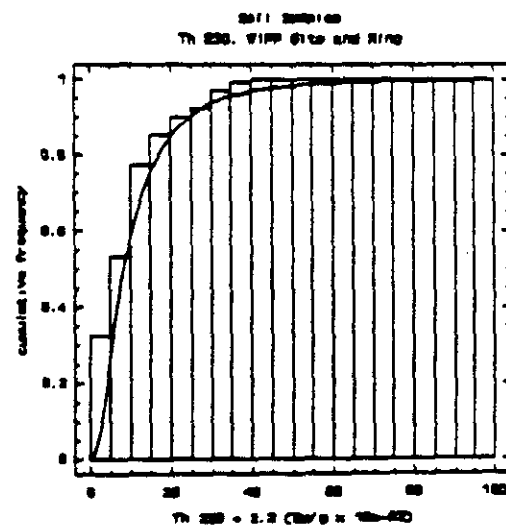


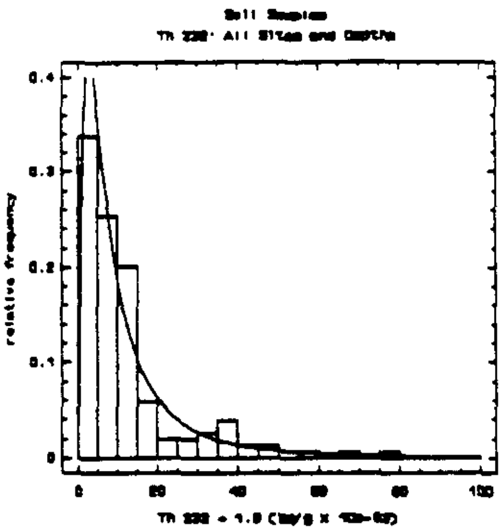


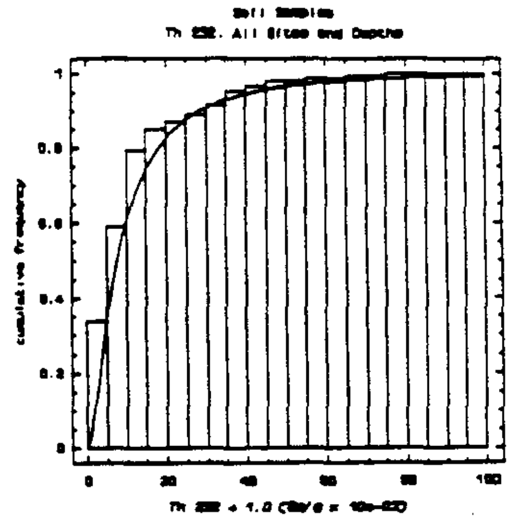


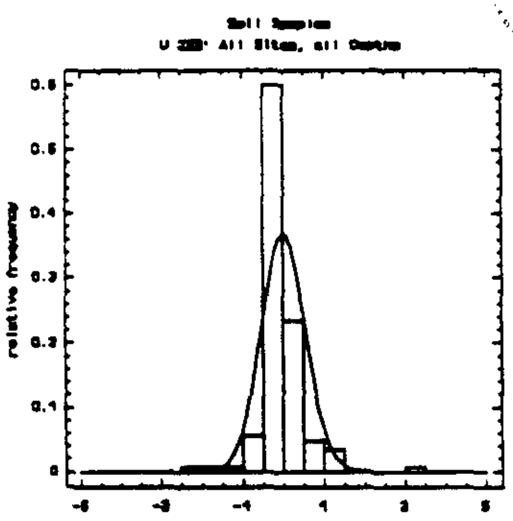


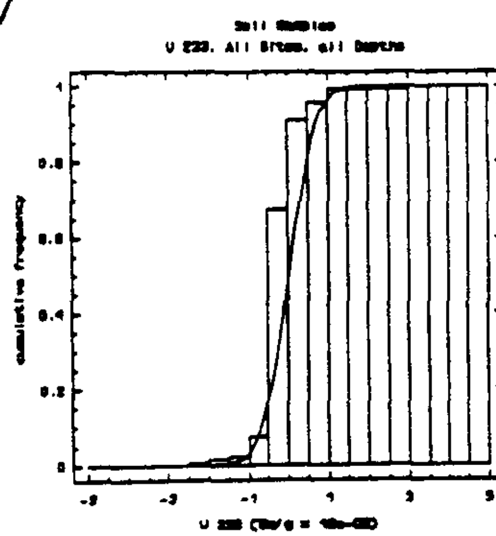


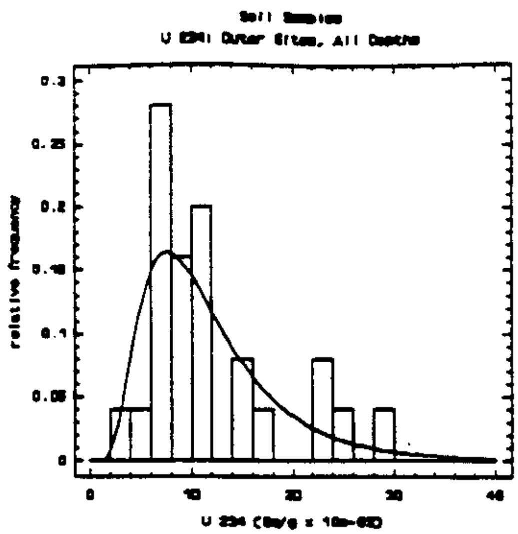


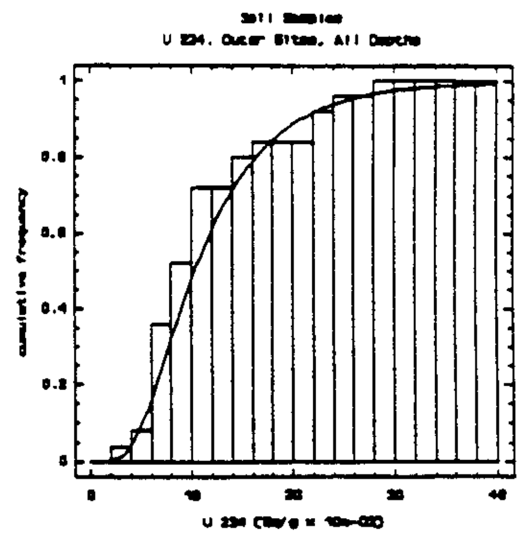


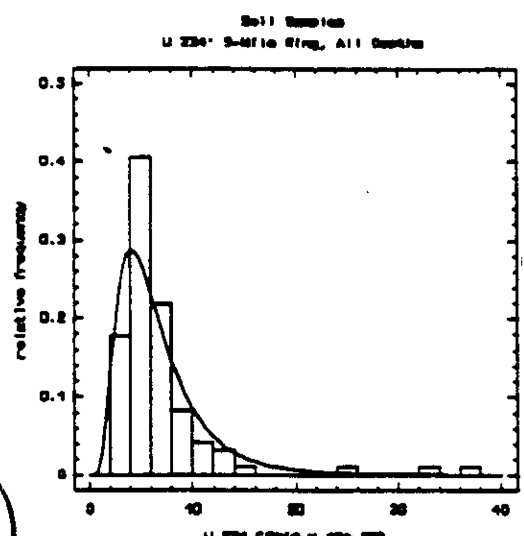


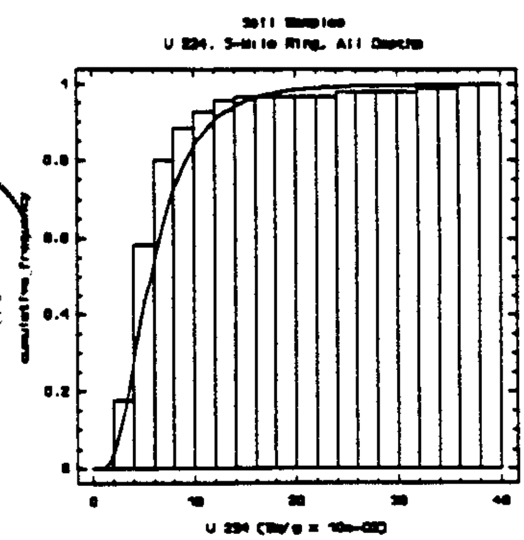


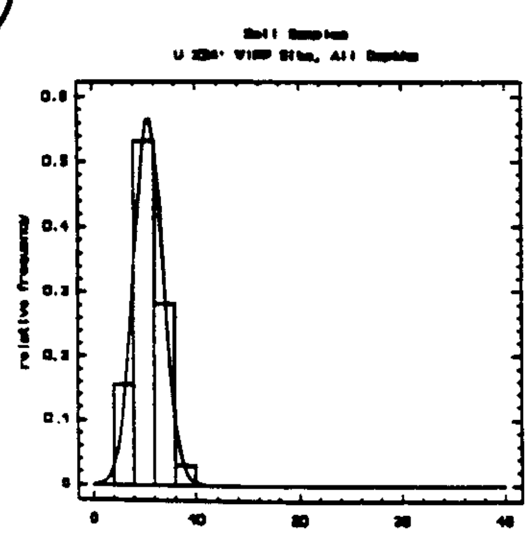


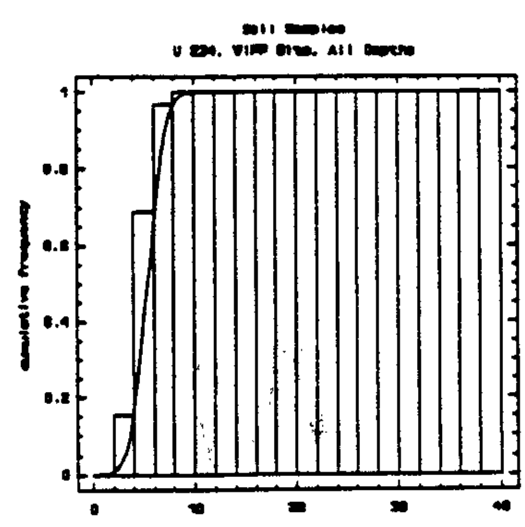


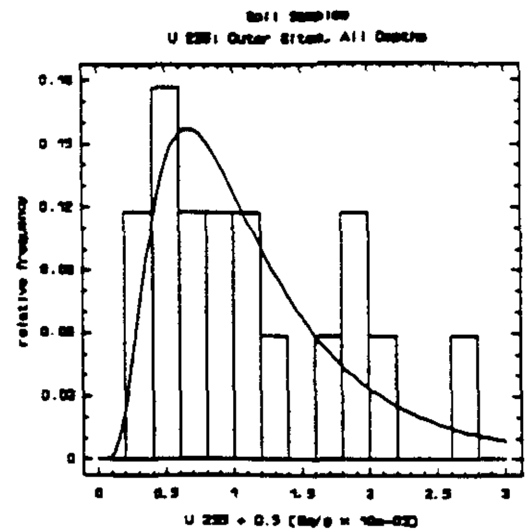


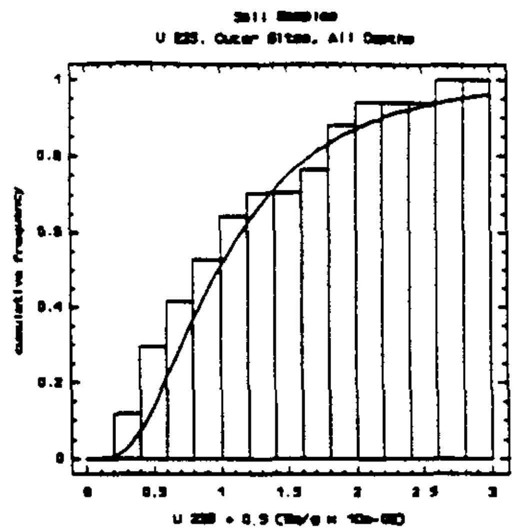


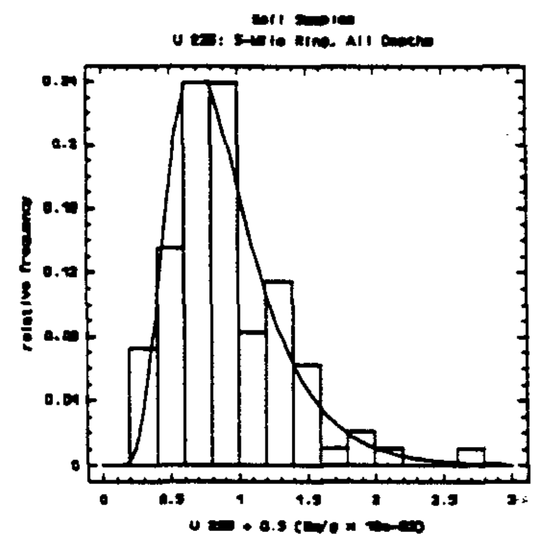


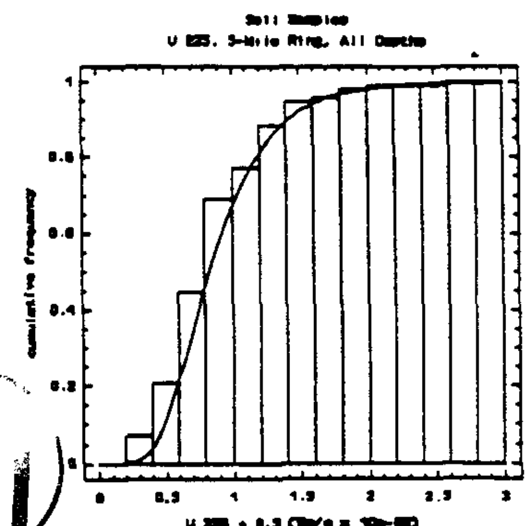


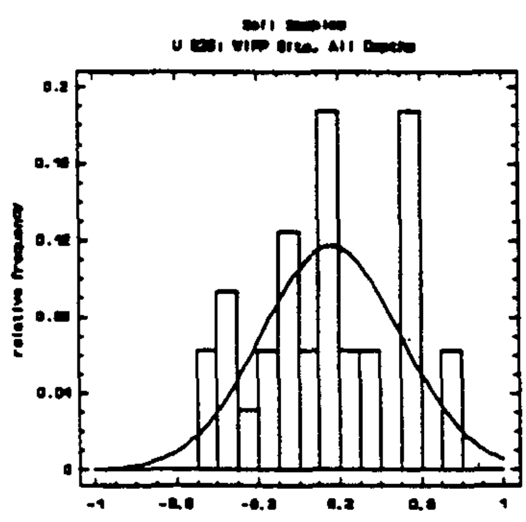


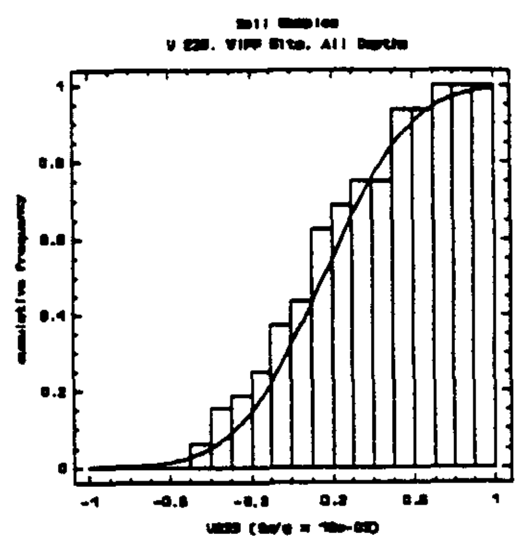

Soil Samples
U 235: Outer Sites, All Depths
relative frequency

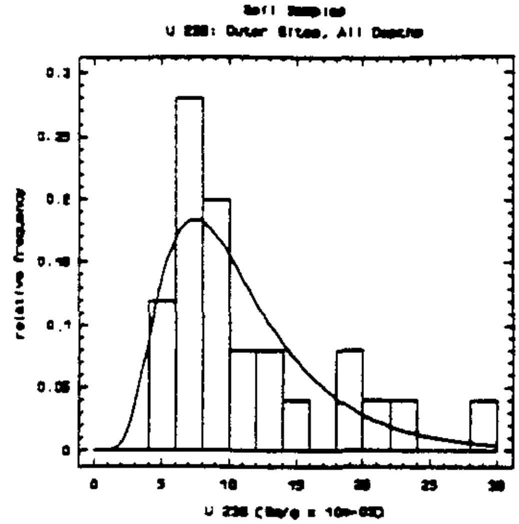

Soil Samples
U 235, Outer Sites, All Depths
cumulative frequency

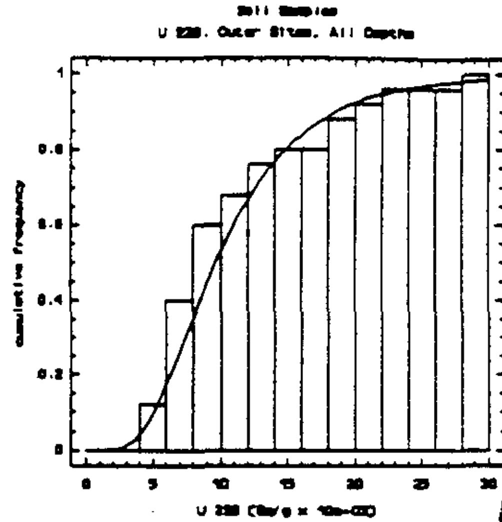

Soil Samples
U 235: 5-Mile Ring, All Depths
relative frequency

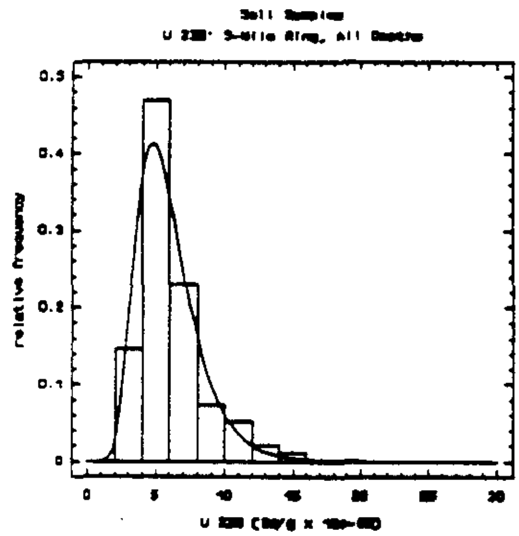

Soil Samples
U 235, 5-Mile Ring, All Depths
cumulative frequency

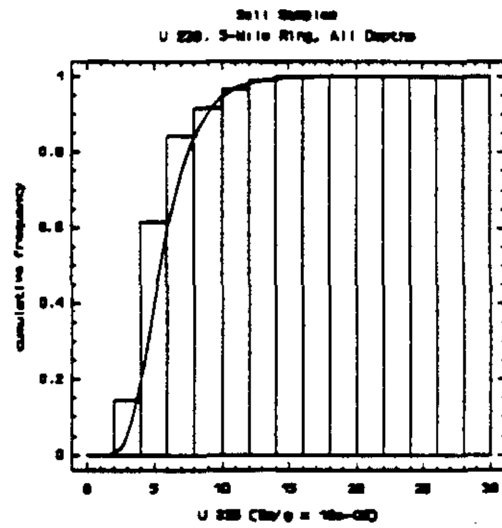

Soil Samples
relative frequency

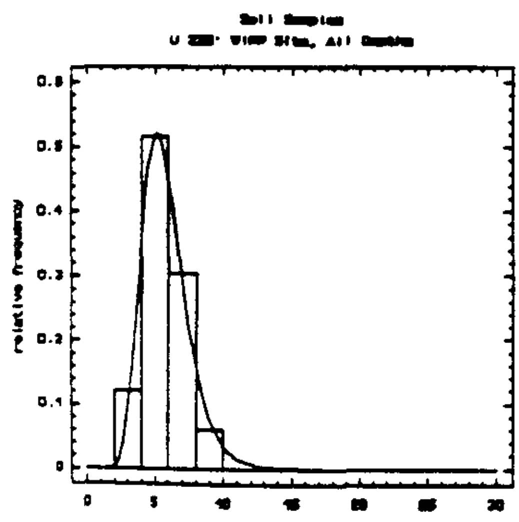

Soil Samples
cumulative frequency

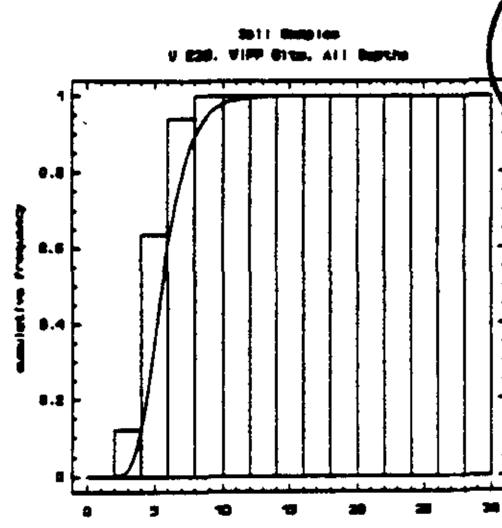


