EVALUATION OF THE SOURCES OF RADIOACTIVE MATERIAL FOUND IN COOLING TOWER SEDIMENTS AT WASHINGTON NUCLEAR PLANT 2

REVISION 1

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1.0 INTRODUCTION AND SUMMARY

A comprehensive evaluation has been performed to determine the most likely source of the radioactive material in the Cooling Tower sediments. This evaluation was undertaken to resolve the question of whether the radionuclides detected in the Cooling Tower sediments are radioactive material originating from the plant or sediment residue drawn into Cooling Towers directly from the Columbia River. The evaluation included an assessment of potential pathways for the introduction of activity originating from the plant entailing the examination of previous work by Supply System personnel and historical plant sample data. This evaluation constitutes a body of evidence substantiating the most likely source of the radioactive material in the Cooling Tower sediments is the Columbia River sediments.

The sediment of the Columbia River is known to contain low levels of naturally occurring radioactive material. Fallout from the atmospheric testing of nuclear devices and radioactive material originating from upstream Department of Energy operations on the Hanford Reservation contribute additional components of river sediment activity (ref. 11). Relatively short half-lived activation products have been measured in the Cooling Tower sediments at concentrations that are several orders of magnitude below the concentrations of naturally occurring radionuclides. Even though these levels are low and do not present a radiological safety issue, there was a concern that the appearance of these radionuclides in the Cooling Tower sediments constituted a potential unanticipated pathway for the release of plant generated activity.

The Tower Make Up system (TMU) intake draws solid material from the Columbia River into the Cooling Tower basins as suspended solids. Estimates of the quantity of this material approach 2 tons per month of tower operations. It is unlikely that WNP-2 liquid effluents are being recirculated from the river as the TMU intake is upstream of the release point. The Columbia River has a relatively high linear velocity in the reach along the WNP-2 TMU intake aiding in the resuspension of river sediments and effectively preventing the upstream migration of plant generated radionuclides (ref. 10). TMU intake samples containing measurable quantities of cesium-137 (Cs-137) as well as the activation products zinc-65 (Zn-65), manganese-54 (Mn-54), and cobalt-60 (Co-60) demonstrate a direct riverborne source of these activation products.

A substantiation of a riverborne source of the radioactive material was obtained by the further evaluation of environmental data. Samples of Cooling Tower sediments taken from the start of commercial operations through the present were compared to samples of river sediment. The comparison of these data sets demonstrate that there is no

statistically significant difference between the means of the two sample populations for concentrations of Cs-137 and Co-60. There were not a sufficient number of samples indicating positive results for other radionuclides to establish a meaningful population for statistical comparisons. A meaningful population is considered to be composed of at least 30 samples.

Evaluations of the potential for radionuclides to be introduced to the Cooling Tower sediments by leakage from plant systems has been performed (ref. 3). The conclusions have discounted the possibility that the activity had originated from any leakage at plant piping system interfaces from operational events to date. In addition, other pathways for the introduction of radionuclides of plant origin into both the river and the Cooling Towers have been evaluated in this report and were found to be insignificant.

The conclusion of this study is that the most likely source of the radioactive material found in the Cooling Tower sediments is the Columbia River sediments.

1.1 Pathway Analysis

An evaluation of measurements of environmental samples has been performed to identify the most likely source of radioactive material identified in the WNP-2 Cooling Tower sediments. The radionuclides found in the Cooling Tower sediments are primarily cesium-137 (Cs-137) and cobalt-60 (Co-60) which have appeared consistently in samples of the sediment with the sporadic appearance of other fission and activation products.

Possible sources of plant generated radioactive material being introduced to the Cooling Towers from interconnecting liquid inventory systems have been evaluated by the plant staff. These liquid inventory sources, primarily the heat exchangers for the reactor building closed cooling water system (RBCCW), have been discounted since no fission products have been identified in any samples from these systems and the amounts of identified leakage in these systems was not sufficient to account for the quantity of activation products found in the Cooling Tower sediments (ref.3). These findings led to a search for other possible sources of radioactive material.

Other pathways by which plant generated radionuclides can be introduced into the Cooling Towers are by atmospheric dispersion and re-entrainment of the particulate fraction of the plant gaseous effluent stream. Radionuclides released to the atmosphere will deposit on the ground and other surfaces where they may be washed into the river upstream of the plant, or they may be drawn along with the air mass passing through the Cooling Tower where they are entrained into the water volume.

In order to evaluate the feasibility of these two pathways, a conservative assessment was performed using annual average dispersion parameters for the nearest approach of the river. (East sector, 3.5 miles) and to the Cooling Towers (Southeast sector, 0.25 miles).

and the total particulate fraction of gaseous effluents. Even assuming 100% efficiency of this process the predicted concentrations in both the river and the Cooling Towers would be several orders of magnitude lower than the amount of activity actually measured in the Cooling Tower sediment. For these reasons, the re-entrainment of particulate gaseous effluents is not considered to be the pathway resulting in the identified radionuclides in the Cooling Tower sediment.

The possibility that plant generated liquid effluents are being recirculated into the TMU intake was examined from the perspective of positioning of the effluent discharge into the river and the average flow velocity of the Columbia River at the TMU intake. This pathway was discounted since the liquid effluent is discharged into the river downstream of the TMU intake. The rapid linear velocity of the reach of the Columbia River in front of WNP-2 (between 0.8 and 4.5 fps) is sufficient to prevent any liquid effluents from being drawn upstream and into the TMU intake (ref. 10).

Columbia River sediments are known to contain low levels of various radionuclides from upstream Department of Energy operations (ref. 11). The velocity of the Columbia River in front of WNP-2 is sufficient to suspend sediments being washed downstream causing them to be drawn into the TMU intake as suspended solids. With these resuspended sediments containing low levels of radioactive material, this pathway would be a source of radionuclides with a direct introduction pathway to the WNP-2 Cooling Towers.

Water is drawn directly from the Columbia River by the Tower Make Up system (TMU) to supply the make-up volume for evaporative and aerosol spray losses from the Cooling Towers . Water sample analysis data from the TMU intake and samples of flocculator sediment from auxiliary water systems that draw from the TMU system were examined and found to contain Cs-137 and various activation products at concentrations comparable to those identified in the Cooling Tower sediments. These samples were taken during the period when Zn-65 and Mn-54 were being detected in Cooling Tower sediments and indicate that measurable quantities of these two activation products were also present in the make-up water being drawn from the river. The location where these samples were obtained is not subject to any significant particulate entrainment effects from the atmosphere. For this reason this source has been identified as the most likely pathway for the introduction of radioactive material into the Cooling Towers.

1.2 Origins of Cooling Tower Sediment

Resuspended river sediment and suspended solids constitute the largest source of the solid material that builds up in the Cooling Towers. A factor that may influence the mass (quantity) of solids collecting in the Cooling Tower is the liquid volume throughput. The tower operation cycle requires additions to the liquid inventory to make up for evaporative and windborne aerosol liquid inventory losses. The suspended solids content of the water drawn into the intake to make up for these losses may influence the amount

of fine sediment that collects in the tower flow basins. USGS water quality data from the Columbia River at the reach along the WNP-2 Site shows a maximum loading of 13 mg/l. This is a significant amount of solids considering the amount of water processed by the TMU system. Estimates of the amount of solid material introduced into the Cooling Towers by this method approach 2 tons per month.

Additions to the bulk solid content of the Cooling Tower sediment occurs within the tower structure as accumulations of dead or fractionated portions of algae colonies (biological material). The addition of this tower generated solids bulk to accumulations of sludge must be considered in any attempt to correlate radionuclide concentrations in river sediments with those in the tower sludges. Supply System studies of the organic carbon content of the sludges have been performed on sediment samples indicating up to a 30% organic content with some seasonal variation. This information has been used to convert Cooling Tower sediment concentrations to river equivalent values (corrected for organic mass ingrowth).

The contribution of windborne dust to the mass of the cooling tower sludges is presently unknown. Such a determination would involve a review of available dust loading factors for various wind velocities and directions, and compensation for factors such as building wake effects. Models describing these processes have been developed; however, most require some custom accommodation to onsite structure physical dimensions. In addition, incorporation of site meteorology would present a formidable task and would have little value without known dust loading parameters.

2.0 The Appearance of Zn-65 and Mn-54 in Cooling Tower Sediments

The appearance of Zn-65 and Mn-54 in the Cooling Tower sediments raised particular concerns since this could represent a potentially unanticipated source of activity from the plant. As there is no indication of the appearance of Mn-54 or Zn-65 in the river sediment or river water above detectable levels, the appearance of Zn-65 in the Cooling Tower sediment presents an apparent paradox. Zinc commonly occurs as a dissociated salt having a soluble chemical characteristic. In this chemical form it is subject to concentrating effects from evaporative processes such as Cooling Tower operations. If the river water/sediment concentrations of Zn-65 were below detectable limits and then concentrated by Cooling Tower evaporation effects, it would be feasible to have measurable quantities of Zn-65 in the Cooling Tower sediments.

Another possibility is that Zn-65 is adsorbed onto suspended solids in the river and is not otherwise associated with river "water" or sediments. Since the river intake for tower make up water is suspended above the bottom of the river, primarily only suspended solids would be expected to be drawn into the make up water treatment system. The river flow velocity in the Hanford Reservation reach is of sufficiently high velocity that only relatively large particles would be subject to sedimentation effects. Adsorption/desorption effects have been shown to be more pronounced on smaller

particles due to the intrinsically higher surface area to volume ratio.

A direct observation of activation products in Columbia River water was made in 1986 during the period of time when Zn-65 and Mn-54 were appearing in the Cooling Tower sediments. Samples had been taken of the river intake water and of the deposits in the potable water system flocculator. These samples (laboratory sample #'s 86-1399, 86-1400, and 86-5371) were counted for 12 hours each.

The results of these analyses were reported as follows:

27-Feb-86 Sample # 86-1399 Sediment from Flocculator Ledge		
Radionuclide	Concentration (μCi/cc)	% Error (1 Sigma)
Mn-54	3.4 E-08	16.51
Co-60	2.2 E-07	4.01
Cs-137	1.2 E-07	5.66
K-40	5.3 E-06	2.33

27-Feb-86 Sample # 86-1400 Flocculator Bottoms		
Radionuclide	Concentration (μCi/cc)	% Error (1 Sigma)
Mn-54	3.5 E-08	21.32
Co-60	4.4E-07	3.31
Cs-137	7.9 E-08	10.71
K-40	3.9 E-06	3.46

23-Jul-86 86-5371 River Intake Water		
Radionuclide	Concentration (μCi/cc)	% Error (1 Sigma)
Mn-54	2.9 E-09	40.47
Zn-65	3.8 E-08	7.75
Co-60	1.7 E-08	8.96
Nb-95	5.8 E-09	20.14
K-40	8.2 E-08	18.01

The sample taken on July 23rd, 1986 was noted to have been left to settle for more than 24 hours prior to counting. The possibility that suspended solids had settled on the bottom of this sample causing activity in the sediments to be oriented closer to the detector may explain the relatively high concentrations reported for this sample. Quantitatively this situation would invalidate this sample result. Qualitatively, the appearance of Zn-65 in this sample is undeniable.

An additional sample was sent to an offsite laboratory for analysis. The result as shown below confirms a detectable Zn-65 component in the incoming river water during this time period.