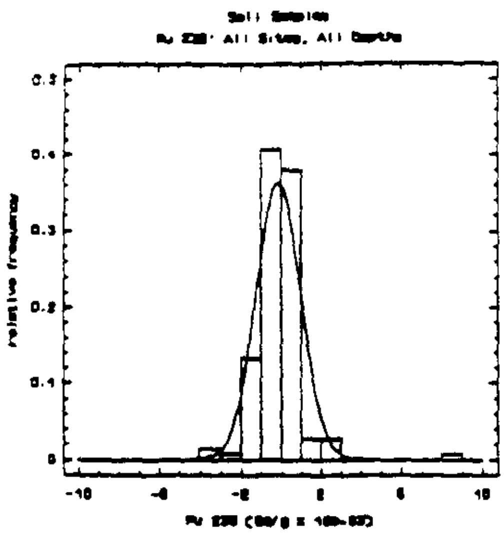


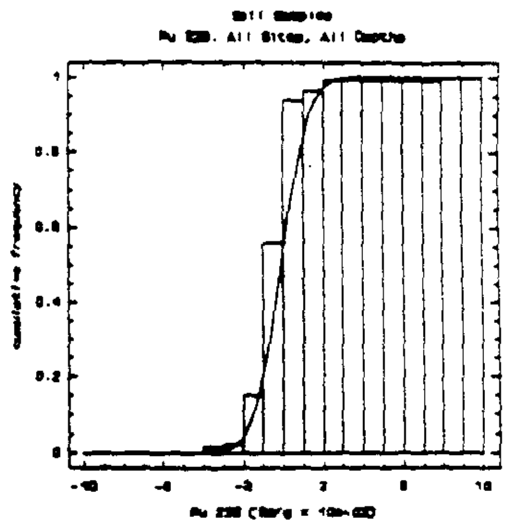


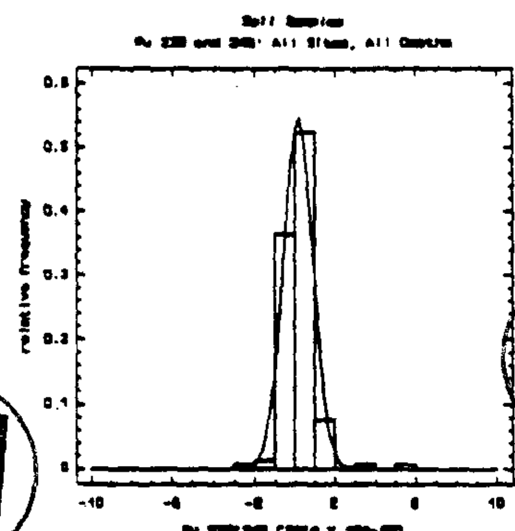


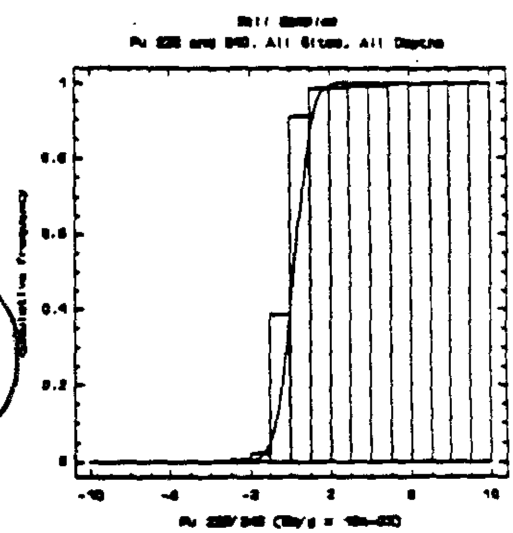


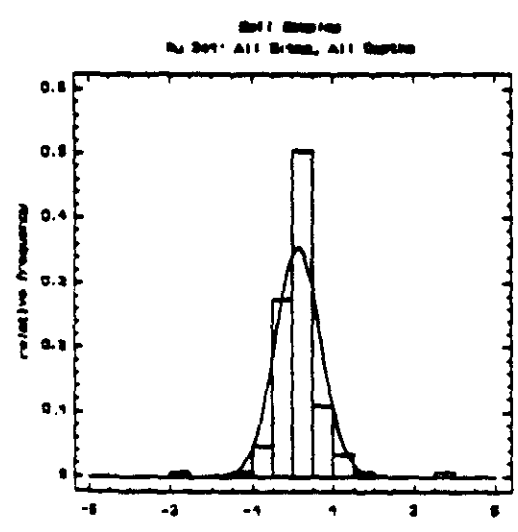


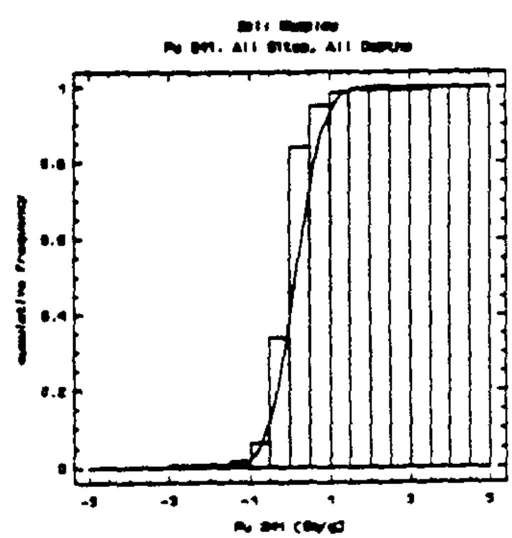


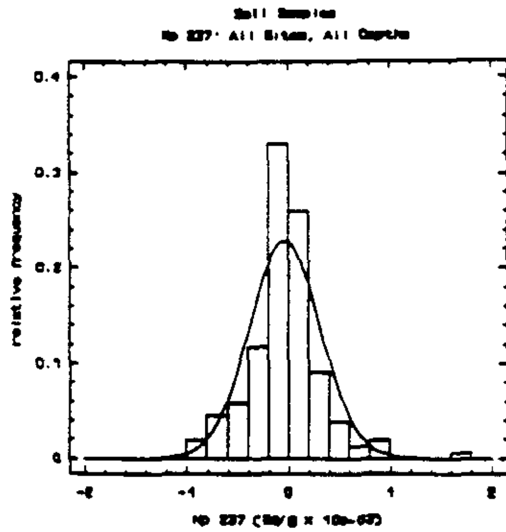


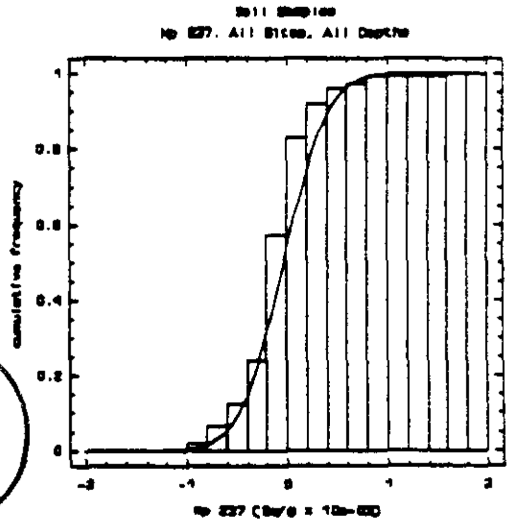


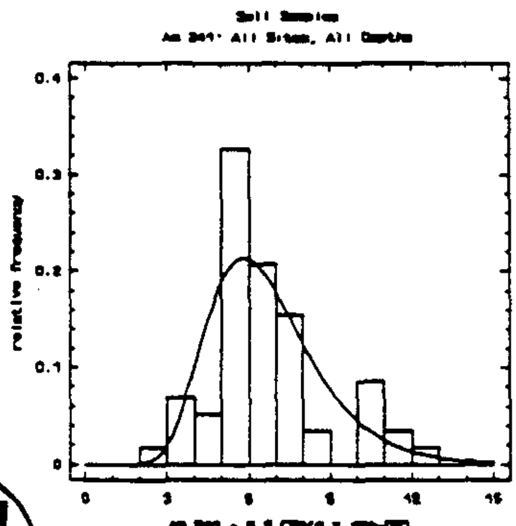


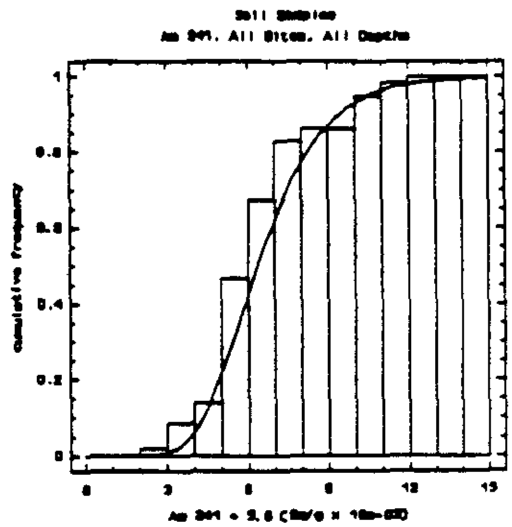


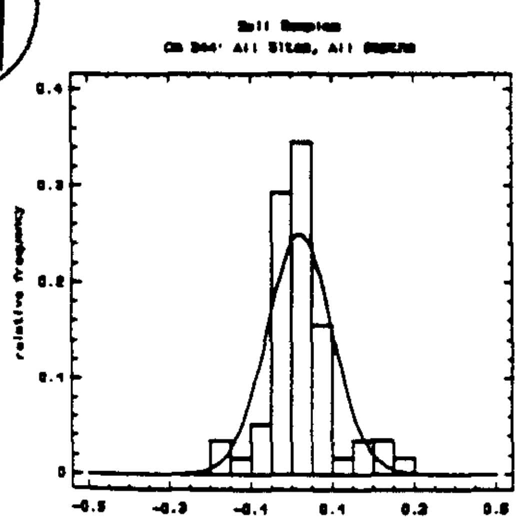


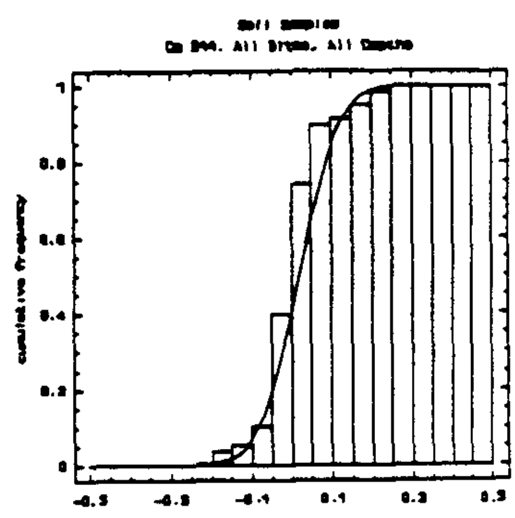


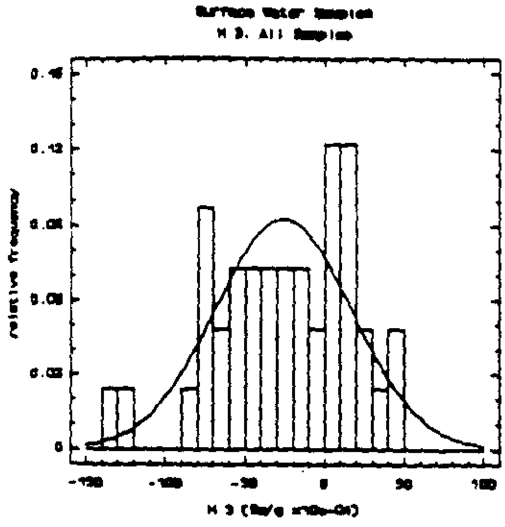


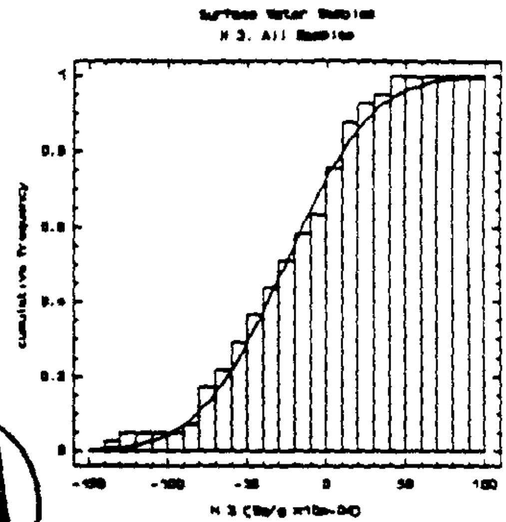


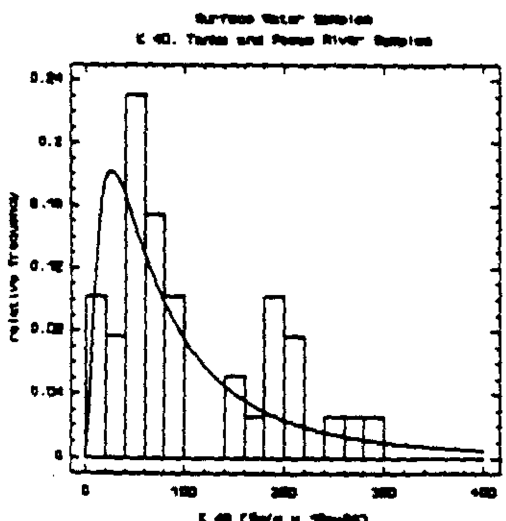


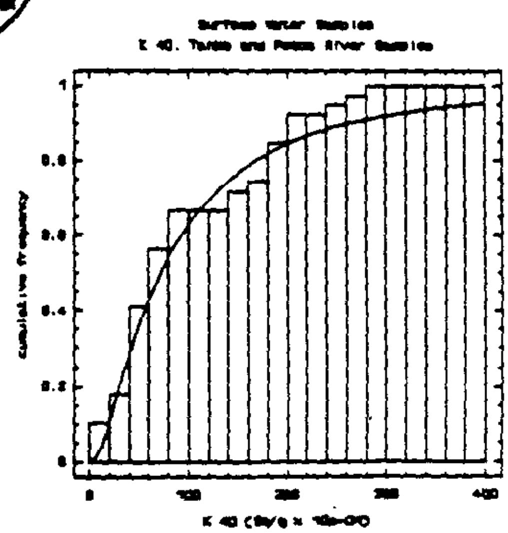


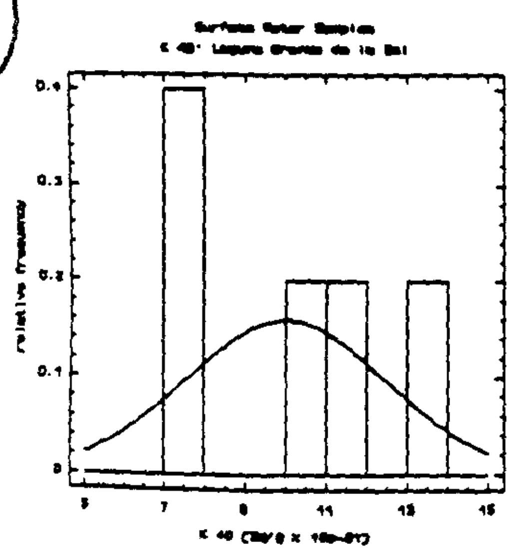


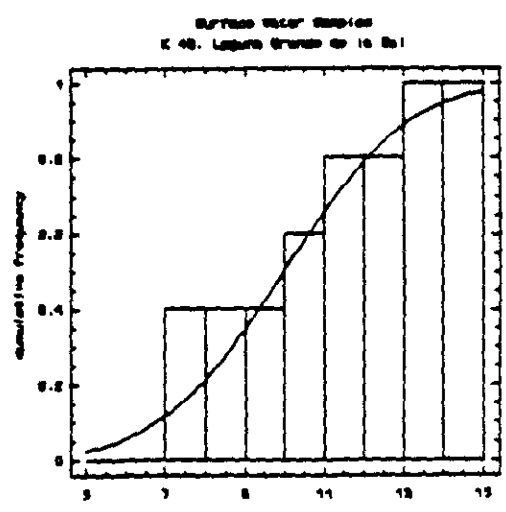


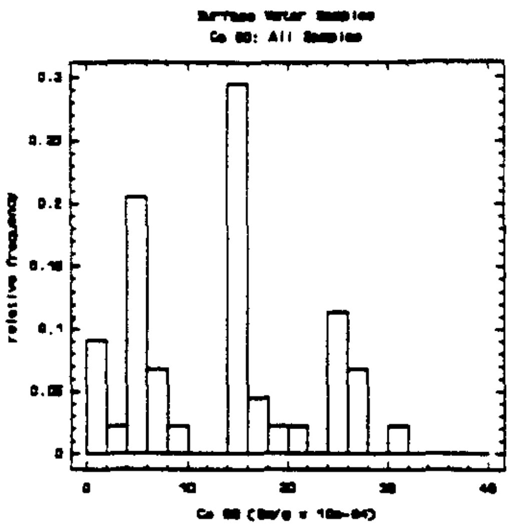








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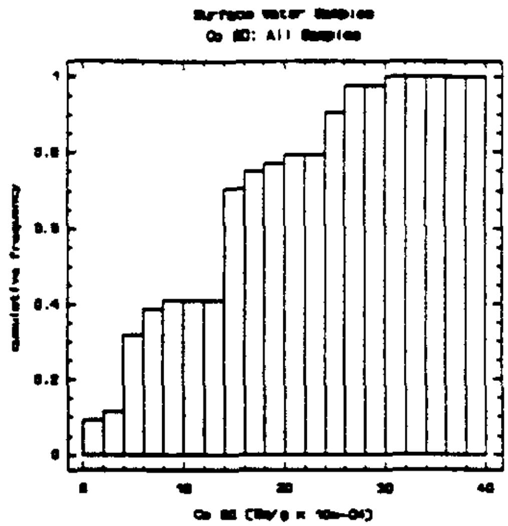
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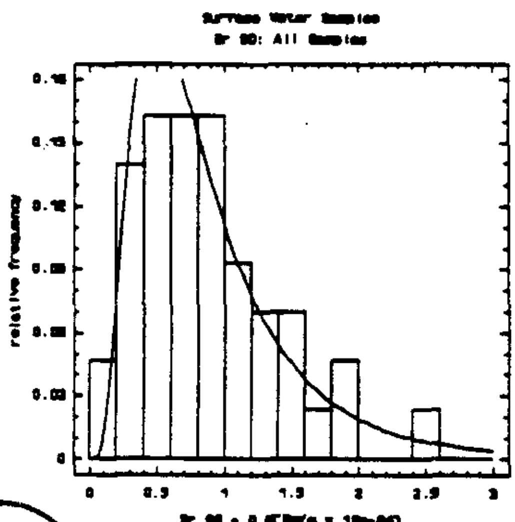
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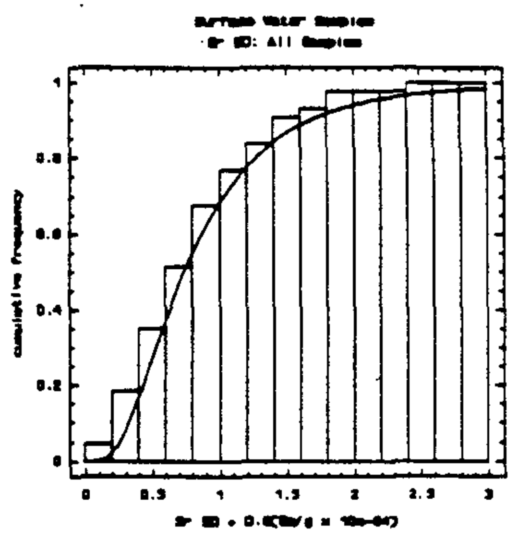
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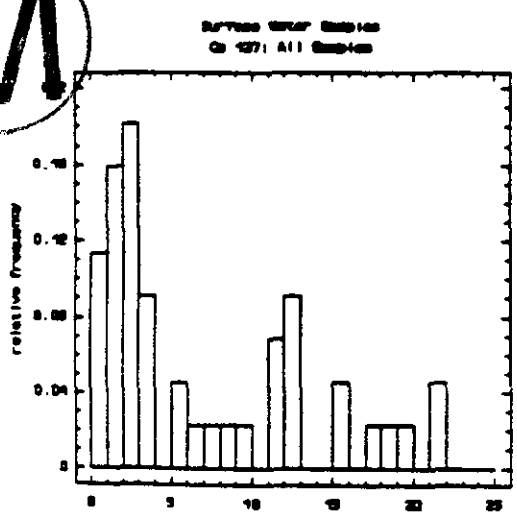
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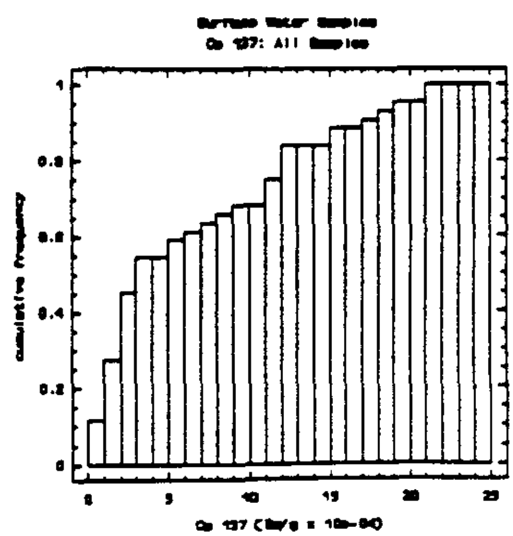