18-Jun-86 Teledyne Sample # 68233 Water from River Intake		
Radionuclide	Concentration (μCi/cc)	% Error (1 Sigma)
Co-60	1.5 E-08	44.85
Zn-65	2.5E-08	50.55

The Zn-65 identified in the river water samples taken on June 18, 1986 (Teledyne Sample # 68233) and again in the sample taken on July 23, 1986 (Sample # 86-5371) appeared at the same time this radionuclide was being identified in the Cooling Tower sediments. Mn-54 was identified consistently in the Intake/Flocculator samples. This data was not substantiated by other agencies conducting environmental surveillance programs in the area.

The data recorded above for the Flocculator and the river water intake are consistent with trends in the Cooling Tower sediment samples. During this same period of time Cooling Tower data indicate that Mn-54 was appearing consistently since August of 1985 (Sample # 85-08-02). Mn-54 had not been detected after June 27, 1986 (Sample # 86-06-26) and then reappeared in the Cooling Tower sediments in January of 1987 (Sample # 87-01-15). Zinc-65 first appeared in the Cooling Tower sediments on January 16, 1986 (Sample # 86-01-16) but then did not reappear until March 20, 1986 (Sample # 86-03-12).

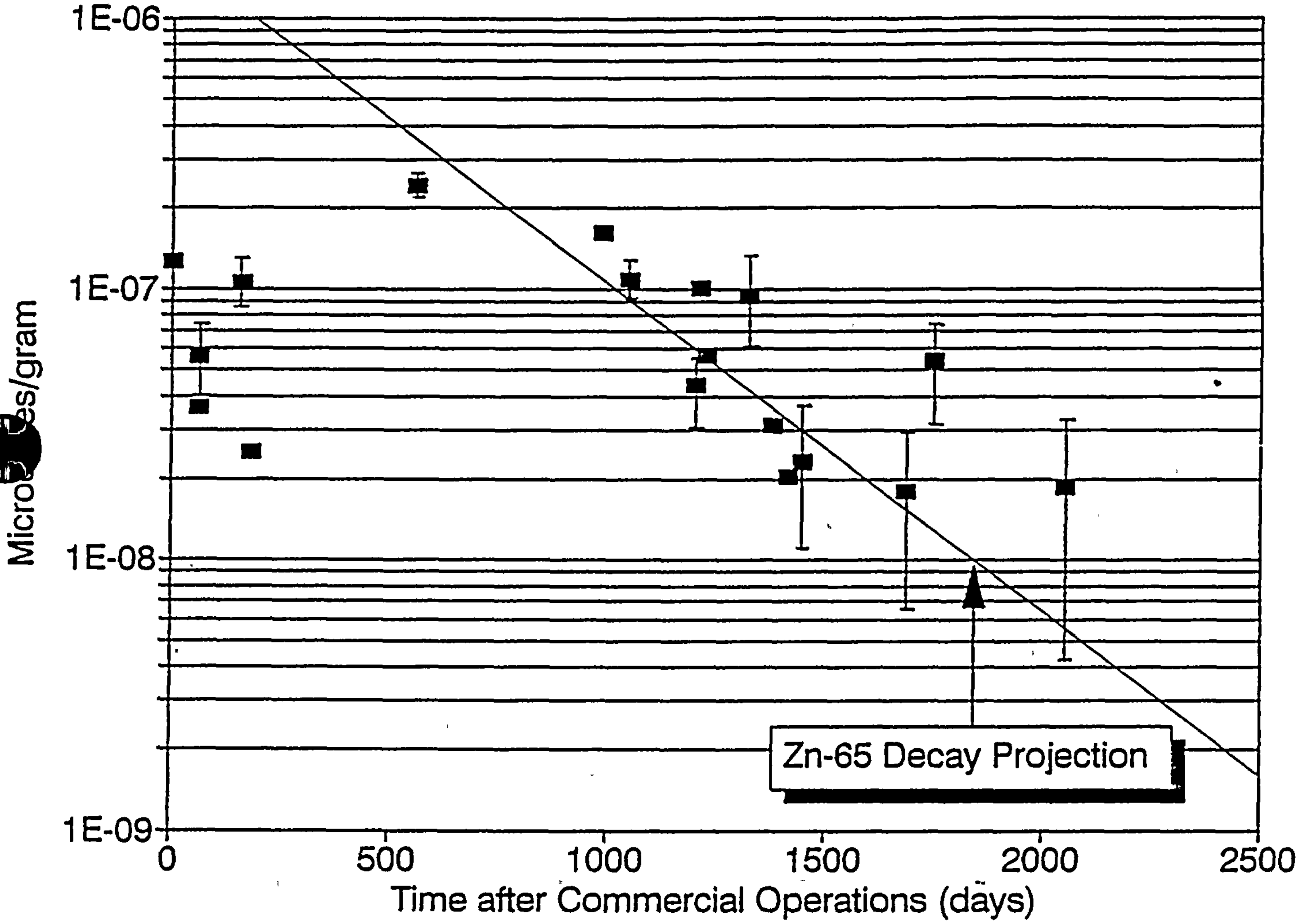
Consideration of these sample data provides evidence that the Columbia River sediments were a source of activation products during this period of time.

The Cooling Tower support systems were examined to identify sample points from which sediment samples could be drawn to substantiate the Columbia River water as the source of the activity. The sample line from the TMU intake was identified as the only point not influenced by additions of flocculent or gaseous effluent entrainment effects.

External influences on the appearance of Zn-65 seem evident (see figure 1). A notable

FIGURE 1

MEASUREMENTS OF ZN-65 IN COOLING TOWER SEDIMENTS WITH THE PROJECTED DECAY OF ZN-65 SUPERIMPOSED



trend evidenced by this data is the steady decline of the concentration of Zn-65 from the fourth quarter of 1988 to the end of 1989. Zn-65 was not identified in samples taken from July 1986 through July 1987. Sporadic appearances of Zn-65 were noted through mid-1991 but not to the previously recorded levels. Although a decline in the Zn-65 with the characteristic half life would be anticipated from a single contaminating event originating from the plant, this behavior would not be manifest since the Cooling Towers are cleaned at least twice a year. If an assumption is made that the source of Zn-65 was an external (upstream river borne) source, the samples of Cooling Tower sediment would exhibit the observed behavior independent of the Cooling Tower clean-out schedule. A step increase in the level of Zn-65 appears to have occurred in Cooling Tower samples collected after July of 1987. The concentrations in these samples appear to follow the 245 day half life of Zn-65 (see Figure 1). Increases in the level of Zn-65 over the projected decay line correspond to both the first cold weather (November and October samples) and the hottest months (August and July samples). The evaporative effect of the Cooling Towers could be concentrating soluble Zn-65 in the sediments.

A possibility that can lead to elevated levels of Zn-65 during both the hot months and the first freeze is that bioaccumulation of Zn-65 in the green algae growing in the Cooling Towers is occurring. This phenomenon is documented to occur with a bioaccumulation factor of 1.4E+05 (ref. 9, Table 5.41). Death of the algae stringers with the first cold weather may release accumulated Zn-65 to the Cooling Tower sediments. The highest biomass of algae occurs during the summer months coinciding with peak Zn-65 measurements.

An upstream source of Zinc-65 is known to exist from past "N" reactor discharges to the ground. Although the Hanford Reservation reports characterize the Zn-65 discharges as non-transportable through the soil, the reported releases identify an upstream source of Zn-65 production (See Attachment I).

3.0 Chernobyl Accident Fingerprint on Cooling Tower Sediments

Beginning in June of 1986 measurable quantities of fission products (cesium-134, ruthenium-103, and rhodium-106) appeared in the Cooling Tower sediments. These additional radionuclides are the fingerprint of the Chernobyl accident. The appearance of the Chernobyl fingerprint in the sample database shortly after the 1986 accident is an indication of a water borne source of this activity. The majority of the residue from this accident appearing in the Cooling Tower sediments is more likely to have been drawn from the river than from the air. The collection medium for this activity is the surface of the entire Columbia River Basin. Rainwater runoff from this large collection area carries fallout deposited on soil surfaces into the river and then downstream. This activity exhibited a steady decline throughout 1987 and did not reappear in the samples after August of 1988.

Environmental monitoring samples of river sediments taken by the Supply System for the Radiological Environmental Monitoring Program (REMP) were drawn before the Chernobyl fallout arrived and would not have shown an increase in sediment activity.

4.0 STATISTICAL ANALYSIS OF COOLING TOWER AND RIVER SEDIMENT DATA

The persistent appearance of Cs-137 and Co-60 in Cooling Tower sediments at comparable concentrations to those exhibited in the Flocculent samples and Columbia River sediment samples point to the river as a potential source of these radionuclides.

The presence of the relatively long half lived radionuclides Cs-137 and Co-60 in the river and Cooling Tower sediments makes tracking and trending feasible over longer periods of time.

Statistical methods are applied to compare the Cooling Tower sediments with the river sediments in order to substantiate the theory that the river is the primary source of the radioactive material found in the Cooling Tower sediments.

4.1 Approach

Since only a few samples of river water from the TMU intake were analyzed, and there are no samples of suspended solids at this location (routine suspended solids sampling is not a component of any existing sample program), a statistical comparison of the results of Cooling Tower sediment samples and Columbia River sediment samples taken upstream of the plant was performed. Numerous samples of both of these sediment types have been taken and analyzed since the beginning of commercial operations at WNP-2. These sample results were segregated into two sample populations for the purpose of statistical testing. These two populations were comprised of all samples taken of the Cooling Tower sediments, and all samples taken of Columbia River Sediments upstream of WNP-2. The purpose of the testing was to establish whether there was a statistically significant difference in the radionuclide content of the two populations of samples.

Only Cs-137 and Co-60 occurred in both sample populations with sufficient frequency to provide a database large enough for reliable statistical comparison. Generally at least twenty samples and preferably at least thirty samples from each population being compared are necessary to ensure a reasonable degree of reliability in any such assessment. The testing methods and acceptance criteria are described in the body of this document and were primarily of two types, the t statistic test for unpaired summary data, and the Wilcoxon Rank Sum test for independent data sets.

4.2 General Statistical Testing Methods

The result of any given statistical test is known as the calculated value. The calculated value for any statistical test X is named X_{calc}. The criteria applied to determine whether any given statistical test passes or fails is generally known as the critical value. In the case of the our hypothetical X test, the critical value is named X_{crit}. The values of the critical values of any statistical test are based on the number of samples in the data set and the Level of Significance (α) that is selected by the tester. The level of significance or Confidence Interval determines the level of confidence (Confidence Level) we can have in the result of any test and as such sets the Confidence Limit for acceptance or rejection of the test results. Generally, the 95% Confidence Level is felt to be appropriate for environmental type population comparisons. The critical value is usually read from a table of values specifically prepared for the given test. When two data sets are being compared, the determining factors in selecting a critical value are the degrees of freedom (a fraction of the number of samples in a data set) and the selected level of confidence one wishes to have in the test result. When a test is conducted to determine if there is a significant (α) difference between two data sets, a "two tailed test" is used. In a two tailed test, one would use $\alpha/2$ to define the confidence limits on either side of the distribution. A null hypothesis (H_0) is then established as the basis of the test. For example, in the comparison of two populations (two tailed test), the null hypothesis is generally stated as, "There is no statistically significant difference between the means of the two populations ($x_1 = x_2$)". The test is then performed and X_{calc} is compared to the X_{crit} obtained from table "X". If the calculated value is less than the critical value we accept the null hypothesis as being substantiated by the test. If the calculated value of the test is greater than the critical value, then the null hypothesis must be rejected and an alternate hypothesis (H_A) must be accepted. The alternate hypothesis in this type of test can only be that the means of the two populations are significantly different ($x_1 \neq x_2$). The selected Confidence Level is the area of the bell shaped curve between the established Confidence Limits. For a 95% Confidence Level this area is 95% of the total area under the curve with 2.5% being located in each of the tails beyond the Confidence Limits. The test then is essentially a target with its edges defined as the confidence limits. Both the calculated and critical values of the test are expressed as multiples of the standard deviation. If the calculated value falls between the confidence limits (within the 95% area) the null hypothesis is accepted (test passes). It can now be clearly seen why a test at the 99% confidence level is less restrictive than a test at the 95% confidence level. The target is larger and the confidence limits defined allow the acceptance of a wider range of the calculated value. These general principles of statistical testing are applied for both the *t* statistic test and the Wilcoxon Rank Sum test.