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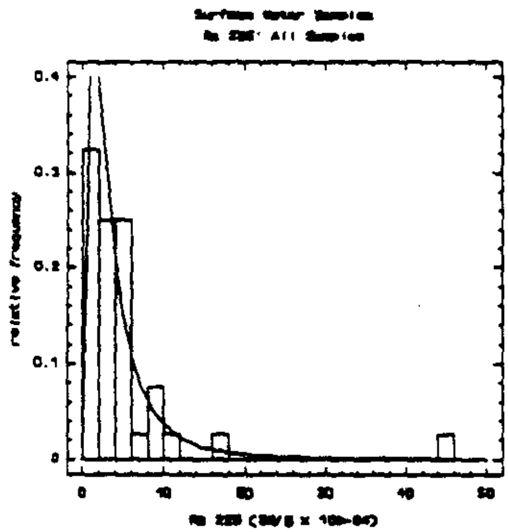

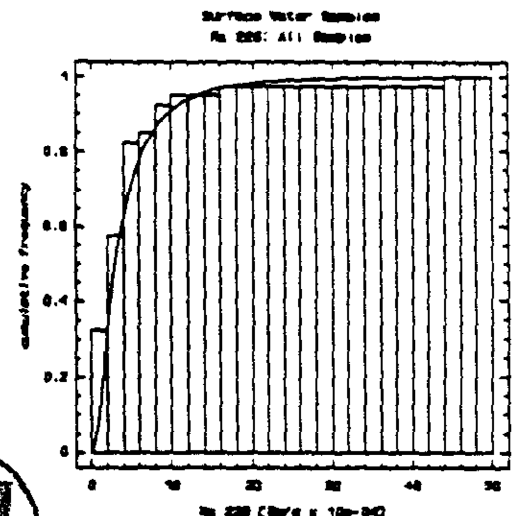

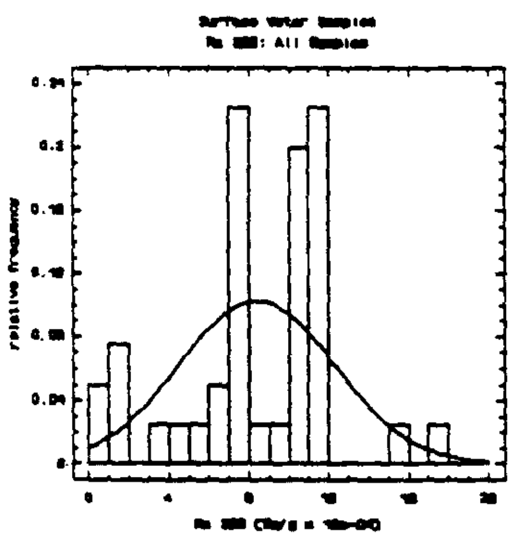

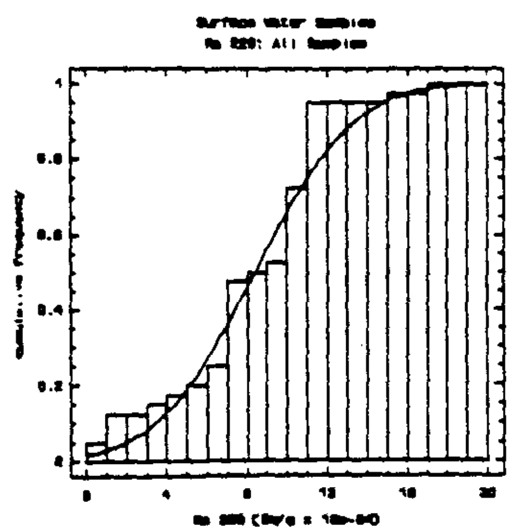

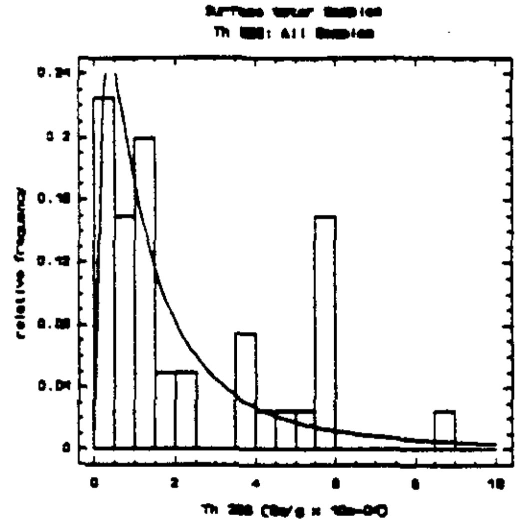
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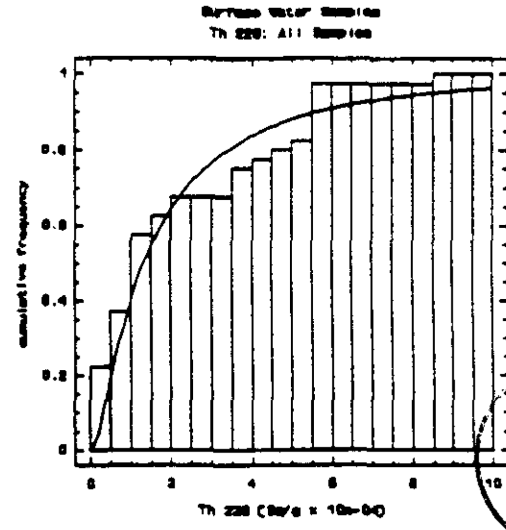
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0
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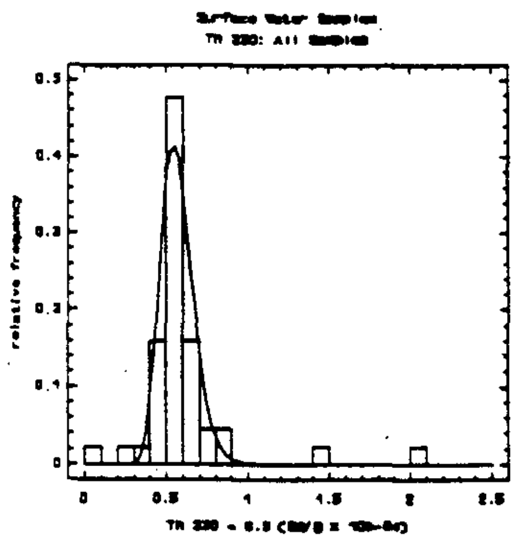
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0
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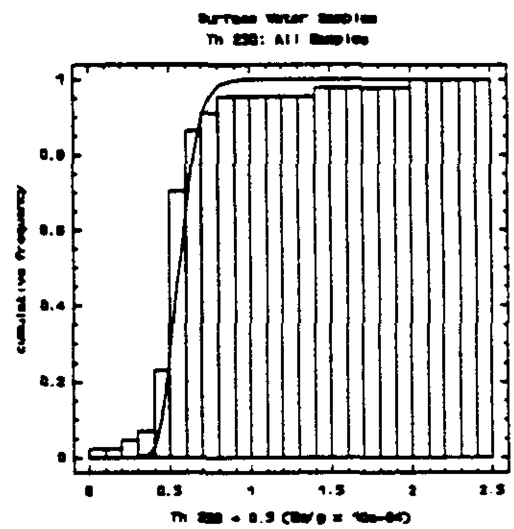
2
2.5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2
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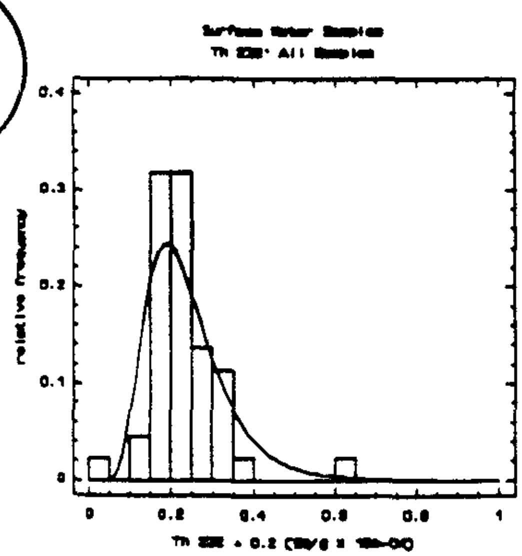
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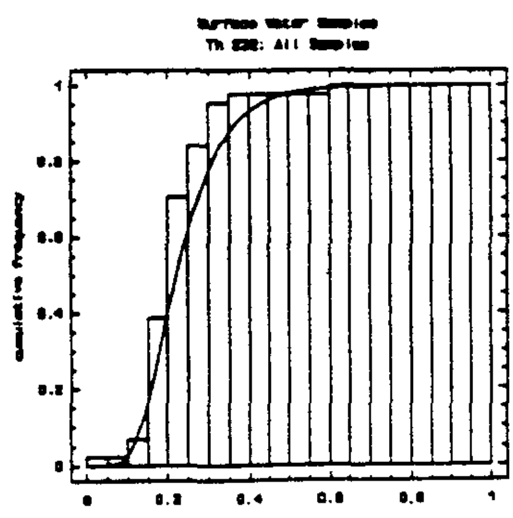
cumulative frequency
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0
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0.2
0.4
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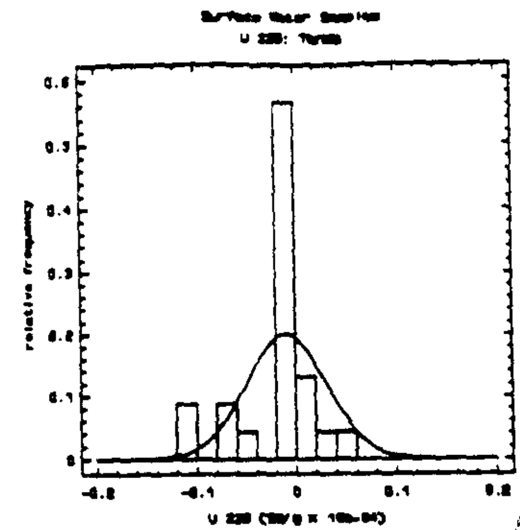
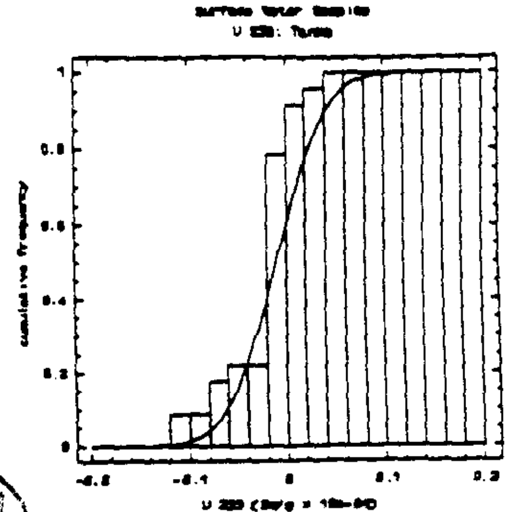
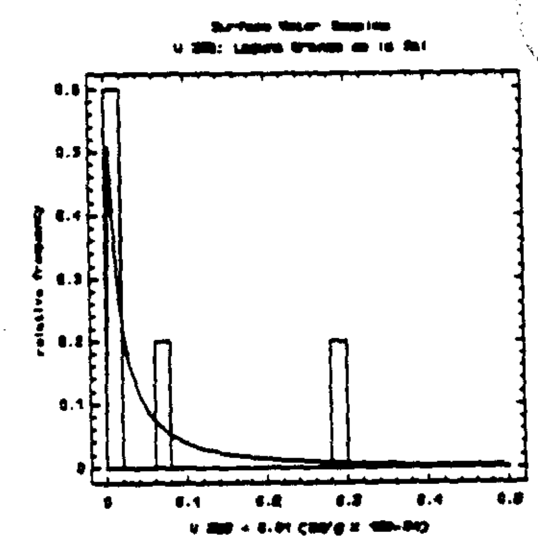
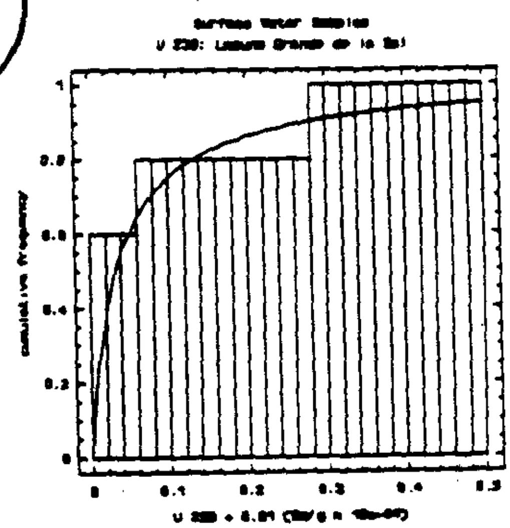
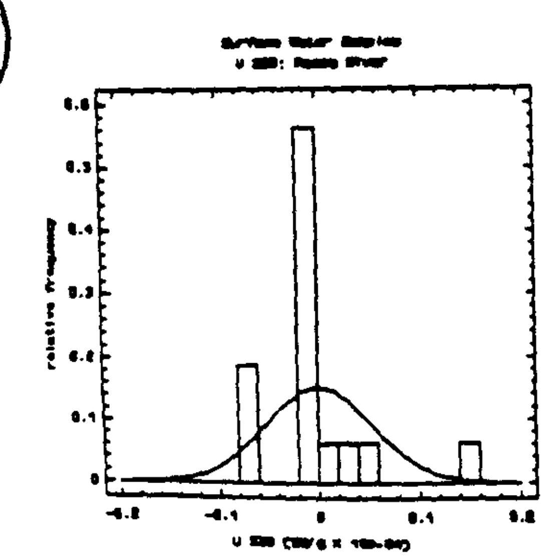
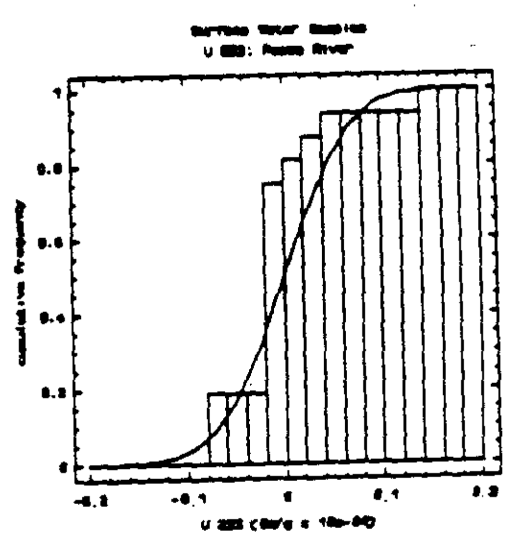