4.3 Data Acceptance

The results of gamma isotopic analyses of samples of Cooling Tower sediments and Columbia River sediments from various sampling programs were reviewed from the start of commercial operations to present. These samples compose two distinct sample

populations (x_1 and x_2) which may be compared to determine if there is a difference in the concentrations of radionuclides found in the samples. Databases were prepared directly from the spectral analysis reports with all data containing less than 66% standard error included in the database. This criteria was selected as there has been found to be a stable relationship between the critical level (C_L) as defined by Currie, and the 66% standard error of counting (ref. 2 and ref.6). The referenced study shows that a fractional standard error (1 sigma counting error) of 66% is a reasonable approximation of the critical level for (non-systematic) low level counting measurements with gamma spectroscopy instrumentation. Those samples exhibiting greater than 66% error did not comprise a significant contribution to the data set (less than five data points over several radionuclides in the Cooling Tower sample population). None of these data points were in the Cs-137 or Co-60 population sets (see Table - A2).

4.4 Sample Conditioning

Prior to conducting the tests the data sets must be adjusted so as to be comparable. For example, most of the Cooling Tower sediment samples were analyzed in a liquid sample geometry having units of μCi/cc. Some other Cooling Tower samples were dried and analyzed in a soil geometry having units of μCi/gm. The various monitoring programs from which the river sediment samples were obtained also had dissimilar measurement units (pCi/kg, pCi/gm dry, and pCi/25 cc wet). Most but not all of the units were able to be converted to units of μCi/gm using known sample densities and standard conversions. If data discrepancies could not be resolved, a common basis for comparison could not be established and the data excluded from the analysis.

4.5 Sample Selection

Attempts were made to ensure that the selected data were representative of the populations being evaluated. In the case of duplicate samples, only one of the samples was included for the purpose of the analysis. The sample selected was that having the result with the least % error. Most of the samples selected were counted for at least 12 hours. Disparate analysis parameters caused a sample to be rejected. For example, any sample with questionable units or liquid samples analyzed on a soil geometry (or vice versa) were rejected.

Results of the Preliminary Sample Screening Process	
Reason for Rejection	# of Samples Rejected
System Abnormality	3
Insufficient Count Time	4
Inappropriate Geometry	13
Insufficient Sample Volume	2
Unidentifiable Units	4
Duplicate Counts	9

Qualitative selection parameters were also applied. The samples taken at Priest Rapids Dam upstream of the Hanford Reservation were accepted for their content of Cs-137 as the origin of this radionuclide is predominantly from fall-out from the atmospheric testing of nuclear devices. These same samples were rejected for their Co-60 content since the concentrations were below those found on the Hanford Reservation by an order of magnitude or more and were not felt to be representative of the population being evaluated. The Co-60 sample data above mile 6 (Vernita Bridge upstream of the Hanford reservation is the datum mile 0) were rejected as they were upstream of any known source of this radionuclide. All data taken below mile 35 were also rejected as they were subject to the influence of WNP-2 liquid effluent discharges. For the most part, all the sample data between these two points were retained as it was felt that the activity drawn by the TMU intake would reflect an average value of this large number of samples.

The few samples (< 5) taken by the State of Washington which were split and co-analyzed by the Supply System were able to be accepted without rejection except when the sample location was not clear or was not on the Hanford Reservation. In the case of split samples, the sample result with the least associated error was selected and the other sample was rejected as duplicate data. When the data were similar in counting error bounds an average value was used and the associated error was recalculated using the sum of the squares rule. It was assumed that systematic error in the detector systems was either minimal or convoluted into the existing error statement.

In addition to the routine REMP samples, a number of samples were taken in 1985 from White Bluffs and other upstream locations that were accepted. Most but not all of the data obtained from the REMP program showed results that were below detectable and therefore were generally not helpful. It should be remembered that the purpose of the REMP is to monitor the impact of plant operations on the surrounding environment and population. These measurements are more than adequate for this purpose and the

results are a testament to the very low levels of activity being monitored by the other programs.

Results of the Qualitative Sample Selection Process	
Population	# of Samples accepted
Cooling Tower (Liquid Geometry)	53
Cooling Tower (Soil Geometry)	18
River Sediment	67

4.6 Outlier Rejection

Once the sample populations had been screened for qualitative discrepancies that resulted in some data rejection, the populations were examined quantitatively to detect the presence of "outliers" Outliers are samples so incongruous with the rest of the population that the data points may be rejected as not being part of the sample population. For example, the river sediment population is known to contain samples taken in close proximity to shoreline "seeps" just downstream of N reactor and the old Hanford town site. Seeps are locations along the Columbia River that exhibit a spring like behavior at times of low river level (flow rate). The seeps represent points where the groundwater table (phreatic surface) intersects the river bed. Groundwater contaminated with radionuclides from old burial yards or reactor effluent discharges to the ground enters the river at these points. The concentrations of radionuclides in the soils around these seeps is usually at least an order of magnitude higher than the general river sediment samples. Leaving these samples in the population would bias the outcome of the analysis. If these samples are truly incongruous, they should be able to be detected by application of quantitative criteria. This quantitative sample population conditioning was performed using Chauvenet's criterion. As expected, when Chauvenet's Criterion was applied to the selected population of river sediment samples, some of the samples taken in the proximity of "N" reactor and the old Hanford townsite were rejected. These samples typically exhibited a concentration more than one order of magnitude above the mean value. Some samples taken below shoreline seeps were rejected, but many were retained since the rejection criterion was not met even though the samples exhibited elevated levels.

Number of Samples Rejected by Chauvenet's Criterion to Sample Populations		
Population	Cs-137	Co-60
Cooling Tower	8	11
River Sediment	2	5

Some of the data for the Cooling Tower data set did not meet the rejection criteria. In the case of Cs-137, the rejected samples were within the time frame of the Chernobyl accident and represent elevated levels of Cs-137 in the sediments. There does not appear to be any obvious reason that the Cooling Tower Samples should have been rejected by Chauvenet's Criterion except that the values were uncharacteristically high for the population.

4.7 Analysis of Variance (ANOVA)

After the data are conditioned and assembled, and after outlier rejection criteria are applied, the general population comparisons can be performed. The two populations were evaluated for various statistical test parameters with the following results:

Results of Statistical Parameter Determinations				
Population	Cooling Tower Sediments		River Sediments	
Radionuclide	Cs-137	Co-60	Cs-137	Co-60
Sample Size	n_1 = 63	n_1 = 57	n_2 = 65	n_2 = 36
Mean	2.36 E-07	1.39 E-07	2.03 E-07	9.58 E-08
Variance	2.04 E-14	7.96 E-15	2.37 E-14	9.37 E-15
Std. Dev.	1.43 E-07	8.92 E-08	1.54 E-07	9.68 E-08
Median	2.01 E-07	1.15 E-07	1.51 E-07	6.70 E-08

The first test that must be performed is test for homogeneous variance in the data sets being compared. This testing technique is generally known as ANalysis Of VAriance (ANOVA) or the "F test". This is important because different testing methods are applied to data sets with non-homogeneous variance and some tests are not even valid if the data sets exhibit non-homogeneous variance (e.g. Wilcoxon's Rank Sum test).

In the case of ANOVA or the "F test", the calculated value is named F_{calc} and the critical value is named F_{crit}. The null hypothesis (H_0) is selected as "the variance of these two

populations are homogeneous". When the variance (σ^2) of the two populations are compared and the calculated value is less than the critical value, the data are substantiated as being of homogeneous variance.

The population homogeneity test (ANOVA) is conducted as follows:

$$F_{(n-1),(n-1)} = \text{Large } \sigma^2/\text{Small } \sigma^2 = F_{calc}$$

Results of the F test for Homogeneous Data Sets				
Radionuclide	F_{calc}	F_{crit} @ 5% Level of Significance	F_{crit} @ 1% Level of Significance	**Result**
Cs-137	1.16	1.53	1.84	H_0 Accepted
Co-60	1.17	1.59	1.94	H_0 Accepted

Both populations have homogeneous variance at both levels of significance; therefore, both the *t* statistic test for unpaired summary data with homogeneous variance and the Wilcoxon Rank Sum test for independent sample populations with homogeneous variance are appropriate for the evaluation of these populations.

4.8 The *t* Statistic Test

The purpose of the *t* statistic test is to determine if the difference in the mean concentrations from the two sample populations is statistically significant. The test is performed for both radionuclides independently.

$$t_{calc} = t_{(N-2)} = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{(n_1-1)\sigma_1^2 + (n_2-1)\sigma_2^2}{(n_1+n_2-2)}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

Where:

$\overline{x_1}$ = the mean value of the Cooling Tower samples
$\overline{x_2}$ = the mean value of the River Sediment samples
σ_1^2 = the variance of the Cooling Tower samples
σ_2^2 = the variance of the River Sediment samples
n_1 = the number of data points in the Cooling Tower population
n_2 = the number of data points in the River Sediment population

Results of the t Statistic Test				
Radionuclide	t_{calc}	t_{crit} @ 95% Confidence Level	t_{crit} @ 99% Confidence Level	Result H_0 Accepted
Cs-137	1.21	1.96	2.58	Both 95% & 99%
Co-60	2.21	1.96	2.58	@ 99% Only

The results of the t statistic test are that there is no statistically significant difference between the means of the Cooling Tower and river sediment sample populations at either the 99% confidence level or the 95% confidence level for Cs-137 data. There was found to be a statistically significant difference between the mean of the Cooling Tower sediment sample population and the river sediment sample population at the 95% confidence level for Co-60 data. This difference was not found to be statistically significant at the 99% confidence level. The mean Co-60 data for the Cooling Tower sediment sample population appears to be slightly larger than the mean of the river sediment sample population.

Because this result for Co-60 may have been influenced by the removal of data by any of the criteria listed above, another t-statistic test was performed using all of the raw (uncorrected) data for both populations. This procedure is acceptable because the Chernobyl accident did not transport globally significant quantities of Co-60, and there is not a significant concentrating effect in the Cooling Towers for insoluble Co-60 species. The reinstatement of the sample results from the shoreline seeps in the river sediment population at concentrations in excess of 1E-6 μCi/gm more than offset the influence of the Cooling Tower data points deleted by Chauvenet's Criterion at concentrations near 5E-7.

The F-test was performed for the total Co-60 uncorrected data set. The number of data points considered in the Cooling Tower data set was 83 and the number of data points in the river sediment data set was 81 with all non-detectable results included. F_{crit} for this number of data points was 1.7 for the 1% level of significance, and 1.4 for the 5% level of significance. The value of F_{calc} for these data sets was 4.64. The result of this test indicated that the two populations have non-homogeneous variance.

The t-statistic test for unpaired summary data with non-homogeneous variance was then applied to determine if there is a statistically significant difference between the means of the data sets at both the 99% and the 95% confidence level. The parameters for the raw Co-60 data set are listed on the table below.

Results of Statistical Parameter Determinations for the Raw Co-60 Data		
Radionuclide	Cooling Tower	River Sediment
Sample Size	n_1 = 83	n_2 = 81
Mean	1.23 E-07	1.2 E-07
Variance	2.24 E-14	1.04 E-13
Std. Dev.	1.5 E-07	3.22 E-07
Median	7.77 E-8	6.98 E-9

The results of the *t*-statistic test for non-homogeneous unpaired summary data performed for the Co-60 raw data are shown on the table below:

Results of the *t* Statistic Two-tailed Test				
t_{crit} Degrees of Freedom	t_{calc}	t_{crit} @ 95% Confidence Level	t_{crit} @ 99% Confidence Level	Result H_0 Accepted
$(n_1 - 1) = 82$	0.08	1.96	2.58	Pass
$(n_2 - 1) = 80$	0.08	1.96	2.58	Pass

Since t_{calc} is less than both values of t_{crit} at both the 99% and 95% confidence levels, then H_0 is accepted. There is no statistically significant difference between the means of the two populations of samples.

4.9 Wilcoxon Rank Sum Test

The purpose of the Wilcoxon Rank Sum Test is the same as the *t* statistic test. The data sets are combined and sorted in ascending numerical order. Each data point is then assigned a rank as its position in the database. When two data points have the same value, they are tied and assigned the average rank value. The sum of the ranks of the smallest of the two populations ($\sum n_1$) is used as the basis for the test.

The Wilcoxon Rank Sum test is then performed for both radionuclides independently.

$$Z_{calc} = Z_{TS} = \frac{W_{TE} - n_1(m + 1)/2}{\sqrt{\frac{n_1 n_2}{12}[(m + 1) - \frac{\sum_{j=1}^{g} t_j(t_j^2 - 1)}{m(m - 1)}]}}$$

Where:

g = the number of tied groups
t_j = the number of tied data in the j[th] group
W_{TE} = $\sum$ of the ranks in the n_1 sample population
n_1 = the number of data points in the smaller population
n_2 = the number of data points in the larger population
m = the sum of n_1 and n_2

The null hypothesis (H_0) is set as "there is not a statistically significant difference in the two populations". If $Z_{calc} \geq -Z_{crit}$ or $\leq Z_{crit}$, then H_0 is accepted. The alternative hypothesis (H_A) is adopted when Z_{calc} falls outside the defined confidence limits. The alternative hypothesis can only be that "there is a statistically significant difference in the two sample populations".

The following statistical parameters were determined for the two populations for each radionuclide.

Radionuclide	Cs-137	Co-60
n_1	63	36
n_2	65	57
m	128	93
W_{TE}	4332	1336

Results of the Wilcoxon Rank Sum Test				
Radionuclide	Z_{calc}	Z_{crit} @ 95% Confidence Level	Z_{crit} @ 99% Confidence Level	Result H_0 Accepted
Cs-137	1.28	1.96	2.58	Both 95% & 99%
Co-60	-2.81	1.96	2.58	No H_A adopted

The results of the Wilcoxon Rank Sum test are that there is no statistically significant difference between the means of the Cooling Tower and river sediment sample populations at either the 99% confidence level or the 95% confidence level for Cs-137 data. There was found to be a statistically significant difference between the mean of the Cooling Tower sludge sample population and the river sediment sample population at both the 95% and the 99% confidence levels for Co-60 data.

The Wilcoxon Rank Sum test is supposedly less sensitive to the presence of outliers and Not Detected results. Not detected results are included as tied values.

The Wilcoxon Rank Sum test can not be performed on populations with non-homogeneous variances so the confirmatory test using raw Co-60 data could not be performed in this case. Since the Wilcoxon Rank Sum Test utilized the same data set as the *t*-statistic test for homogeneous data it is reasonable to expect the same result. Since there is the possibility that deletion of the higher concentration Co-60 data by Chauvenet's criterion may have influenced the result of this test as well, we conclude that the case presented by the result of raw data comparison using the *t*-test for unpaired summary data and non-homogeneous variance overrides the borderline result of this test.

4.10 Multiple Linear Regression

While there appear to be many variables that effect the appearance of Zn-65 in the Cooling Tower sludges the number of positive sample results in the accepted population (18) is too small to perform any meaningful correlation analyses. Even simple linear regression correlations are difficult due to the many variables involved. Although many comparisons were attempted, none resulted in the display of any meaningful pattern of behavior that was clearly amenable to correlation techniques. Such a task might be accomplished with a much larger database and if any of the variables could be characterized in common units of expression. It does seem apparent from informal qualitative observations that some of the variables are important from a source resolution standpoint. These observations are included in the discussion section of this document.

5.0 DISCUSSION

5.1 Statistical Parameters

The frequency distributions of both data sets are asymmetrical (see Figures 2 and 3). Any shift of the peak frequency to one side or the other of the range of the data is considered to represent non-normal (non-symmetrical) conditions. A normal distribution pattern is represented by the classical bell shaped curve (symmetrical). A test for data normalcy is to plot the concentration values against cumulative frequency using a linear-probability plot. Normally distributed data would have the appearance of a straight line. When the data were plotted in this manner a straight line was not observed.

The non-normal character of these particular data sets might be attributed to log-normal frequency distributions exhibited by these sample populations. This can be tested by plotting the data on log-probability paper. A straight line plot indicates a log-normal distribution. When the data were plotted on log-probability scales straight lines were not observed. The indication is that these data are neither normally distributed or log-normally distributed. The confidence limits of the *t* statistic test are slightly altered by the presence of non-normal data distributions but the extent of these changes can be determined. The error in the use of Normal distribution assumptions on asymmetrical data sets does not exceed 10% (ref. 4).

When measurements are made at levels very close to the lower limit of detection of the counting systems, it is inevitable that many of the results will be reported as being below the lower limit of detection of the instrument. In this case, the lower tail of an otherwise normal distribution (bell shaped) will be clipped. This circumstance results in what are known as censored data sets. Only the Co-60 data set from the river population had a significant number of "not detected" results. The majority of the sample populations are free of from censorship. When the raw Co-60 data (including non-detectable results) were analyzed by the *t*-statistic test for unpaired summary data with non-homogeneous variance, the result indicated that there was no statistically significant difference between the means of the two sample populations.

5.2 Unknown Factors Which may Influence Testing Results

The concentrating effect of the Cooling Tower could not be estimated with the data available due to the absence of Tower throughput data. Examination of the sample populations does not provide any indication that there is a significant tower concentration effect for Cs-137 and Co-60. This is believable if activity is only introduced to the tower adsorbed onto sediment. A concentrating effect would be more likely if radionuclides were drawn into the towers in as a soluble chemical species.

Another effect of unknown magnitude is the difference in partition coefficients for radionuclides between the suspended solids in the river and the river sediment. The

swiftness of flow in the Columbia River at the TMU intake suspends all but the largest of particles. It is a physical principle that smaller particles have a larger surface area for adsorption gram for gram than do larger particles. This suggests that there may be slight differences in the quantity of radioactive material adsorbed onto suspended solids than is found in the river sediment. A slight elevation in the activity per gram of suspended solids over that of normal river sediment is predicted based on the inclusion of smaller particles in this material that would not be large enough to settle out in the river. The very small mass of this excess small diameter material would predict only a slight increase even though the difference in partition could be quite large. A monitoring program based on paired samples of suspended solids from the TMU intake and Cooling tower sediments may be more appropriate to characterize the amount of river borne radioactivity being introduced to on-site water systems.

6.0 CONCLUSIONS

The result of this evaluation indicates that the activity in the Cooling Tower sediments is not of plant origin but is being brought onsite from the suspended solids content of the Columbia River.

7.0 RECOMMENDATIONS

If it is desirable to monitor the introduction of riverborne radionuclides into the plant Cooling Towers, a program based on the sampling of suspended solids at the TMU intake is recommended.