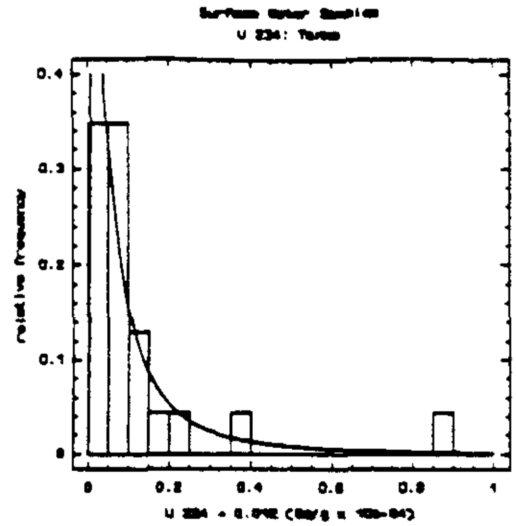


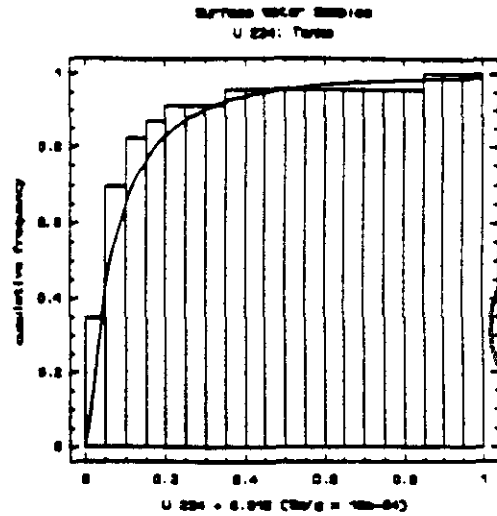


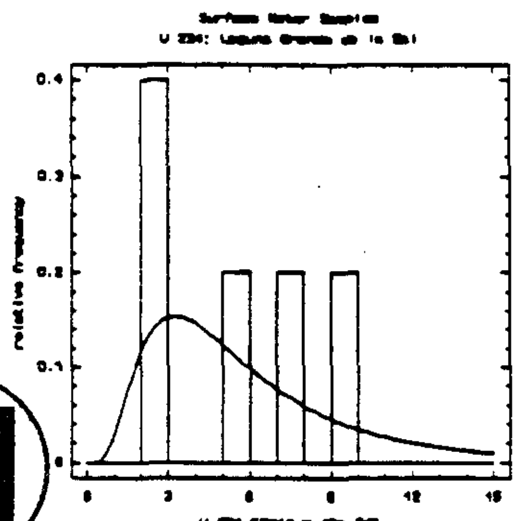


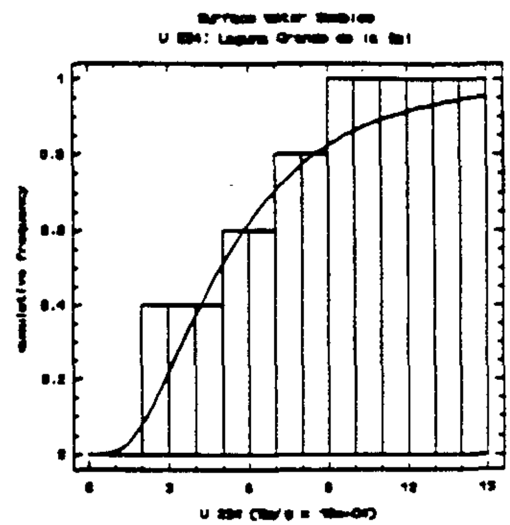


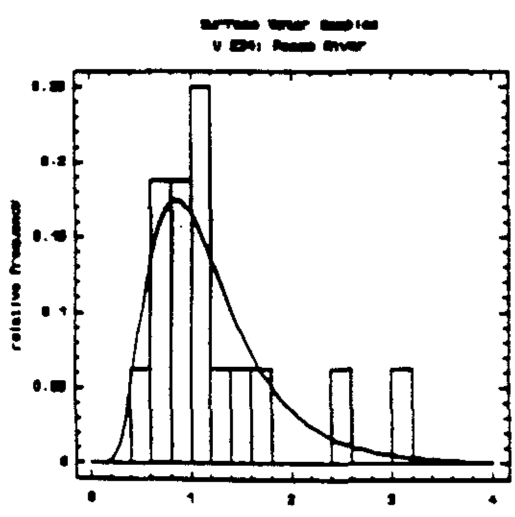


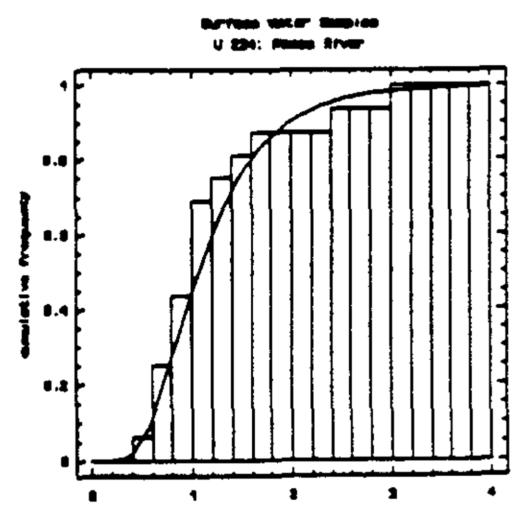


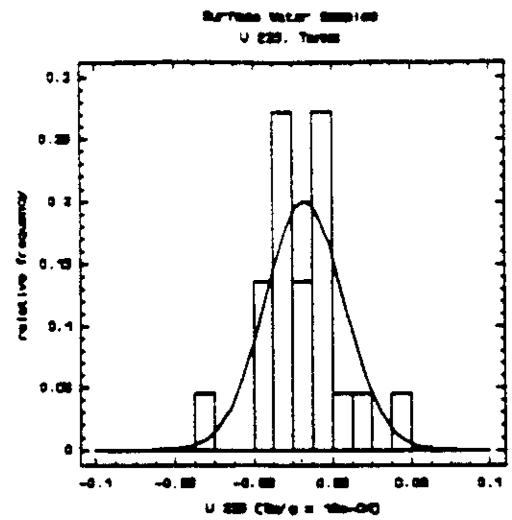


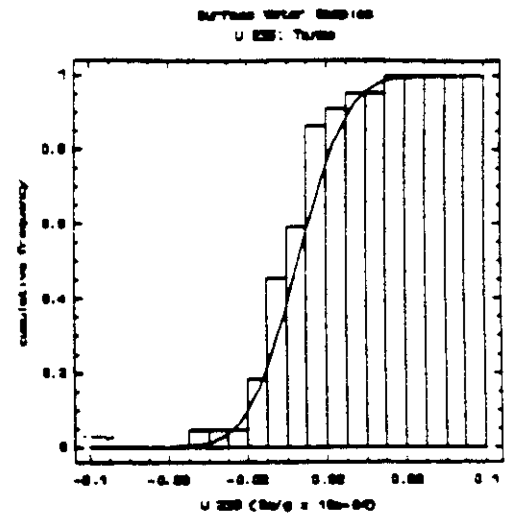


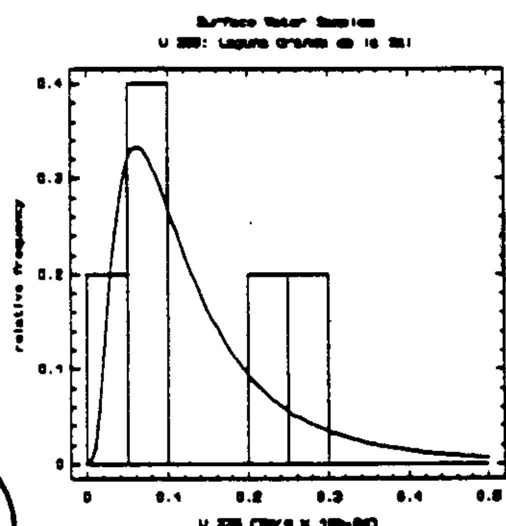


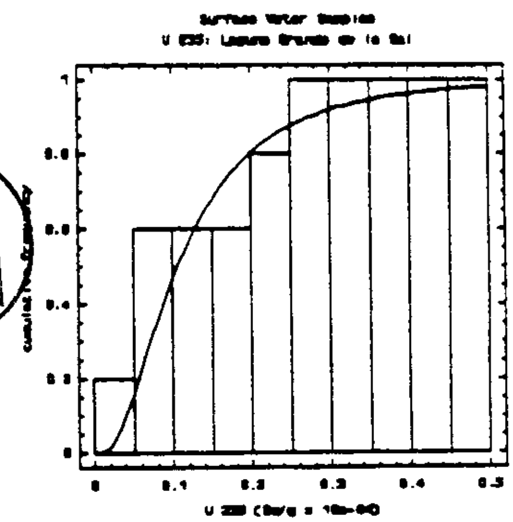


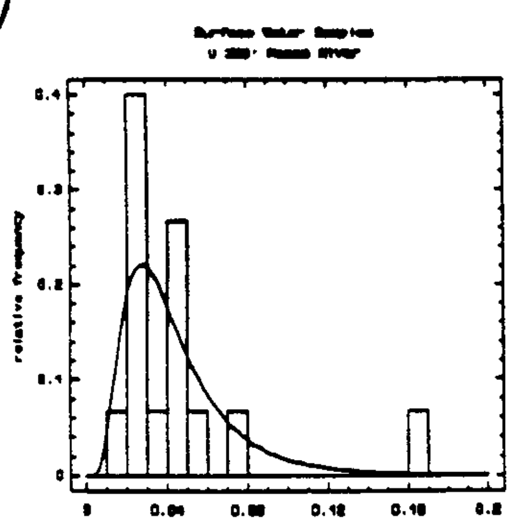


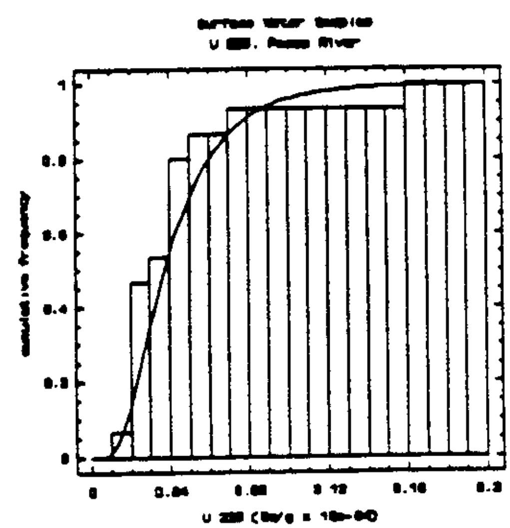

Surface Water Samples
relative frequency

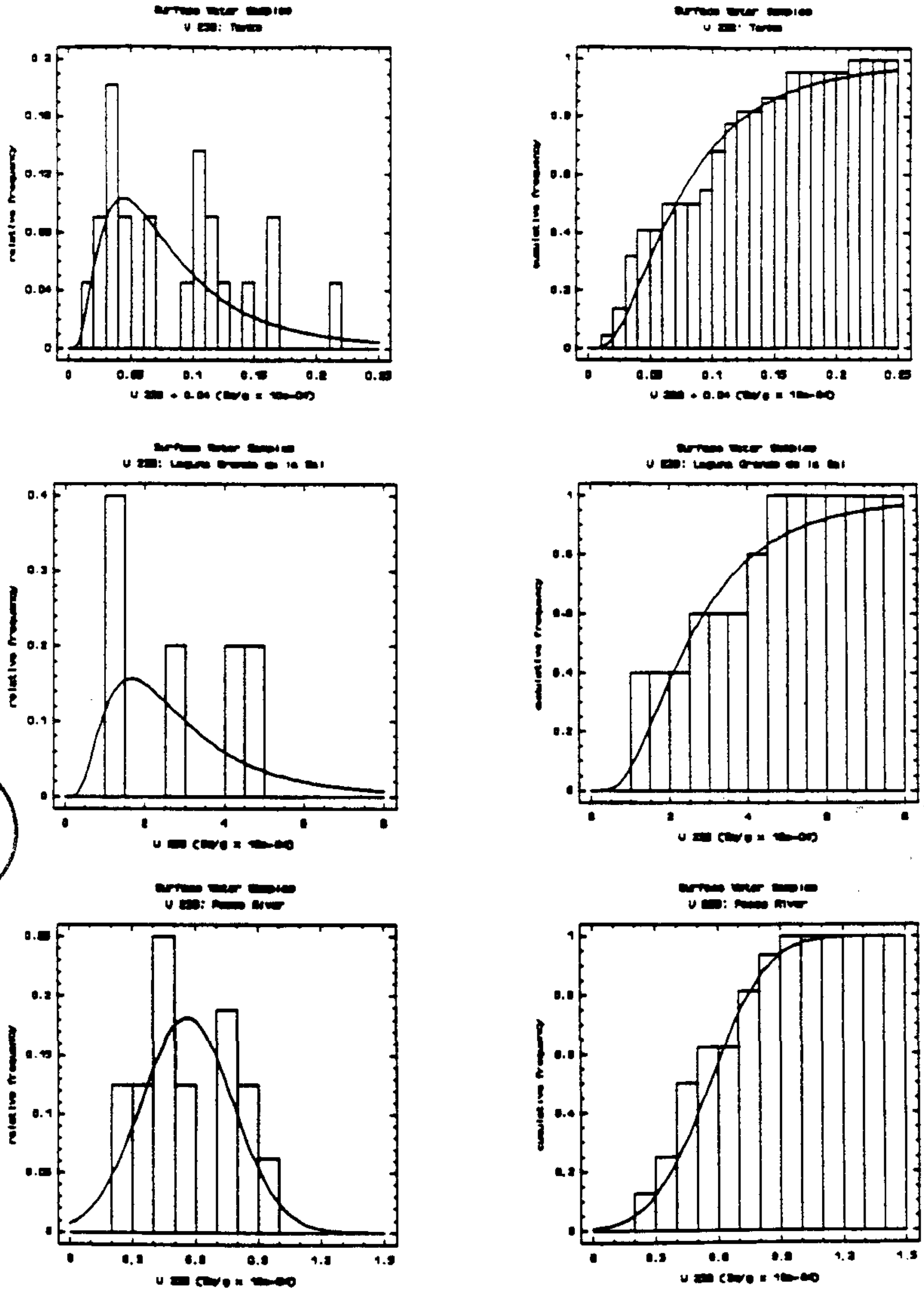

Surface Water Samples
cumulative frequency

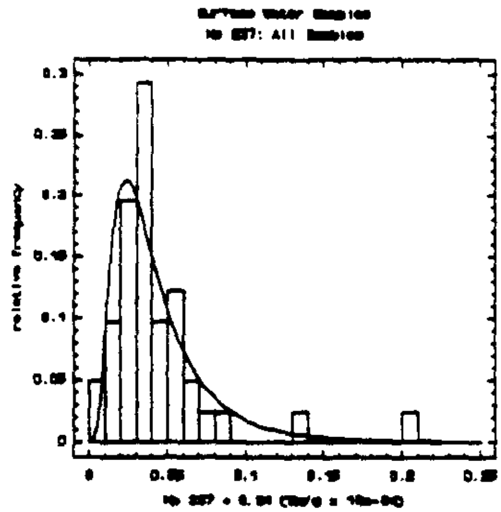

Surface Water Samples
relative frequency

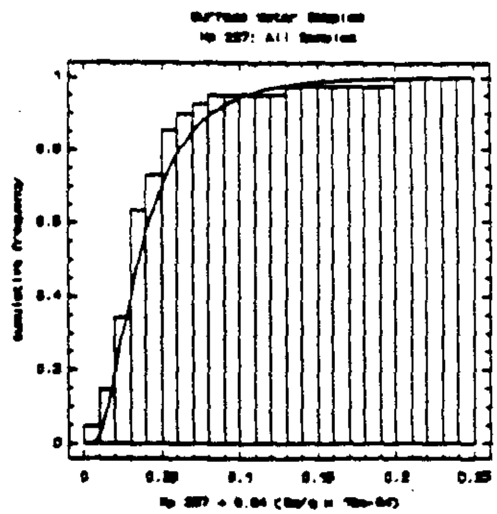

Surface Water Samples

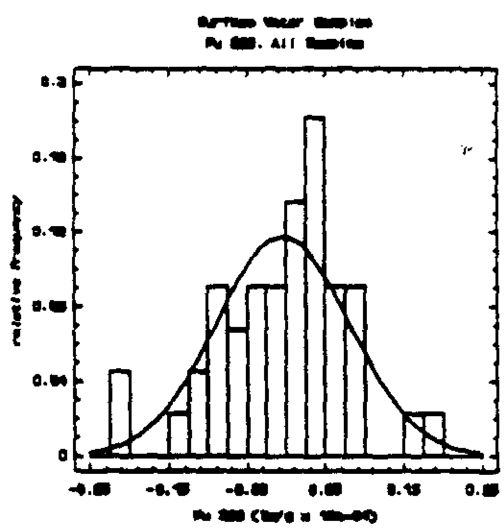

Surface Water Samples
relative frequency

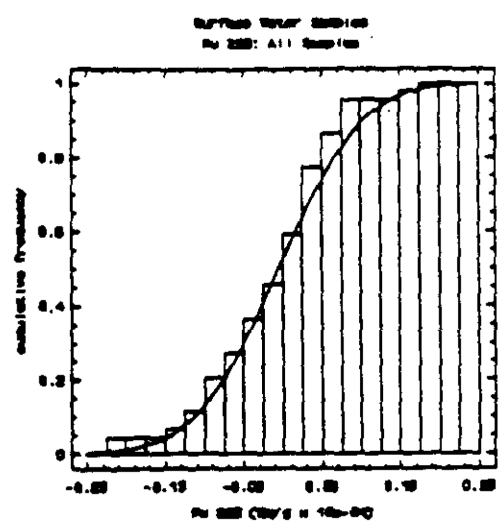

Surface Water Samples
cumulative frequency

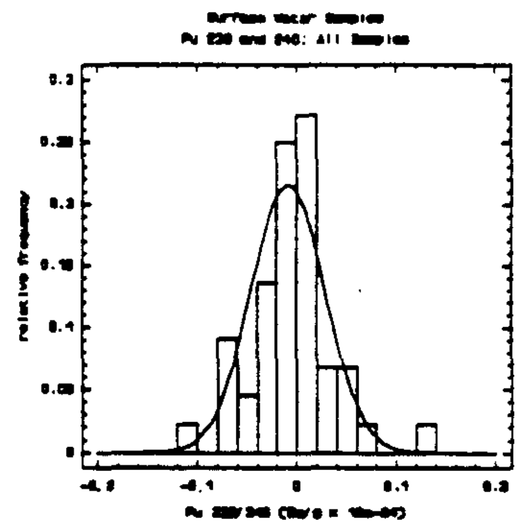


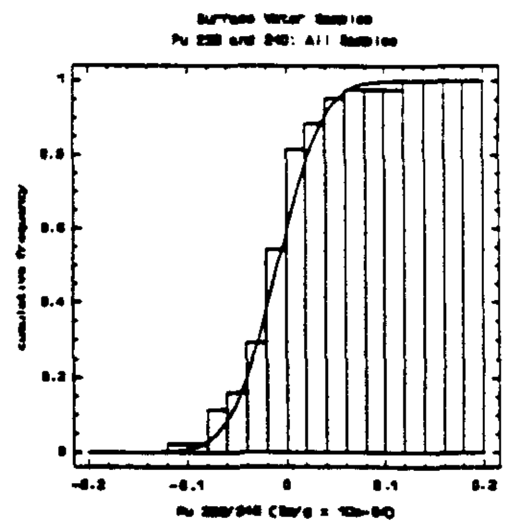


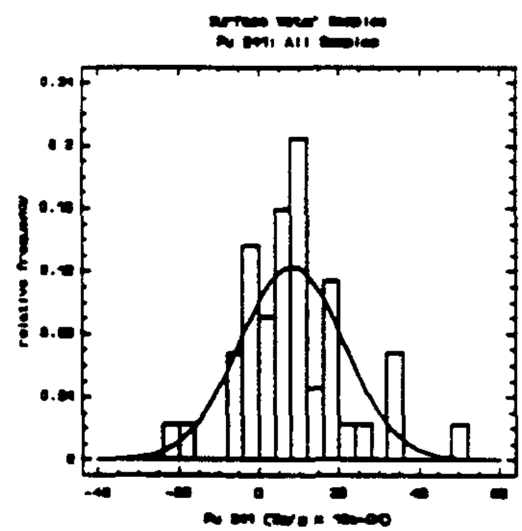


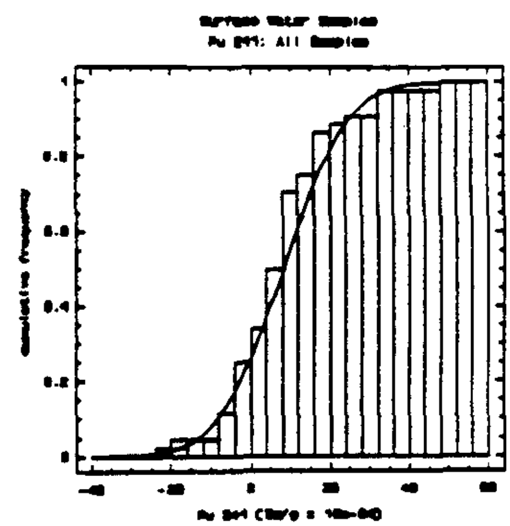


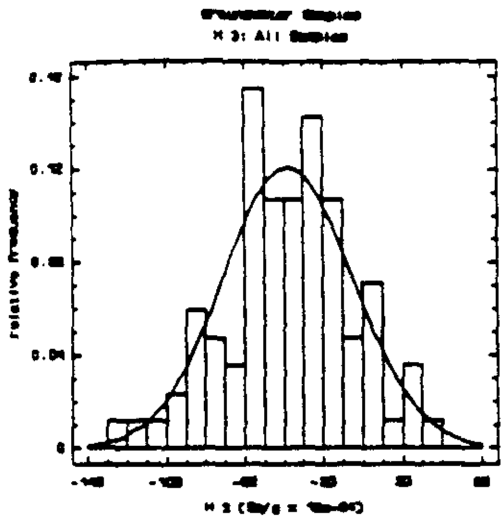


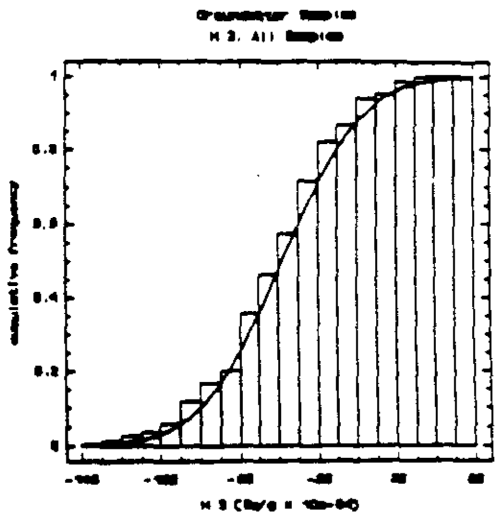