FIGURE 2

FREQUENCY DISTRIBUTIONS OF THE CESIUM-137 CONTENT OF RIVER SEDIMENT vs. COOLING TOWER SEDIMENT

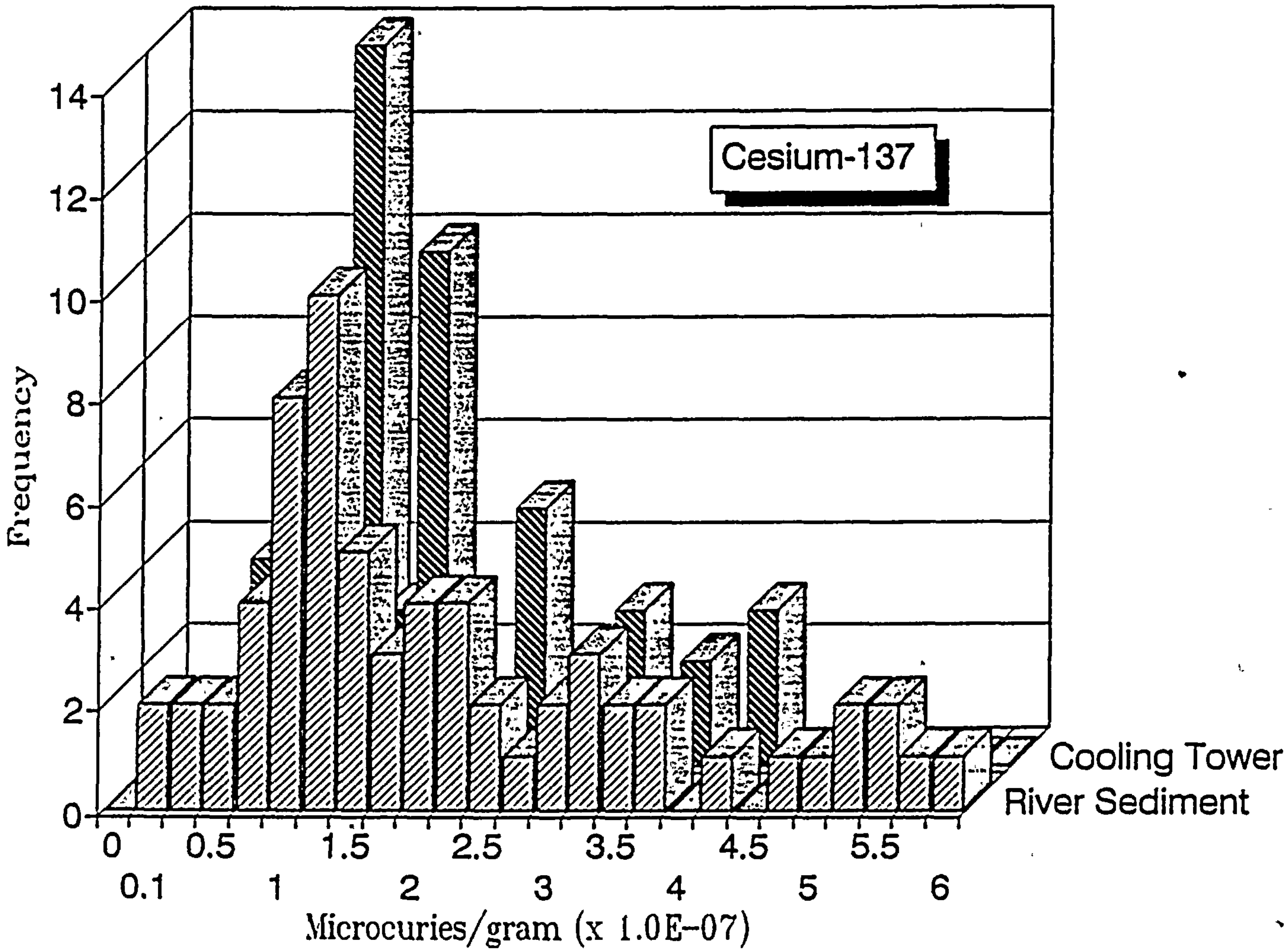
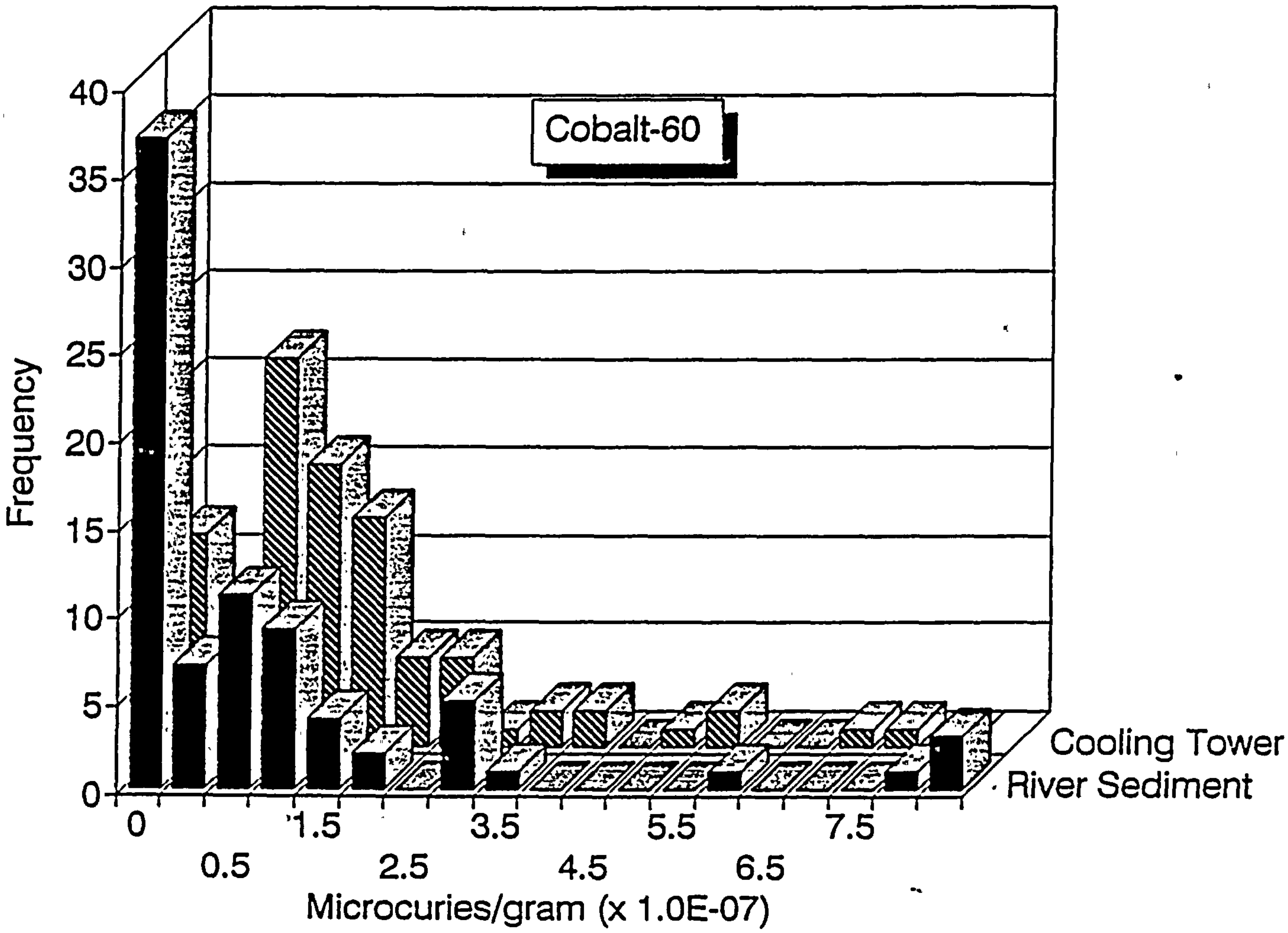


FIGURE 3

FREQUENCY DISTRIBUTIONS OF THE COBALT-60 CONTENT OF RIVER SEDIMENT vs. COOLING TOWER SEDIMENT



8.0 REFERENCES

1. Buske, Norm and Josephson, Linda, Water and Sediment Reconnaissance of the Hanford Shoreline, Hanford Reach Project, Data Report 4, ISBN 0-032975-03-8, Spring 1989.

2. Currie, L. A., Lower Limit of Detection: Definition and Elaboration of a proposed Position for Radiological Effluent and Environmental Measurements, NUREG/CR 4007, (September 1984)

3. Davis, A.I., "Tower Sludge Contamination Pathways from the Plant", Washington Public Power Supply System Interoffice Memorandum to D. J. Pisarcik (9 November, 1989)

4. Gilbert, Richard O. and Kinnison, Robert R., "Statistical Methods for Estimating the Mean and Variance from Radionuclide Data Sets Containing Negative, Unreported or Less-than Values", Health Physics Vol. 40 (1981), pp 377-390.

5. Hornung, Richard W. and Reed, Laurence D., "Estimation of Average Concentration in the Presence of Nondetectable Values", Applied Occupational and Environmental Hygiene, Vol. 5 No. 1, (January 1990), pp 46-51

6. Moon, J. W., Bland, J. S., "Peak Rejection Criteria Based on Counting Error for Low Level Gamma Spectroscopy Measurements", Internal Report, J. Stewart Bland Associates, Inc. (September 1992)

7. Oresegun, Modupe O., Decker, Karin M. and Sanderson, Colin G., "Determination of Self-Absorption Corrections by Computation in Routine Gamma-Ray Spectrometry for Typical Environmental Samples", Radioactivity and Radiochemistry, Vol. 4 No. 1, 1993, pp 38-45

8. Snedacor, G. W. and Cochran, W. G., Statistical Methods, 8th Edition, Iowa State University Press, 1989.

9. Till, J. E. and Meyer, H. R., Radiological Assessment, NUREG/CR 3332 (September 1983), Table 5.41

10. Washington Public Power Supply System, WNP-2 Environmental Report (ER), Pre-operational Evaluation of Site Environmental Characteristics and Parameters, Amendment 2 October, 1978.

11. Woodruff, R.K., et al, Hanford Site Environmental Reports 1985 - 1991, Battelle, Pacific Northwest Laboratories, NTIS, U.S. Department of Commerce, Springfield, VA.

9.0 ATTACHMENT I

3.0 LIQUID RELEASES TO THE ENVIRONMENT FROM THE 100 AREAS

3.1 Radioactive Liquid Releases From 100-N Area

3.1.1 Activity Discharged to the LWDFs and via Seepage to the Columbia River

Radionuclide	To the 1301-N and 1325-N LWDFs			Seepage to river via N-Springs		
	Release, Ci	Avg. Conc., pCi/L	Peak Conc., pCi/L	Release, Ci	Avg. Conc., pCi/L	Peak Conc., pCi/L
H-3	2.7E2	7.4E4	3.9E5	2.7E2 +	5.6E4	3.0E5
P-32	2.2E1	5.9E3	3.2E4	1.1E-2	5.9E0	5.9E1
Cr-51	7.5E1	2.0E4	8.5E4	1.3E-1	7.0E1	1.7E2
Mn-54	7.1E2	1.9E5	7.2E5	•		
Co-58	2.8E1	7.6E3	2.3E4	•		
Fe-59	2.6E2	7.1E4	2.2E5	•		
Co-60	5.9E2	1.6E5	6.8E5	3.0E-1	1.6E2	2.7E2
Zn-65	1.5E1	4.0E3	6.0E3	•		
Sr-89	3.9E2	1.1E5	8.3E5	1.3E0	7.2E2	6.0E3
Sr-90	2.4E2	6.5E4	6.5E5	8.4E0	4.5E3	6.1E3
ZrNb-95	3.2E2	8.7E4	2.9E5	•		
MoTc-99m	7.8E2	2.1E5	1.7E5	1.6E-1	8.6E1	4.4E2
Ru-103	5.4E1	1.5E4	7.1E4	3.7E-1	2.0E2	4.3E2
Ru-106	8.0E1	2.2E4	7.0E4	3.0E-1	1.6E2	2.5E2
Sb-124	6.1E0	1.7E3	4.3E3	1.5E-2	8.1E0	1.3E1
Sb-125	1.2E1	3.4E3	6.7E3	3.3E-1	1.8E2	2.4E2
I-131	3.7E2	1.0E5	4.6E5	5.4E0	2.9E3	1.1E4
Xe-133	2.9E2	8.0E4	2.7E5	1.9E0	1.0E3	2.9E3
Cs-134	5.7E0	1.6E3	4.3E3	•		
Cs-137	8.8E1	2.4E4	2.1E5	1.9E-2	1.0E1	1.7E2
BaLa-140	4.1E3	1.1E6	4.4E6	•		
Ce-141	7.4E1	2.0E4	8.0E4	•		
CePr-144	2.8E2	7.6E4	7.2E5	•		
Sm-153	7.2E1	2.0E4	7.7E4	•		
Pu-238	5.0E-1	1.4E2	9.7E2	3.8E-6	2.0E-3	1.2E-2
Pu 239/240	3.4E0	9.4E2	6.5E3	1.7E-5	9.1E-3	5.5E-1
Np-239	3.2E2	8.7E4	6.6E5	•		
SLR	2.6E4	7.1E6	4.3E7	••		

SLR = Short-lived radionuclides ($T_{1/2}$ <48 hours)

* Indicates radionuclides in particulate form or with a high ionic exchange potential which are trapped within the LWDFs' soil columns, and removed beyond detection limits.

** Indicates short half-life radionuclides which have decayed beyond detection limits before reaching in the riverbank springs.

\+ This is the same value as for tritium to the LWDFs, since all tritium released to the LWDFs is assumed to eventually, though not necessarily in one year's time, reach the Columbia River via the N-Springs. Average and peak concentrations represent the analyses of CY 1985 N-Springs seepage.

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10.0 APPENDIX A

List of Tables:

Table A1 Cooling Tower Sludge Samples 1985 through 1993

Date	Sample #	Quantity	Geometry	Comment	Selection	Time
14-Jun-85	85-06-25	971 cc	L0012	0.5 hrs	No time	17
01-Aug-85	85-08-02	1380 cc	L0012	12 hrs	Y Liq	65
22-Aug-85	85-08-34	234 cc	L0012	0.5 hrs	No duplicate	86
22-Aug-85	85-08-34	234 cc	L0012	4 hrs	No duplicate	86
22-Aug-85	85-08-34	234 cc	L0012	12 hrs	No Vol/geom	86
28-Aug-85	85-08-35	1086 cc	L0012	12 hrs	Y Liq	92
28-Aug-85	85-08-36	1536 cc	L0012	0.5 hrs	No duplicate	92
28-Aug-85	85-08-36	1536 cc	L0012	12 hrs	Y Liq	92
28-Aug-85	85-08-37	1279 cc	L0012	0.5 hrs	No time	92
29-Aug-85	85-08-41	1408 cc	L0012	12 hrs	Y Liq	93
30-Aug-85	85-08-49	1403 cc	L0012	0.5 hrs	No duplicate	94
30-Aug-85	85-08-49	1403 cc	L0012	12 hrs	Y Liq	94
04-Sep-85	85-09-03	560 gm	L0014	2 hrs	No units	99
04-Sep-85	85-09-03	560 cc	L0014	12 hrs	No units	99
05-Sep-85	85-09-02	1263 cc	L0012	0.5 hrs	No duplicate	100
05-Sep-85	85-09-02	1263 cc	L0012	12 hrs	Y Liq	100
20-Sep-85	85-09-31	1119 cc	L0012	12 hrs	Y Liq	115
03-Oct-85	85-10-04	1030 cc	L0012	0.5 hrs	No duplicate	128
03-Oct-85	85-10-04	1030 cc	L0012	12 hrs 2B	Y Liq	128
16-Oct-85	85-10-24	1200 gm	L0012	12 hrs 2A	No Special	141
17-Oct-85	85-10-31	1220 gm	L0012	12 hrs 2B	No Special	142
18-Oct-85	85-10-32	1141 gm	L0012	12 hrs 1A	No Special	143
18-Oct-85	85-10-33	1040 gm	L0012	12 hrs 1C	No Special	143
18-Oct-85	85-10-34	1250 gm	L0012	12 hrs 1B	No Special	143
18-Oct-85	85-10-35	1060 cc	L0012	12 hrs 2C	No Special	143
01-Nov-85	85-11-03	500 cc	Shelf 0 (PGT2)	12 hrs	No Geometry	157
18-Dec-85	85-9356	500 cc	Shelf 0 (PGT2)	12 hrs 2B	Y Liq	204
18-Dec-85	85-9356	500 cc	Shelf 0 (PGT2)	12 hrs	No Duplicate	204
16-Jan-86	86-01-16	500 cc	L0014	12 hrs	Y Liq	233
16-Jan-86	86-01-17	500 cc	L0014	12 hrs	Y Liq	233
14-Feb-86	86-02-03	500 cc	L0014	12 hrs	No Duplicate	262
14-Feb-86	86-02-03	500 cc	L0014	12 hrs	Y Liq	262
20-Mar-86	86-03-12	500 cc	L0014	12 hrs	Y Liq	296
20-Mar-86	86-03-13	500 cc	L0014	12 hrs	Y Liq	296
27-Jun-86	86-06-25	500 cc (700 gm)	L0014	12 hrs	Y Liq	395
27-Jun-86	86-06-26	500 cc (700 gm)	L0014	12 hrs	Y Liq	395
18-Jul-86	86-07-14	630 gm (500 cc)	L0014	12 hrs	Y Liq (c)	416
18-Jul-86	86-07-15	620 gm (500 cc)	L0014	12 hrs	Y Liq (c)	416

Table A1 Cooling Tower Sludge Samples 1985 through 1993

Date	Sample #	Quantity	Geometry	Comment	Selection	Time
15-Aug-86	86-08-02	690 gm (500 cc)	L0014	12 hrs	Y Liq (c)	444
26-Sep-86	86-09-16	545 gm (500 cc)	L0014	12 hrs	Y Liq (c)	486
19-Nov-86	86-11-19	500 cc	L0014	12 hrs	Y Liq	540
30-Dec-86	86-12-18	570 gm (500 cc)	L0014	12 hrs	Y Liq (c)	581
27-Jan-87	87-01-15	500 cc	L0014	12 hrs	Y Liq	609
03-Mar-87	87-03-01	480 cc	L0014	12 hrs	Y Liq	644
03-Apr-87	87-04-02	500 cc	L0014	12 hrs	Y Liq	675
31-Jul-87	87-07-25	592 cc	L0014	12 hrs	Y Liq	794
01-Sep-87	87-09-01	500 cc	L0014	12 hrs	Y Liq	826
26-Aug-88	88-08-35	500 cc	L0014	12 hrs	Y Liq	1186
29-Sep-88	88-09-46	783 gm (dry)	S0012	12 hrs	Y Soil	1220
29-Sep-88	88-09-47	734 gm (dry)	S0012	12 hrs	Y Soil	1220
29-Sep-88	88-09-48	707 gm (dry)	S0012	12 hrs	Y Soil	1220
29-Sep-88	88-09-49	709 gm (dry)	S0012	12 hrs	Y Soil	1220
29-Sep-88	88-09-50	774 gm (dry)	S0012	12 hrs	Y Soil	1220
29-Sep-88	88-09-51	762 gm (dry)	S0012	12 hrs	Y Soil	1220
30-Sep-88	88-09-52	450 cc	L0014	12 hrs	Y Liq	1221
04-Nov-88	88-11-06	250 ml	L0307	12 hrs	No Vol/Geom	1256
29-Nov-88	88-11-40	450 cc	L0014	12 hrs	Y Liq	1281
04-Jan-89	89-01-03	450 cc	L0014	12 hrs	Y Liq	1317
30-Mar-89	89-03-30	450 cc	S0012	12 hrs	N Units/geom	1402
30-Apr-89	89-05-02	450 cc	L0014	12 hrs	Y Liq	1433
10-May-89	89-05-09	881 gm (dry)	S0012	12 hrs	Y Soil	1443
10-May-89	89-05-10	879 gm (dry)	S0012	12 hrs	Y Soil	1443
10-May-89	89-05-11	945 gm (dry)	S0012	12 hrs	Y Soil	1443
03-May-89	89-05-15	139 gm (dry)	L0014	12 hrs	No Vol/Geom	1436
24-May-89	89-05-25	234 gm (dry)	S0012	12 hrs	Y Soil	1457
24-May-89	89-05-26	223 gm (dry)	S0012	12 hrs	Y Soil	1457
10-Jul-89	89-07-03	450 cc	S0014	12 hrs	N Units/Geom	1504
28-Jul-89	89-07-12	450 cc	S0014	12 hrs	N Units/geom	1522
30-Aug-89	89-08-33	450 cc	L0014	12 hrs	Y Liq	1555
27-Oct-89	89-10-25	518 gm	S0014	12 hrs	Y Soil	1613
01-Dec-89	89-12-01	450 ml	L0014	24 hrs	Y (count Time)	1648
02-Jan-90	90-01-01	450 ml	L0014	12 hrs	Y Liq	1680
02-Feb-90	90-02-04	450 ml	L0014	24 hrs	Y (count time)	1711
02-Mar-90	90-03-01	450 ml	NL0014	12 hrs	No NaI Det	1739
22-Jun-90	90-06-11	247 gm (dry)	S0014	12 hrs	Y Soil	1851
01-Aug-90	90-08-01	450 ?	S0014	24 hrs	No Units?	1891

Table A1 Cooling Tower Sludge Samples 1985 through 1993

Date	Sample #	Quantity	Geometry	Comment	Selection	Time
29-Aug-90	90-08-28	450 ml	L0014	24 hrs	Y Liq	1919
29-Aug-90	90-09-01	450 ml	L0014	12 hrs	No Possible Dup	1919
28-Sep-90	90-09-17	450 ml	S0014	12 hrs	No units	1949
30-Oct-90	90-10-19	450 ml	L0014	12 hrs	Y Liq	1981
03-Dec-90	90-12-01	450 ml	L0014	12 hrs	Y Liq	2015
15-Jan-91	91-01-05	450 ml	L0014	12 hrs	Y Liq	2058
29-Jan-91	91-01-11	450 ml	L0014	12 hrs	Y Liq	2072
01-Mar-91	91-03-01	450 ml	L0014	12 hrs	Y Liq	2103
02-Apr-91	91-04-01	450 ml	S0014	12 hrs	No Units/Geom	2135
22-Apr-91	91-04-12	450 ml	L0014	12 hrs	Y Liq	2155
28-Aug-91	91-08-10	450 ml	L0014	12 hrs	Y Liq	2283
03-Oct-91	91-10-02	450 ml	S0014	12 hrs	No Units/Geom	2319
29-Oct-91	91-10-08	450 ml	L0014	12 hrs	Y Liq	2345
03-Jan-92	92-01-02	450 ml	L0014	12 hrs	Y Liq	2411
04-Feb-92	92-02-01	450 ml	L0014	12 hrs	Y Liq	2443
28-Feb-92	92-03-13	450 ml	L0014	12 hrs	Y Liq	2467
07-Apr-92	92-04-02	450 ml	L0014	12 hrs	Y Liq	2506
02-Oct-92	92-10-08	500 ml	L0014	12 hrs	Y Liq	2684
30-Oct-92	92-10-22	450 ml	L0014	12 hrs	Y Liq	2712
30-Nov-92	92-12-01	450 ml	L0014	12 hrs	Y Liq	2743
28-Dec-92	92-12-13	450 ml	L0014	12 hrs	Y Liq	2771
28-Dec-92	93-01-03	450 ml	L0014	12 hrs	Y Liq	2771
28-Dec-92	93-01-03	450 ml	L0014 BS Enabled	12 hrs	No Bkg Subtract	2771
28-Dec-92	93-01-04	450 ml	L0014	3 hrs	No Count Time	2771
28-Dec-92	93-01-04	450 ml	L0014 BS Enabled	3 hrs	No Bkg Subtract	2771
29-Dec-92	93-01-02	450 ml	L0014	1 hr	No Count Time	2772
28-Jan-93	93-01-36	450 ml	L0014	12 hrs	Y Liq	2802
16-Mar-93	93-03-27	510 gm	S0014	4 hrs	Y Soil	2849
16-Mar-93	93-03-26	456 gm	S0014	4 hrs	Y Soil	2849
16-Mar-93	93-03-25	460 gm	S0014	4 hrs	Y Soil	2849
16-Mar-93	93-03-24	490 gm	S0014	4 hrs	Y Soil	2849
16-Mar-93	93-03-29	537 gm	S0014	4 hrs	Y Soil	2849

Table - A2 Cooling Tower Sample Results All Data

Date	Sample #	Cs-137	Cs%Err	Co-60	Co%Err	Mn-54	Mn%Err	Zn-65	Zn%Err	Co-58	Co%Err	Cs-134	Cs%Err	Ru-103	Ru%Err	Rh-106	Rh%Err
14-Jun-85	85-06-25	5.6E-07	8.98	1.3E-07	4.35	2.6E-08	13.23		-								
01-Aug-85	85-08-02	3.7E-07	1.86														
22-Aug-85	85-08-34	ND	-														
22-Aug-85	85-08-34	2.6E-07	13.39														
22-Aug-85	85-08-34	1.9E-07	10.84														
28-Aug-85	85-08-35	7.3E-08	6.88	8.0E-08	6.09	1.5E-08	22.14		-								
28-Aug-85	85-08-36	3.7E-07	9.14														
28-Aug-85	85-08-36	3.5E-07	1.8	1.1E-07	5.33	2.9E-08	10.39		-								
28-Aug-85	85-08-37	1.2E-07	20.26														
29-Aug-85	85-08-41	1.2E-07	3.74	6.8E-08	6.65	1.3E-08	21.94		-								
30-Aug-85	85-08-49	2.3E-07	12.38														
30-Aug-85	85-08-49	2.5E-07	2.38	1.1E-07	5.42	2.2E-08	16.48		-								
04-Sep-85	85-09-03	6.1E-08	17.85														
04-Sep-85	85-09-03	1.9E-08	22.9														
05-Sep-85	85-09-02	2.2E-07	13.65														
05-Sep-85	85-09-02	2.4E-07	2.42	9.6E-08	5.37	2.0E-08	18.51		-								
20-Sep-85	85-09-31	1.5E-07	4.31	8.7E-08	6.86	1.3E-08	23.62		-								
03-Oct-85	85-10-04	1.2E-07	29.42														
03-Oct-85	85-10-04	1.2E-07	5.23	9.8E-08	7.5		-		-								
16-Oct-85	85-10-24	1.4E-07	4.32	1.2E-07	5.05	3.1E-08	12.29										
17-Oct-85	85-10-31	1.5E-07	3.48	7.8E-08	7.56	2.0E-08	16.68										
18-Oct-85	85-10-32	1.4E-07	3.87	9.6E-08	6.01	1.6E-08	22.63										
18-Oct-85	85-10-33	8.5E-08	6.69	5.7E-08	8.58	1.7E-08	18.46										