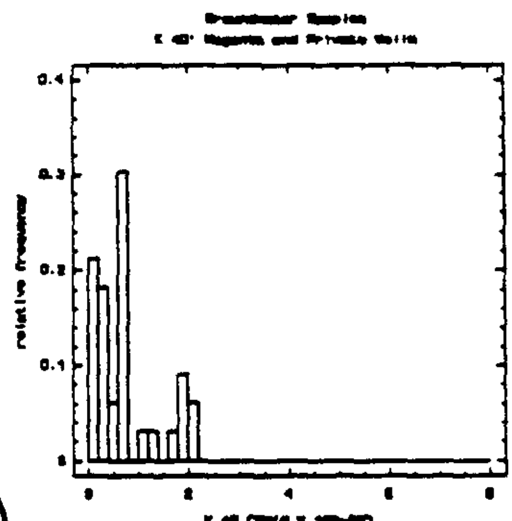


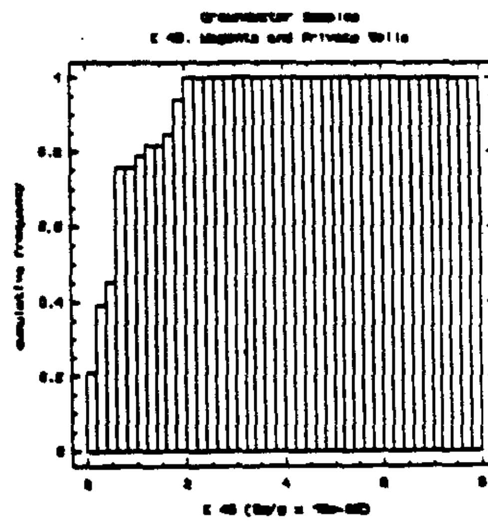


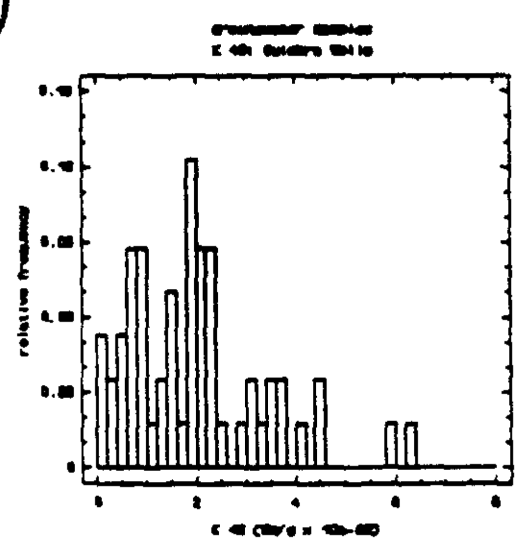


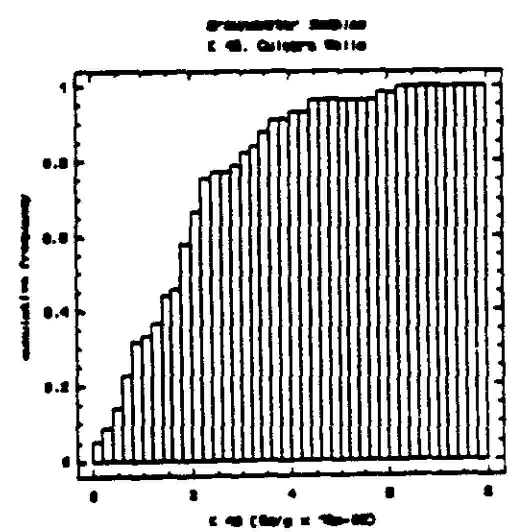


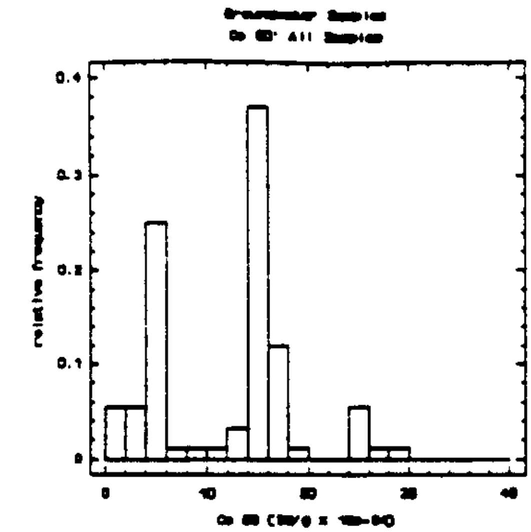


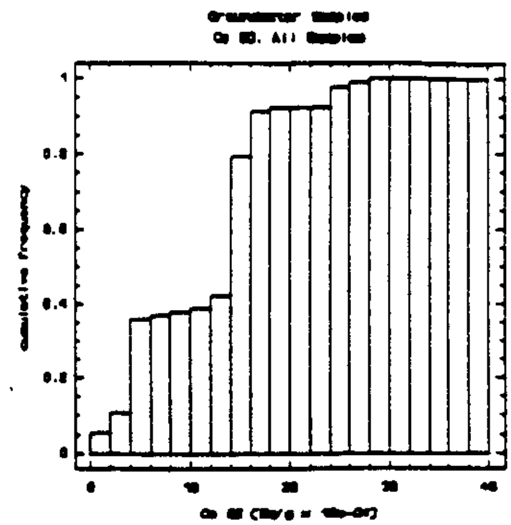


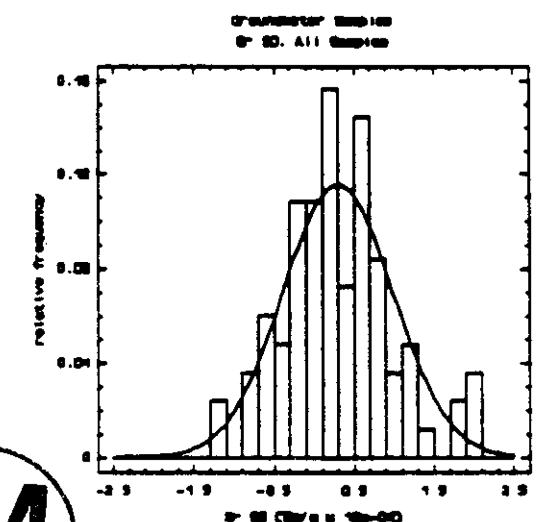


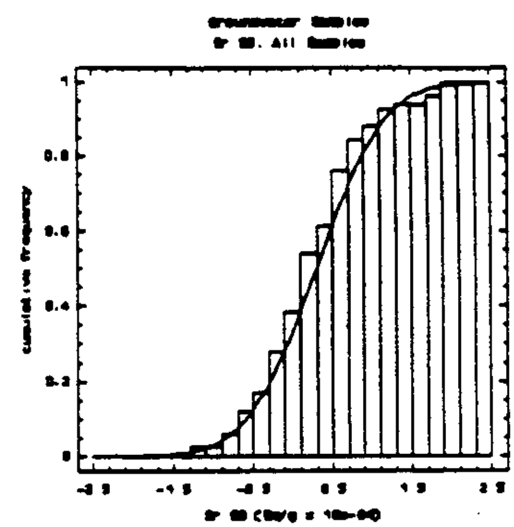


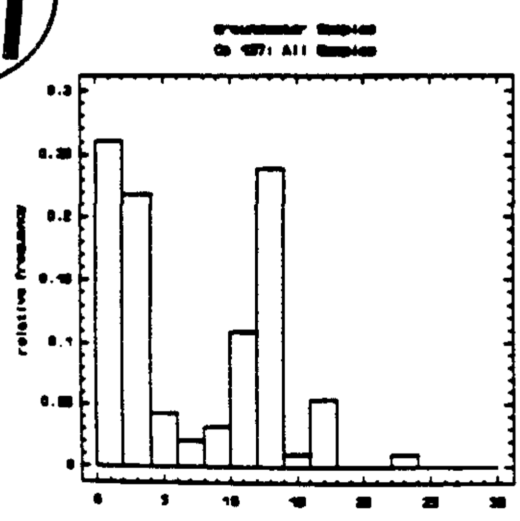


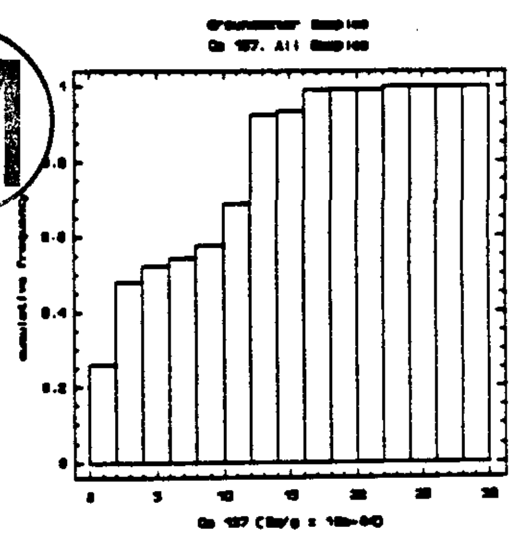


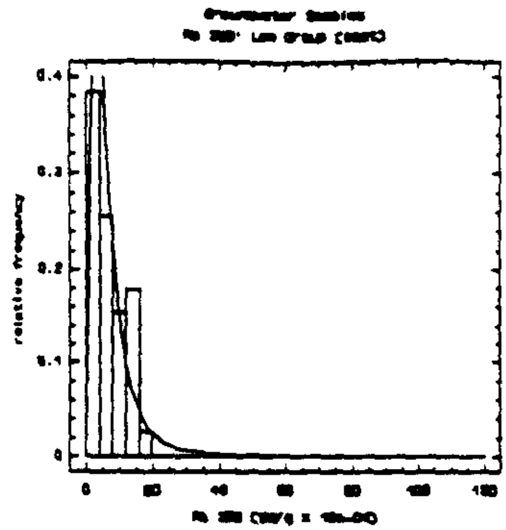


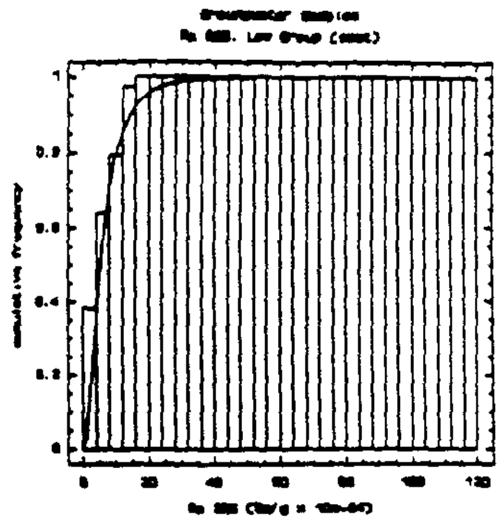


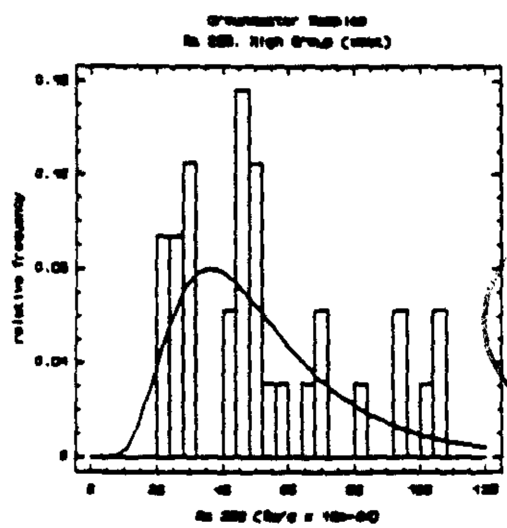







relative frequency


cumulative frequency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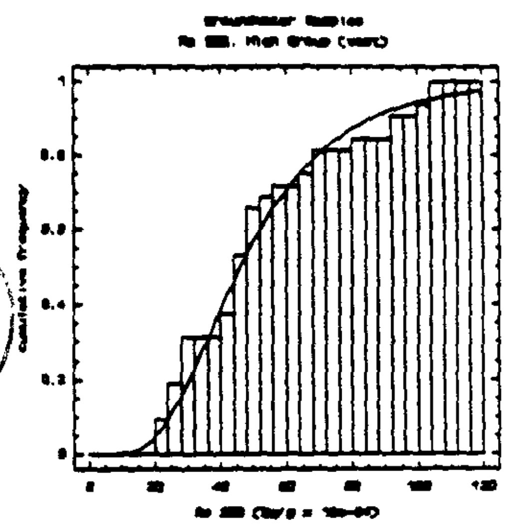
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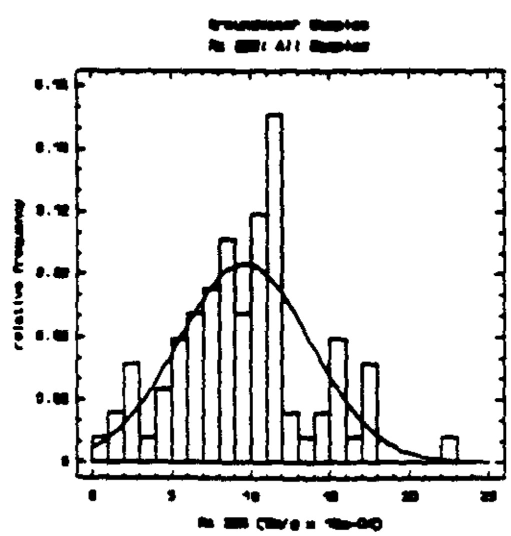
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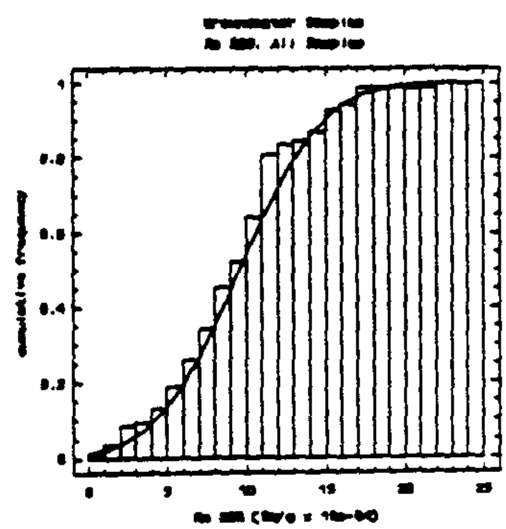
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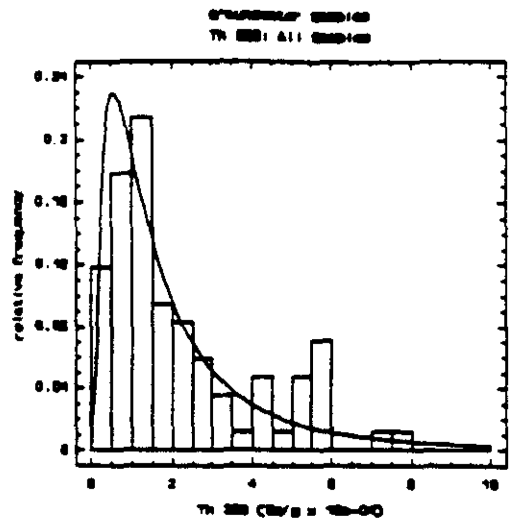

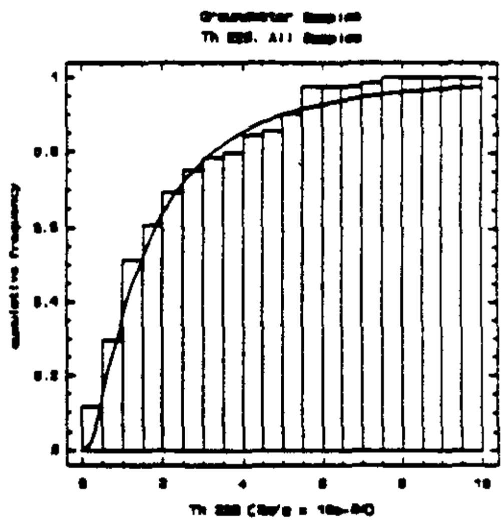

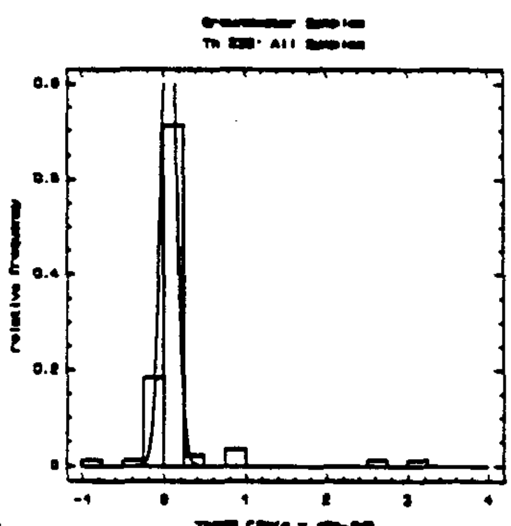

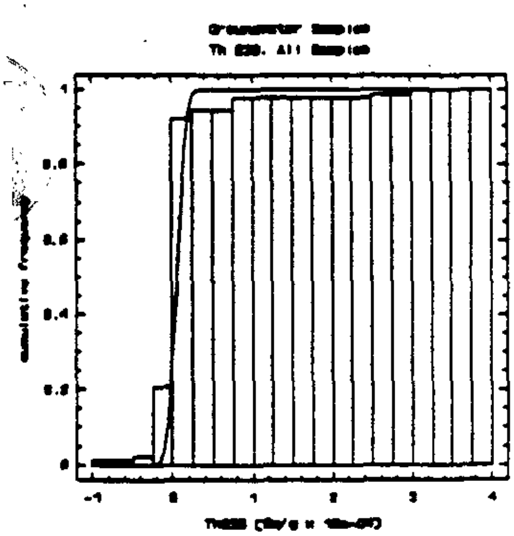

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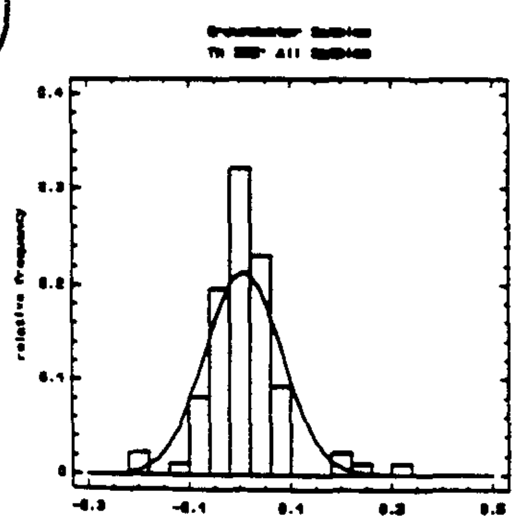

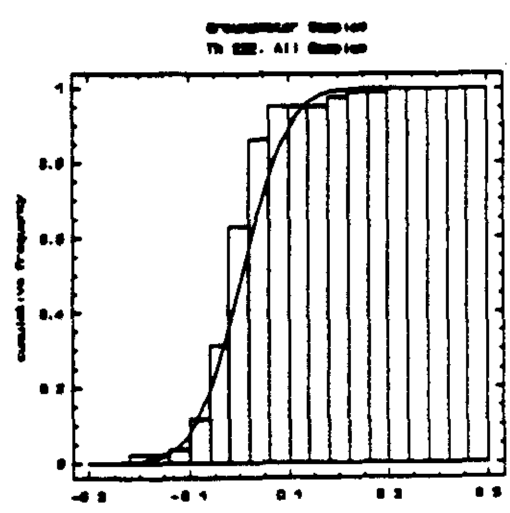

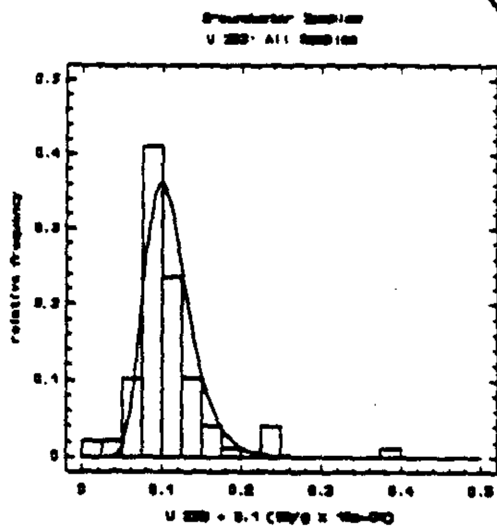

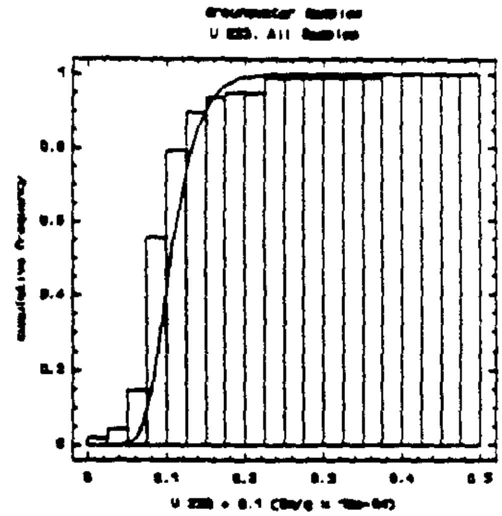

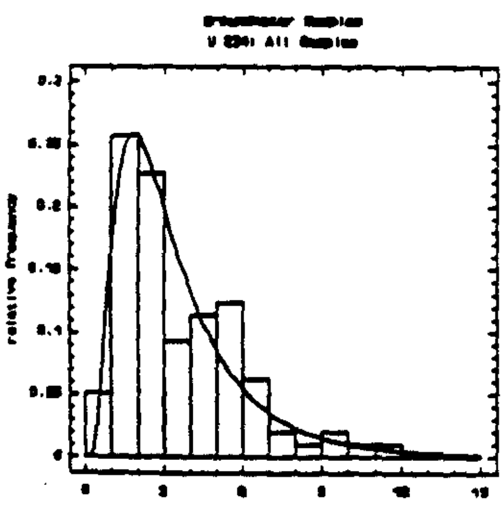

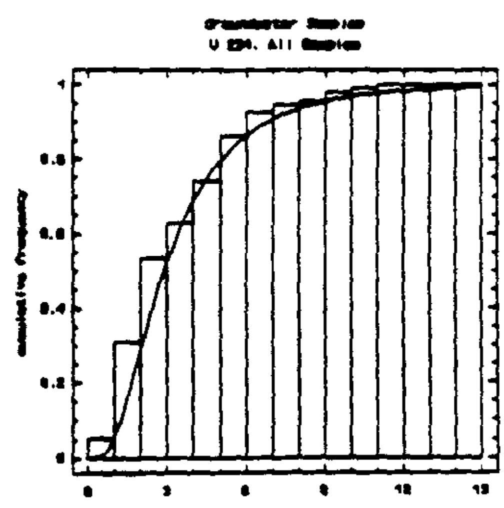

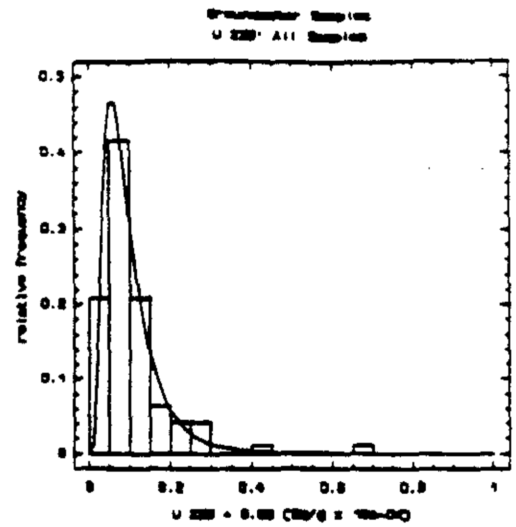
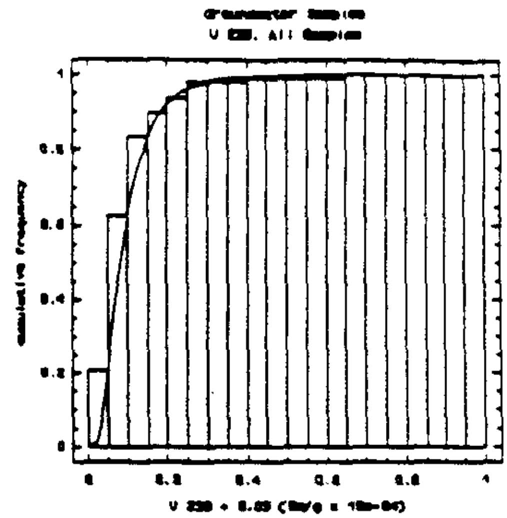
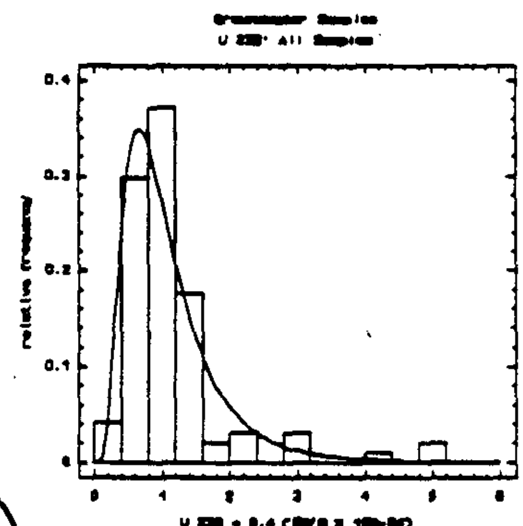
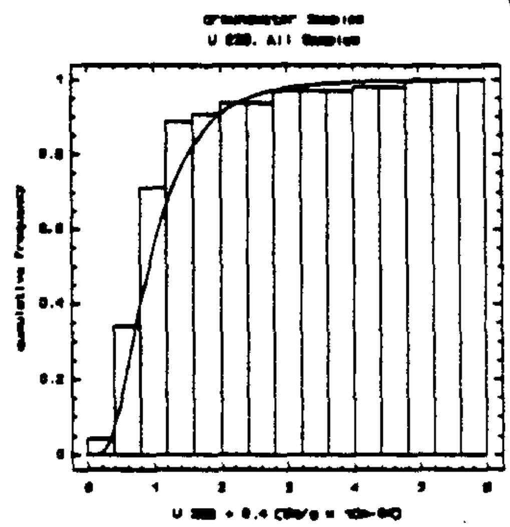
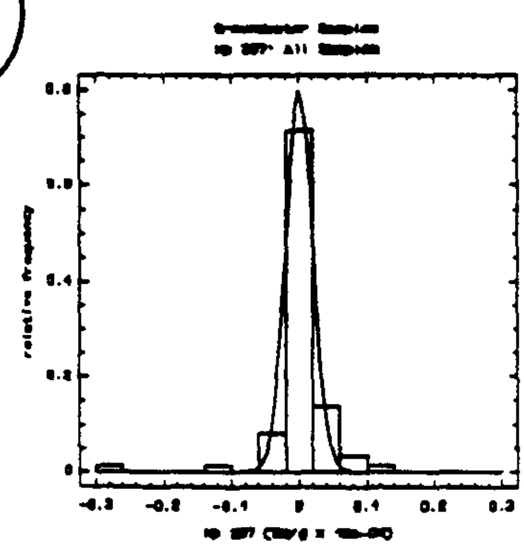
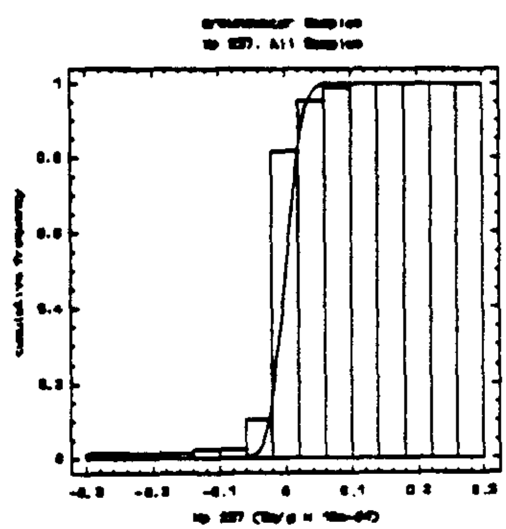