Table - A2 Cooling Tower Sample Results All Data

Date	Sample #	Cs-137	Cs%Err	Co-60	Co%Err	Mn-54	Mn%Err	Zn-65	Zn%Err	Co-58	Co%Err	Cs-134	Cs%Err	Ru-103	Ru%Err	Rh-106	Rh%Err
18-Oct-85	85-10-34	3.4E-07	2.11	1.2E-07	4.95	7.7E-09	42.87										
18-Oct-85	85-10-35	2.2E-07	3.17	9.1E-08	6.99												
01-Nov-85	85-11-03	2.5E-08	16.96														
18-Dec-85	85-9356	1.6E-07	4.53														
18-Dec-85	85-9356	1.7E-07	4.39														
16-Jan-86	86-01-16	1.1E-07	6.9	1.5E-07	5.2	7.8E-09	62.06	1.3E-07	8.32	7.0E-08	8.04		-		-		-
16-Jan-86	86-01-17	9.8E-08	5.9	4.5E-08	13.53	4.3E-09	85.99 (<CL)		-				-		-		-
14-Feb-86	86-02-03	7.5E-08	10.77														
14-Feb-86	86-02-03	8.7E-08	8.73	8.4E-08	9.91	1.6E-08	28.5		-				-		-		-
20-Mar-86	86-03-12	1.7E-07	4.99	1.2E-07	8.98	1.7E-08	38.88	5.7E-08	22.75	7.5E-09	45.34		-		-		-
20-Mar-86	86-03-13	1.5E-07	5.48	1.5E-07	6.42	2.6E-08	22.98	3.6E-08	28.41				-		-		-
27-Jun-86	86-06-25	6.1E-07	2.02	1.4E-07	8.34	1.2E-08	54.29	1.0E-07	14.15	1.2E-08	46.06	2.1E-07	3.45	9.7E-08	7.52	1.8E-07	32.26
27-Jun-86	86-06-26	5.8E-07	2.14	1.1E-07	8.45	2.0E-08	31.72	1.1E-07	12.34	2.4E-08	27.03	2.2E-07	3.37	8.3E-08	10.02		-
18-Jul-86	86-07-14	1.8E-07	3.47	2.9E-08	22.03		-	2.7E-08	39.99			6.0E-08	6.09	3.4E-08	13.3	2.6E-08	66.05 (<CL)
18-Jul-86	86-07-15	1.1E-07	5.16	1.9E-08	26.4		-	2.3E-08	32.55			4.3E-08	11.99	3.1E-08	16.18		-
15-Aug-86	86-08-02	1.6E-07	3.58	2.1E-08	22.11		-		-			5.8E-08	6.47	2.7E-08	14.04	1.9E-07	20.58
26-Sep-86	86-09-16	1.1E-07	6.72	3.6E-08	20.55		-		-				-	1.0E-08	41.56	5.6E-08	65.82
19-Nov-86	86-11-19	7.6E-08	8.74	3.4E-08	21.4		-		-			2.6E-08	22.14		-		-
30-Dec-86	86-12-18	1.6E-07	4.17	1.6E-07	5.88		-		-			4.2E-08	10.03		-		-
27-Jan-87	87-01-15	1.1E-07	5.98	4.1E-08	17.71	5.2E-09	86.33 (<CL)		-			2.3E-08	17.49		-		-
03-Mar-87	87-03-01	1.4E-07	3.6	4.5E-08	16.24		-		-			3.1E-08	14.81		-		-
03-Apr-87	87-04-02	6.6E-08	9.53	1.7E-08	22.78		-		-				-		-		-
31-Jul-87	87-07-25	1.6E-07	5.17	2.3E-07	4.41	8.9E-08	7.6	2.4E-07	5.83	9.2E-08	6.5	3.0E-08	16.02		-	1.4E-07	35.29

Table - A2 Cooling Tower Sample Results All Data

Date	Sample #	Cs-137	Cs%Err	Co-60	Co%Err	Mn-54	Mn%Err	Zn-65	Zn%Err	Co-58	Co%Err	Cs-134	Cs%Err	Ru-103	Ru%Err	Rh-106	Rh%Err
01-Sep-87	87-09-01	3.5E-08	15.62	2.6E-08	19.91		-		-				-		-		-
26-Aug-88	88-08-35	2.9E-08	18.96	2.8E-08	23.23		-		-				-		-		-
29-Sep-88	88-09-46	3.1E-07	2.91	4.0E-07		7.0E-08		1.5E-07				1.2E-07					
29-Sep-88	88-09-47	5.1E-07	2.99	4.9E-07		7.6E-08		1.7E-07				9.0E-08					
29-Sep-88	88-09-48	4.1E-07	3.76	3.7E-07	4.69	5.0E-08	16.65	1.4E-07	16.02			8.9E-08	13.03				
29-Sep-88	88-09-49	4.3E-07	3.73	2.9E-07	4.77	3.1E-08	3.24	1.7E-07	12.74			7.3E-08	17.19				
29-Sep-88	88-09-50	4.2E-07	3.18	3.3E-07	4.32	4.8E-08	18.57	1.6E-07	20.13			7.8E-08	19.42				
29-Sep-88	88-09-51	3.1E-07	4.43	3.1E-07	5.03	4.1E-08	18.3	1.9E-07	10.21			7.4E-08	17.12				
30-Sep-88	88-09-52	7.6E-08	8.62	7.8E-08	10.3	1.3E-08	39.49		-				-		-		-
04-Nov-88	88-11-06	4.7E-07	12.52	7.4E-07	8.94			8.2E-08	13.02								
29-Nov-88	88-11-40	7.9E-08	10.34	1.2E-07	7.56		-	1.1E-07	16.28				-		-		-
04-Jan-89	89-01-03	1.1E-07	7.14	3.2E-08	19.83		-		-			2.1E-07	7.7				
30-Mar-89	89-03-30	2.5E-07	6.59														
30-Apr-89	89-05-02	1.3E-07	6.31	1.3E-08	12.96		-	4.4E-08	32.4			1.1E-07	7.7				
10-May-89	89-05-09	3.6E-07	3.34	2.4E-07	4.73	3.4E-08	18.67	1.4E-07	13.5			1.5E-07	7.8				
10-May-89	89-05-10	3.6E-07	3.11	2.3E-07	5.2	3.4E-08	19.25	8.3E-08	20.6			1.5E-07	8.5				
10-May-89	89-05-11	3.2E-07	3.99	1.5E-07	6.62	2.8E-08	24.48	8.4E-08	14.79			1.2E-07	7.28				
03-May-89	89-05-15	5.5E-07	6.33	2.2E-07	12.15							3.9E-07	8.81				
24-May-89	89-05-25	1.4E-06	2.7	5.3E-07	10.08	1.2E-07	21.87	1.5E-07	42.95			2.9E-07	11.97				
24-May-89	89-05-26	1.4E-06	2.93	6.8E-07	7.06	1.4E-07	17.44	9.9E-08	69.82			2.8E-07	13.21				
10-Jul-89	89-07-03	1.2E-07	6.15	9.9E-08	8.21	8.9E-09	30.81	4.7E-08	38.19			4.6E-08	20.73				
28-Jul-89	89-07-12	3.2E-08	12.05														
30-Aug-89	89-08-33	1.1E-07	7.49	6.8E-08	11.28		-	9.4E-08	34.93			3.2E-08	26.32				

Table - A2 Cooling Tower Sample Results All Data

Date	Sample #	Cs-137	Cs%Err	Co-60	Co%Err	Mn-54	Mn%Err	Zn-65	Zn%Err	Co-58	Co%Err	Cs-134	Cs%Err	Ru-103	Ru%Err	Rh-106	Rh%Err
27-Oct-89	89-10-25	6.2E-08	10.09	6.9E-08		1.3E-08		3.2E-08									
01-Dec-89	89-12-01	8.6E-08	5.96	8.9E-08	8.14			2.0E-08	40.53			2.5E-08	20.51				
02-Jan-90	90-01-01	1.2E-07	7.32	9.4E-08	10.68		-	2.3E-08	51.9								
02-Feb-90	90-02-04	9.9E-08	6.27	7.8E-08	7.46		-		-								
02-Mar-90	90-03-01	3.8E-08	40.09														
22-Jun-90	90-06-11	5.4E-07	4.93	2.3E-07		1.1E-08											
01-Aug-90	90-08-01	1.9E-07	4.14														
29-Aug-90	90-08-28	1.5E-07	4.51	1.4E-07	5.46	1.0E-08	45.75	1.8E-08	64.27								
29-Aug-90	90-09-01	1.5E-07	7.34														
28-Sep-90	90-09-17	2.0E-07	7.07														
30-Oct-90	90-10-19	1.2E-07	7.55	5.1E-07	3.37		-	5.4E-08	40								
03-Dec-90	90-12-01	1.0E-07	8.42	2.4E-08	28.33		-		-								
15-Jan-91	91-01-05	1.3E-07	7.59	ND	-		-		-								
29-Jan-91	91-01-11	1.2E-07	6.61	2.1E-08	38.92		-		-								
01-Mar-91	91-03-01	1.4E-07	6.85	3.9E-08	20.55		-		-								
02-Apr-91	91-04-01	1.6E-07	7.21														
22-Apr-91	91-04-12	2.6E-07	4.11	1.8E-07	7.72		-		-								
28-Aug-91	91-08-10	1.1E-07	7.66	1.5E-07	7.75		-	1.9E-08	76.96 (<CL)								
03-Oct-91	91-10-02	1.2E-07	9.11														
29-Oct-91	91-10-08	6.3E-08	11.1	4.2E-08	27.4	2.2E-08	28.51		-								
03-Jan-92	92-01-02	9.8E-08	9.72	5.1E-08	19.49		-		-								
04-Feb-92	92-02-01	1.1E-07	10.01	1.8E-07	8.06		-		-								
28-Feb-92	92-03-13	9.0E-08	8.95	8.2E-08	13.82		-		-								

Table - A2 Cooling Tower Sample Results All Data

Date	Sample #	Cs-137	Cs%Err	Co-60	Co%Err	Mn-54	Mn%Err	Zn-65	Zn%Err	Co-58	Co%Err	Cs-134	Cs%Err	Ru-103	Ru%Err	Rh-106	Rh%Err
07-Apr-92	92-04-02	1.2E-07	7.87	6.6E-08	14.81		-		-								
02-Oct-92	92-10-08	2.0E-08	30.09	1.9E-08	29.77		-		-								
30-Oct-92	92-10-22	2.3E-08	31.47	4.2E-08	27.71	1.4E-08	50.34		-								
30-Nov-92	92-12-01	2.9E-08	23.01	2.5E-08	36.94												
28-Dec-92	92-12-13	4.7E-08	16.5	2.5E-08	36.94		-		-								
28-Dec-92	93-01-03	4.0E-08	18.73	2.2E-08	41.79		-		-								
28-Dec-92	93-01-03	4.0E-08	18.73														
28-Dec-92	93-01-04	4.5E-08	29.11														
28-Dec-92	93-01-04	4.5E-08	29.11														
29-Dec-92	93-01-02	5.0E-08	44.6														
28-Jan-93	93-01-36	7.4E-08	9.15	2.3E-08	30.8		-		-								
16-Mar-93	93-03-27	2.3E-07	7.31	6.8E-08		3.1E-08											
16-Mar-93	93-03-26	1.6E-07	13.61	1.6E-07													
16-Mar-93	93-03-25	1.6E-07	13.17	1.1E-07													
16-Mar-93	93-03-24	1.9E-07	8.86	6.8E-08													
16-Mar-93	93-03-29	5.0E-08	29.87														