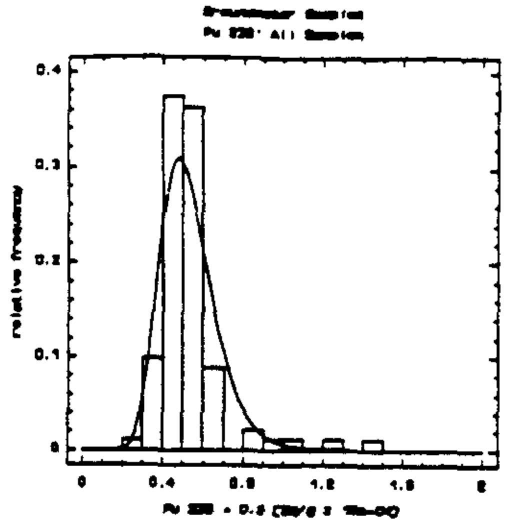

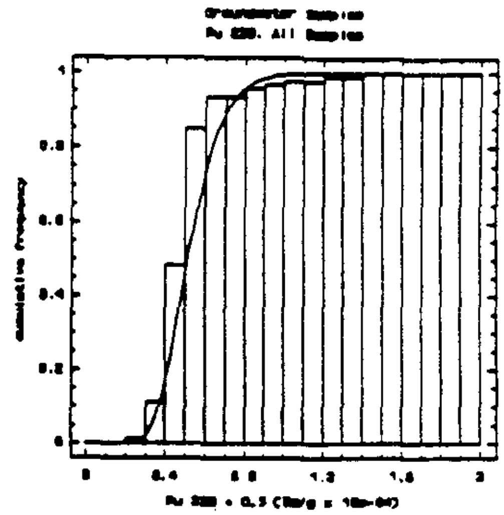

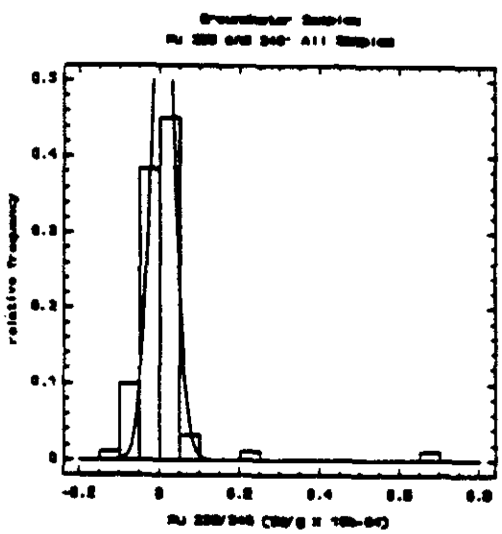

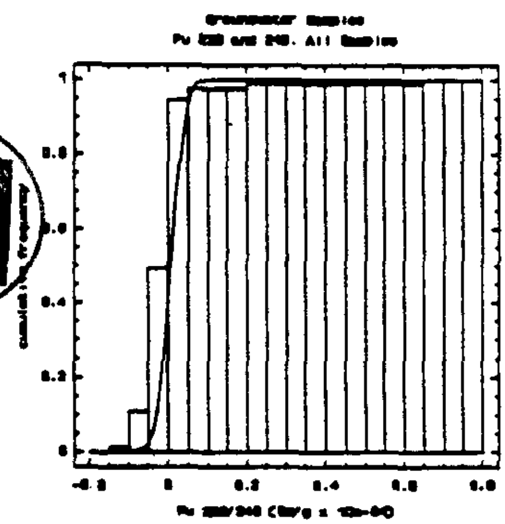

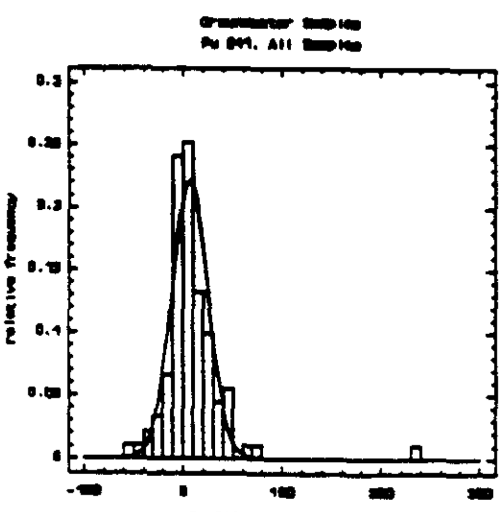

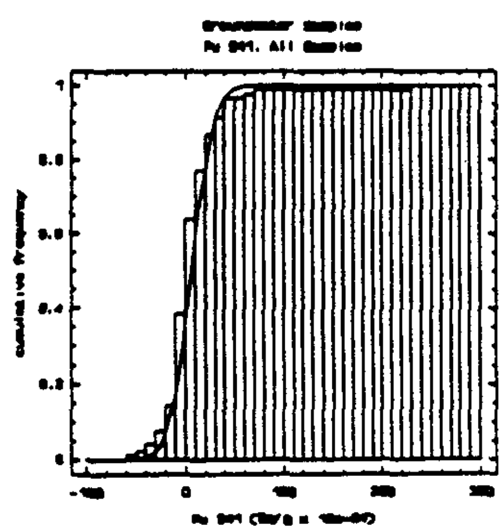

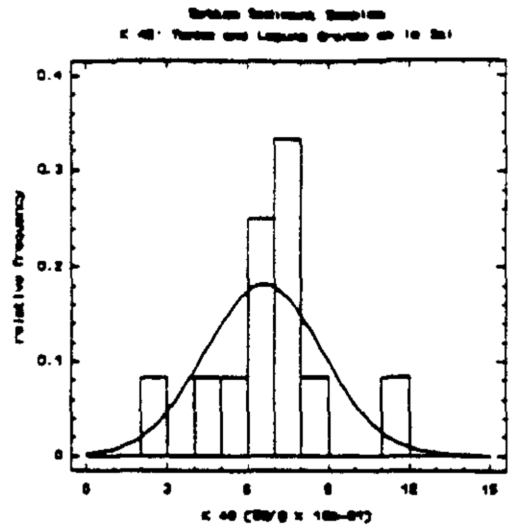

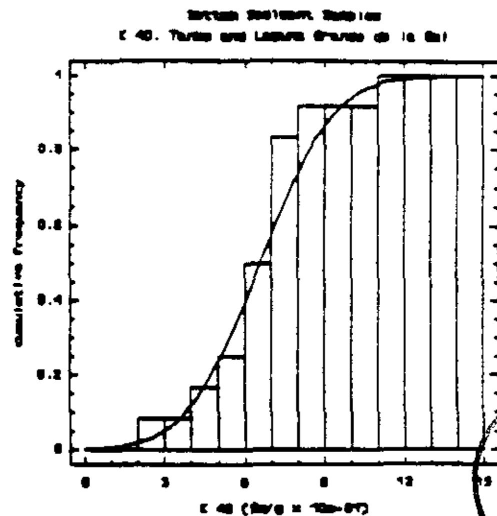

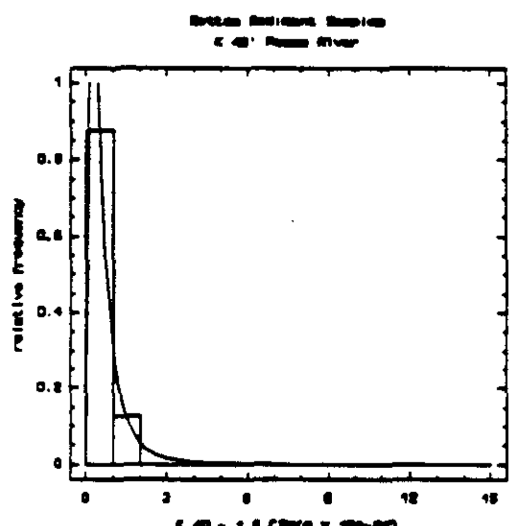

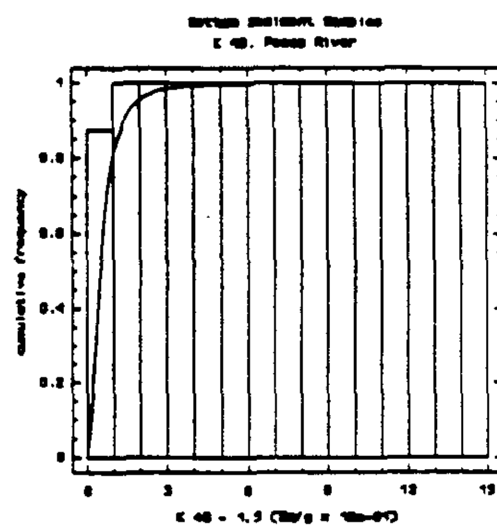

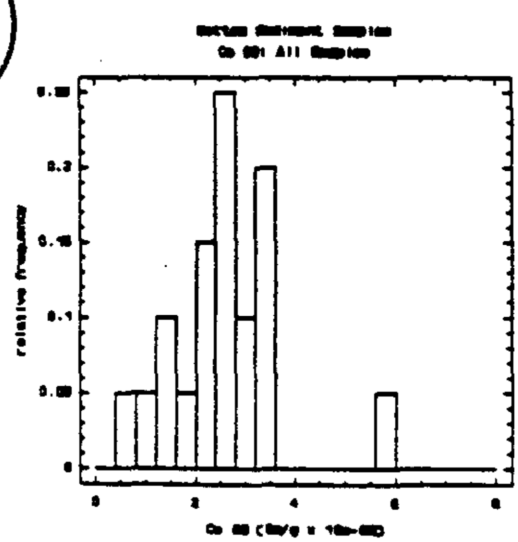

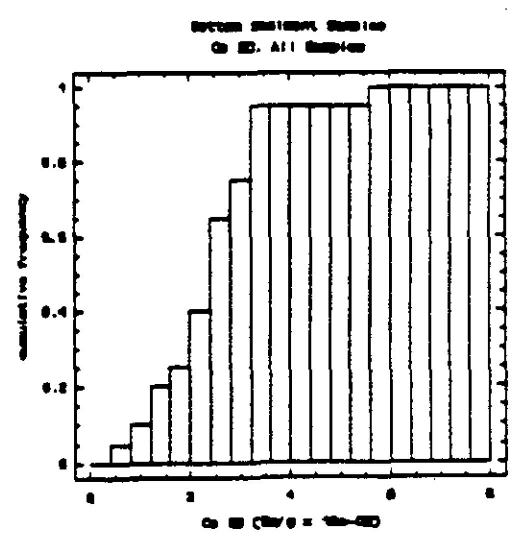

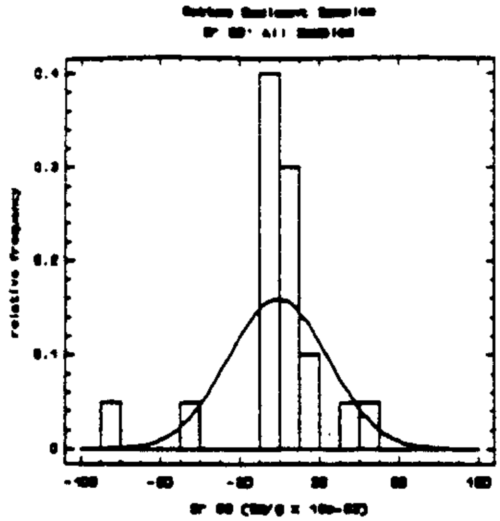

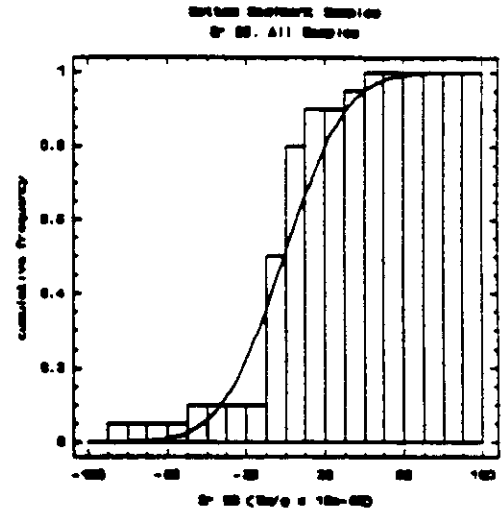

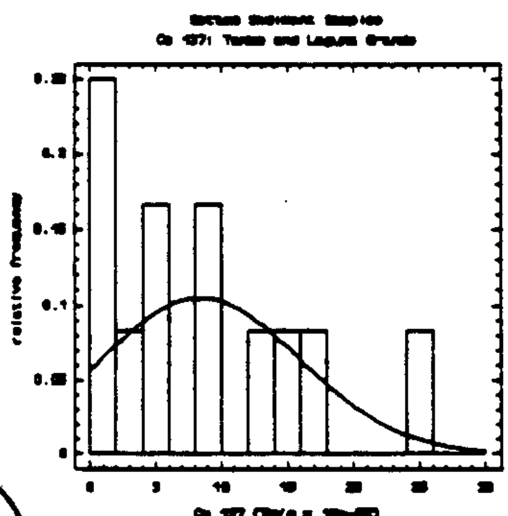

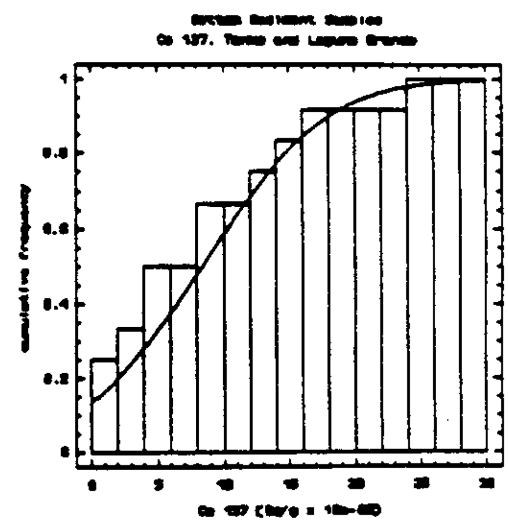

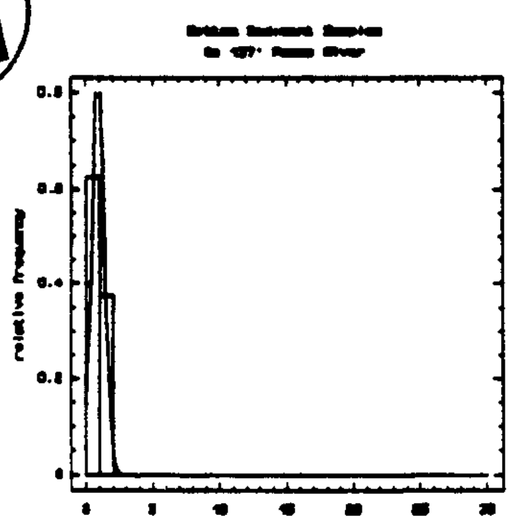

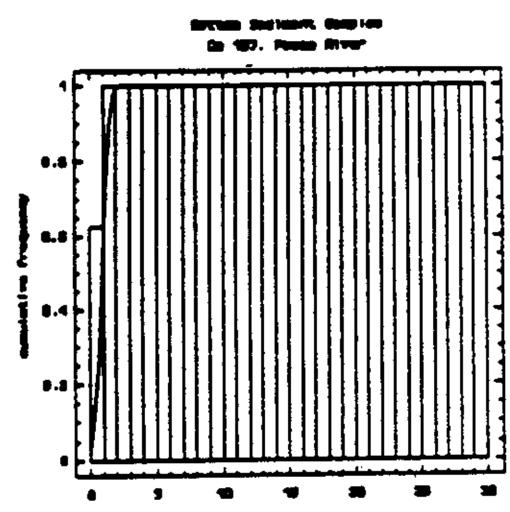

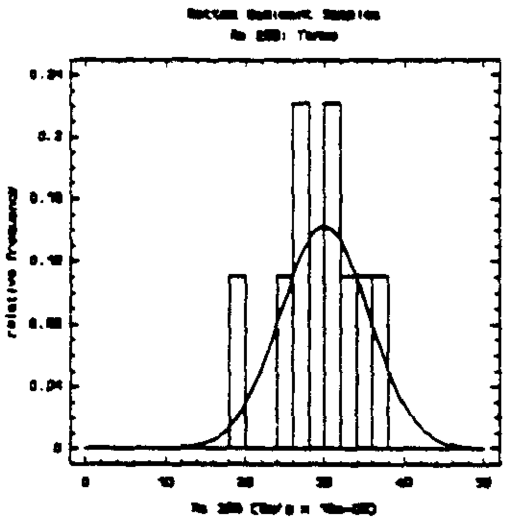

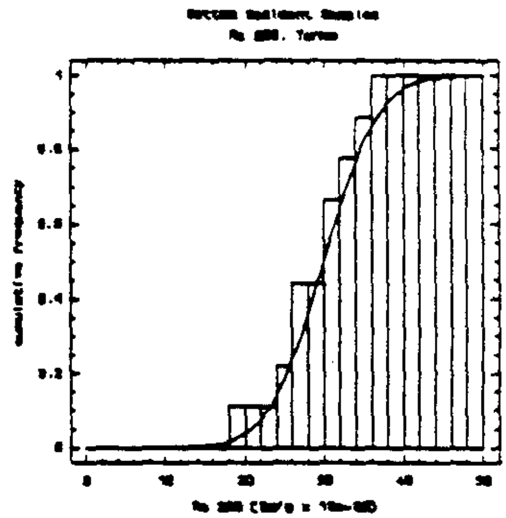

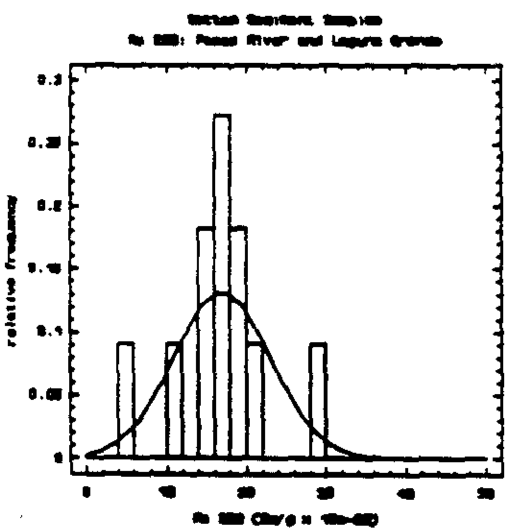

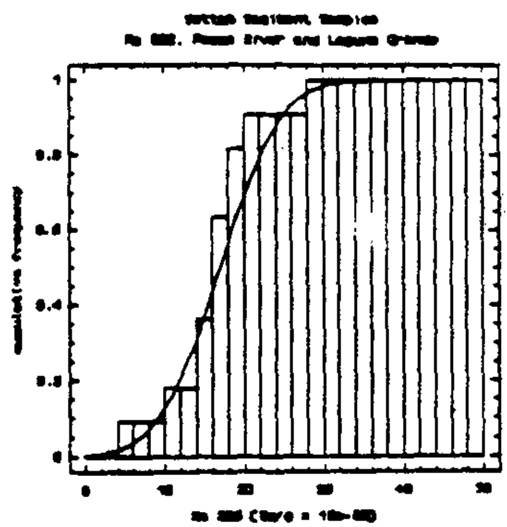

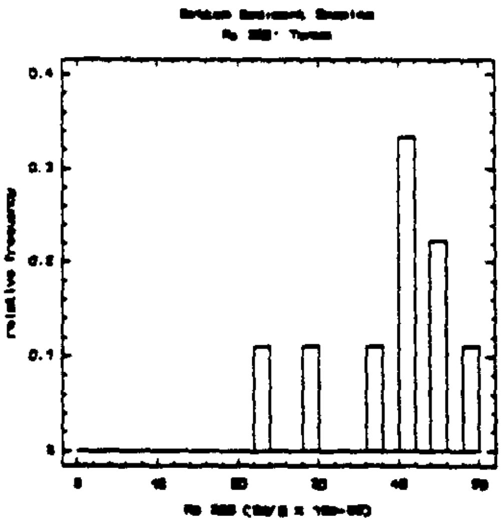

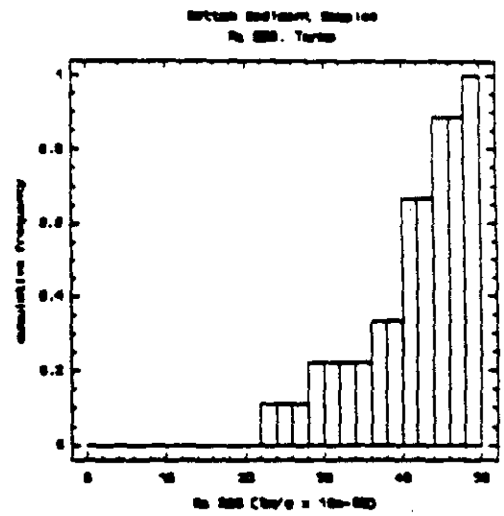

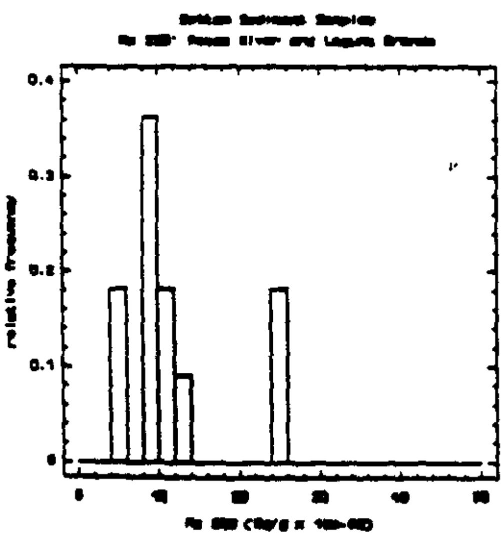

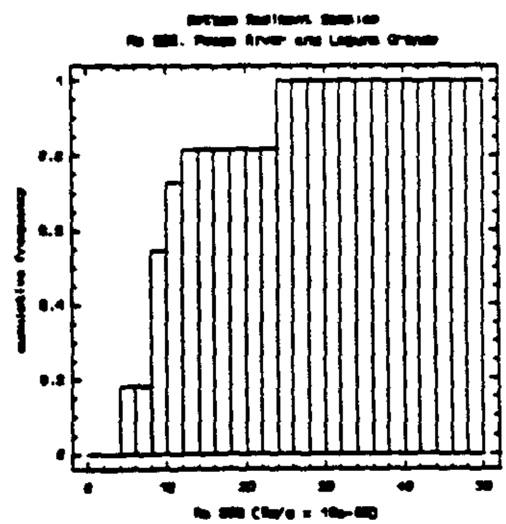

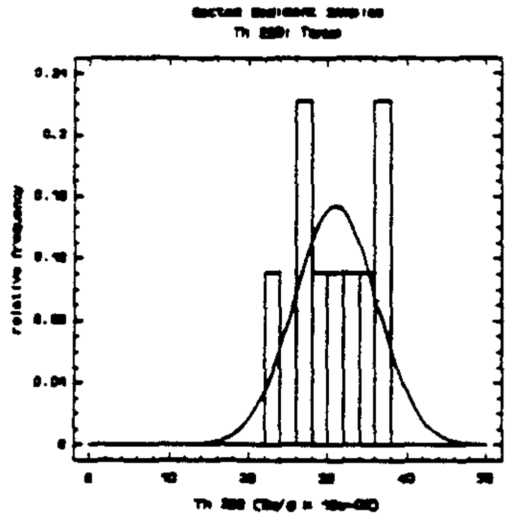

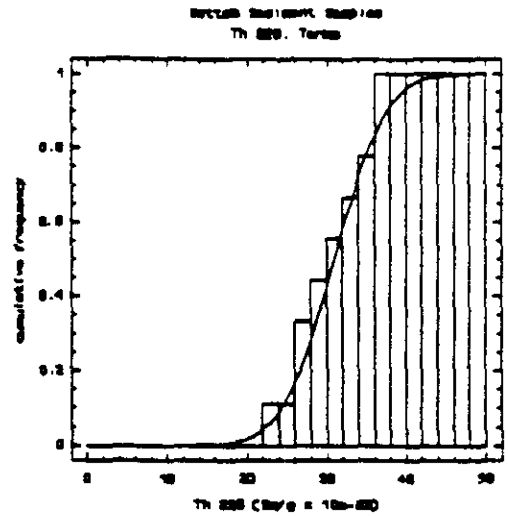

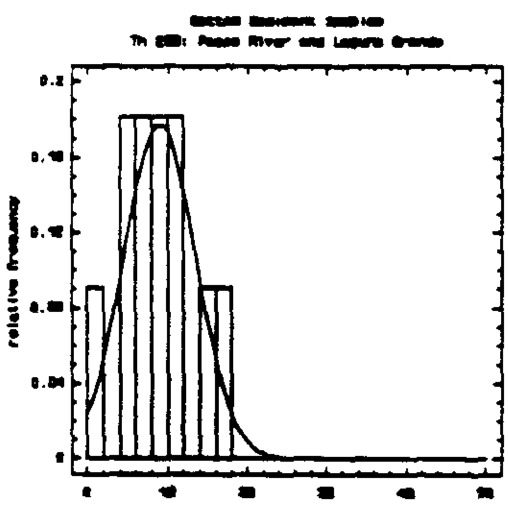

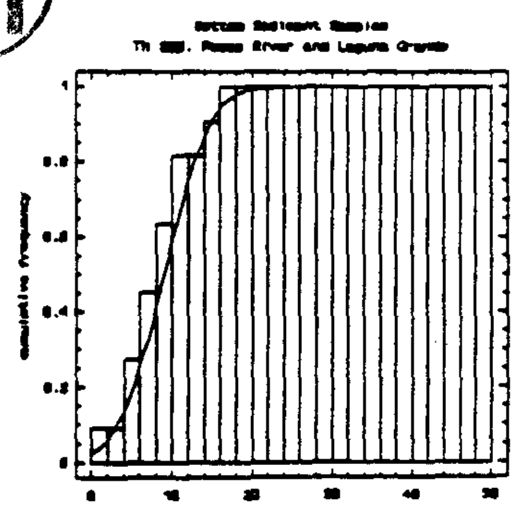

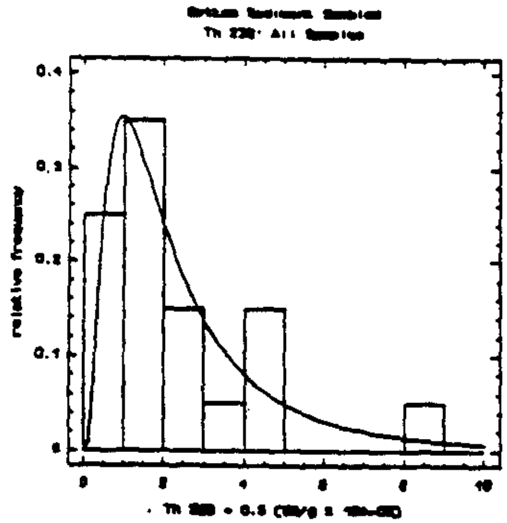
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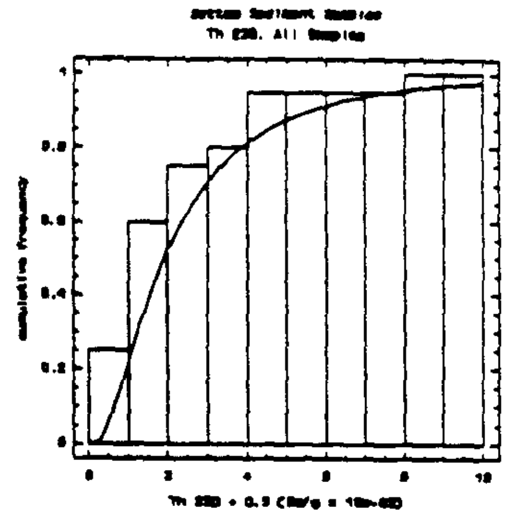
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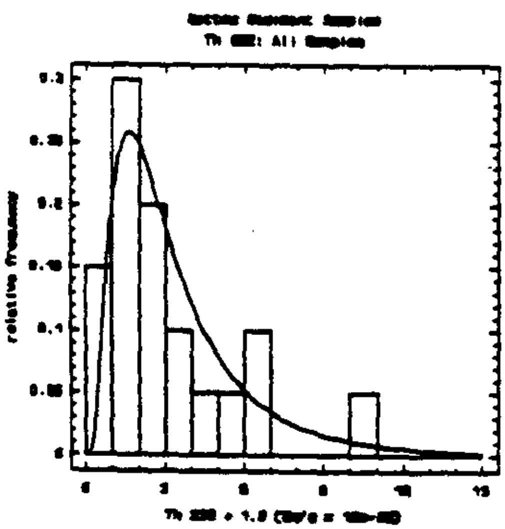
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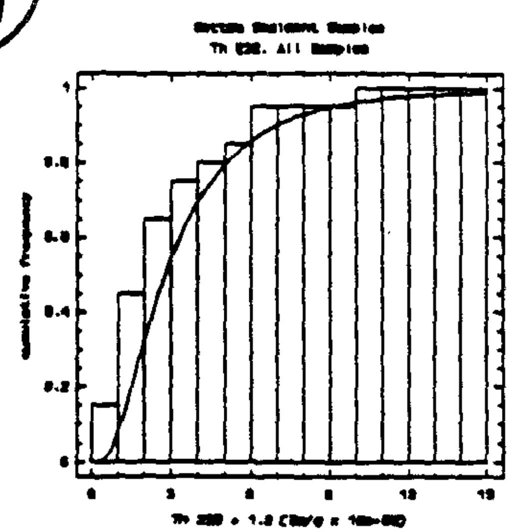
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