Table A3 Cooling Tower Samples for t Statistic Test

Note: (c) = Mass Corrected River Equivalence

Sample#	Cs-137	Cs-137(c)	Co-60	Co-60(c)
85-8-2			1.33E-07	2.24E-07
85-8-35	7.32E-08	1.23E-07	8.04E-08	1.35E-07
85-8-36			1.05E-07	1.77E-07
85-8-41	1.20E-07	2.02E-07	6.82E-08	1.15E-07
85-8-49	2.47E-07	4.15E-07	1.08E-07	1.81E-07
85-9-2	2.45E-07	4.12E-07	9.61E-08	1.62E-07
85-9-31	1.47E-07	2.47E-07	8.69E-08	1.46E-07
85-10-4	1.20E-07	2.01E-07	9.77E-08	1.64E-07
86-1-16	1.14E-07	1.91E-07	1.51E-07	2.54E-07
86-1-17	9.84E-08	1.65E-07	4.47E-08	7.51E-08
86-2-3	8.69E-08	1.46E-07	8.40E-08	1.41E-07
86-3-12	1.73E-07	2.91E-07	1.19E-07	2.00E-07
86-3-13	1.53E-07	2.57E-07	1.46E-07	2.45E-07
86-6-25			1.39E-07	2.33E-07
86-6-26			1.12E-07	1.89E-07
86-7-14	2.31E-07	3.88E-07	3.71E-08	6.23E-08
86-7-15	1.34E-07	2.25E-07	2.36E-08	3.96E-08
86-8-2	2.21E-07	3.71E-07	2.88E-08	4.85E-08
86-9-16	1.16E-07	1.95E-07	3.98E-08	6.69E-08
86-11-19	7.63E-08	1.28E-07	3.43E-08	5.77E-08
86-12-18	1.86E-07	3.13E-07	1.77E-07	2.98E-07
87-1-15	1.11E-07	1.86E-07	4.08E-08	6.87E-08
87-3-1	1.45E-07	2.43E-07	4.51E-08	7.57E-08
87-4-2	6.56E-08	1.10E-07	1.73E-08	2.90E-08
87-7-25	1.57E-07	2.64E-07		
87-9-1	3.46E-08	5.82E-08	2.63E-08	4.42E-08
88-08-35	2.92E-08	4.92E-08	2.83E-08	4.75E-08
88-09-52	7.56E-08	1.27E-07	7.79E-08	1.31E-07
88-11-40	7.87E-08	1.32E-07	1.18E-07	1.98E-07
89-01-03	1.10E-07	1.85E-07	3.18E-08	5.34E-08
89-05-02	1.29E-07	2.17E-07		
89-08-33	1.09E-07	1.84E-07	6.85E-08	1.15E-07
90-01-01	1.20E-07	2.02E-07	9.40E-08	1.58E-07
90-02-04	9.86E-08	1.66E-07	7.77E-08	1.31E-07
90-08-28	1.52E-07	2.56E-07	1.38E-07	2.31E-07

Table A3 Cooling Tower Samples for t Statistic Test

Note: (c) = Mass Corrected River Equivalence

Sample#	Cs-137	Cs-137(c)	Co-60	Co-60(c)
90-10-19	1.16E-07	1.95E-07		
90-12-01	1.03E-07	1.73E-07	2.43E-08	4.09E-08
91-01-05	1.28E-07	2.14E-07		
91-01-11	1.20E-07	2.02E-07	2.12E-08	3.56E-08
91-03-01	1.42E-07	2.38E-07	3.90E-08	6.56E-08
91-04-12	2.58E-07	4.34E-07	1.75E-07	2.95E-07
91-08-10	1.06E-07	1.78E-07	1.47E-07	2.47E-07
91-10-08	6.35E-08	1.07E-07	4.17E-08	7.01E-08
92-01-02	9.81E-08	1.65E-07	5.07E-08	8.52E-08
92-02-01	1.08E-07	1.82E-07	1.81E-07	3.05E-07
92-03-13	9.01E-08	1.51E-07	8.21E-08	1.38E-07
92-04-02	1.18E-07	1.99E-07	6.62E-08	1.11E-07
92-10-08	1.95E-08	3.28E-08	1.94E-08	3.25E-08
92-10-22	2.31E-08	3.88E-08	4.20E-08	7.06E-08
92-11-01	2.93E-08	4.93E-08	2.49E-08	4.19E-08
92-12-13	4.67E-08	7.85E-08	3.20E-08	5.38E-08
93-01-03	3.99E-08	6.71E-08	2.24E-08	3.77E-08
93-01-36	7.35E-08	1.24E-07	2.32E-08	3.90E-08
88-09-46	3.05E-07	4.36E-07		
88-09-47				
88-09-48	4.12E-07	5.89E-07		
88-09-49	4.25E-07	6.08E-07		
88-09-50	4.17E-07	5.95E-07		
88-09-51	3.09E-07	4.42E-07		
89-05-09	3.63E-07	5.18E-07	2.43E-07	3.48E-07
89-05-10	3.64E-07	5.20E-07	2.30E-07	3.29E-07
89-05-11	3.25E-07	4.64E-07	1.50E-07	2.14E-07
89-05-25				
89-05-26				
89-10-25	6.24E-08	8.92E-08	6.85E-08	9.78E-08
90-06-11			2.33E-07	3.33E-07
93-03-27	2.28E-07	3.25E-07	6.82E-08	9.74E-08
93-03-26	1.61E-07	2.30E-07	1.55E-07	2.21E-07
93-03-25	1.62E-07	2.31E-07	1.12E-07	1.60E-07
93-03-24	1.86E-07	2.66E-07	6.80E-08	9.72E-08

Table A3 Cooling Tower Samples for t Statistic Test

Note: (c) = Mass Corrected River Equivalence

Sample#	Cs-137	Cs-137(c)	Co-60	Co-60(c)
93-03-29	5.03E-08	7.19E-08		
		2 reject		7 reject
Mean	1.49E-07	2.36E-07	8.61E-08	1.39E-07
Variance	1.00E-14	2.04E-14	3.38E-15	7.96E-15
Std Dev	1.00E-07	1.43E-07	5.82E-08	8.92E-08

Table - A4 River Sediment Results All Data

Date	Sample #	Cs-137	Co-60	Cs-134	Mn-54
28-May-85	WHBLUFF	2.78E-08	2.41E-08		1.06E-08
28-May-85	MKR-19	1.09E-07	8.46E-08		
28-May-85	HNFRD1	3.66E-07	1.82E-07		1.42E-08
28-May-85	HNFRD2	2.19E-07	1.3E-07		
02-Jun-85	HNFRDW	3.25E-07	5.91E-07		4.15E-08
16-Apr-86	WP-33	1.2E-07		4.6E-08	
25-Jun-86	WP-33	1.9E-07		8.9E-07	
25-Jun-86	WP-33	2.3E-07			
25-Jun-86	WP-33	1.35E-07	2.45E-08	2E-09	1.65E-08
25-Jun-86	WP-33	1.4E-07	4.4E-08	6.5E-08	2.6E-08
10-Dec-86	WHBLUFF	5.2E-07	7.1E-08	1.5E-08	
10-Dec-86	WHBLUFF	3.1E-07	2.6E-07		3.8E-08
10-Dec-86	WHBLUFF	5.5E-07	2.8E-07		3.4E-08
10-Dec-86	WHBLUFF	7E-07	2.9E-07	9.7E-08	
10-Dec-86	WHBLUFF	8E-07	1E-07	5.7E-08	
10-Dec-86	OLDHNFD	4.8E-07	1.3E-07		1.7E-08
10-Dec-86	OLDHNFD	4.6E-07	1.1E-06	6.3E-08	
09-Apr-87	WP-33	1.3E-07	2.6E-08		
21-Apr-88	WA-33-01	2E-07	3.6E-08	1.7E-08	
17-May-88	WA-21	3E-08			
17-May-88	WA-23	3.2E-07			
17-May-88	WA-01	3.3E-07			
19-Jun-88	GP-6.1	7.51E-08			
19-Jun-88	GP-6.3	4E-09			
26-Jun-88	GP-14.6	5.52E-08			
26-Jun-88	GP-14.7	5.6E-07	2.98E-07		
26-Jun-88	GP-15.1		8.7E-08		
26-Jun-88	GP-15.1	8.33E-09			
26-Jun-88	GP-17.8	2.87E-07	2.87E-09		
26-Jun-88	GP-18.5	1.74E-07	6.11E-08		
10-Jul-88	GP-7.1	1.01E-07	1.05E-08		
10-Jul-88	GP-7.9	1.76E-08			
10-Jul-88	GP-8.2	1E-07	3.17E-08		
10-Jul-88	GP-8.3	6.62E-08			
10-Jul-88	GP-8.6	2.32E-08			
10-Jul-88	GP-9.0	1.81E-07	1.6E-06		
10-Jul-88	GP-9.3	5.86E-07	3.24E-07		
10-Jul-88	GP-9.9	1.2E-07	4.87E-08		
10-Jul-88	GP-10.2	1.47E-07			

Table - A4 River Sediment Results All Data

Date	Sample #	Cs-137	Co-60	Cs-134	Mn-54
17-Jul-88	GP-22.6	3.44E-07			
17-Jul-88	GP-22.6	3.53E-07			
17-Jul-88	GP-24.8	1.76E-07	2.87E-09		
17-Jul-88	GP-24.8	1.84E-07			
17-Jul-88	GP-28	9.21E-08	1.16E-07		
14-Aug-88	GP-6.5	7.87E-08			
14-Aug-88	GP-6.5	9.68E-08			
14-Aug-88	GP-6.1	7.4E-08			
14-Aug-88	GP-4.1	8.93E-08			
14-Aug-88	GP-9.0	4.19E-07	2.04E-06		
14-Aug-88	GP-10.2	1.7E-07	1.56E-07		
14-Aug-88	GP-10.2	2.09E-07	2.73E-07		
14-Aug-88	GP-10.8	2.87E-07			
14-Aug-88	GP-11.1	2.02E-07	2.76E-08		
14-Aug-88	GP-11.4	1.04E-07			
14-Aug-88	GP-18.8	5.91E-08			
14-Aug-88	GP-21.5		2.29E-08		
14-Aug-88	GP-28	1.41E-07	1.02E-07		
06-Sep-88	GP-9.3		7.73E-07		
06-Sep-88	WA-100F	2.57E-07	6.7E-08		
06-Sep-88	GP-22.6	1.03E-07			
06-Sep-88	GP-26.5	1.51E-07	7.14E-08		
06-Sep-88	GP-28.05	1.02E-07	1.57E-08		
11-Apr-89	WA-33-01	9.6E-08			
01-May-89	HRPRDAM	2.5E-07	1E-08		
19-Apr-90	WA-33-01	1.2E-07	1.7E-08		
01-May-90	HRPRDAM	5.5E-07	1E-08		
16-Oct-90	WP-33-90	9.08E-08		8.59E-08	
10-Apr-91	WP-33-04	1.18E-07		3.76E-08	
01-May-91	HRPRDAM	5E-07	1E-08		
31-Oct-91	WP-33-10	9.61E-08		5.61E-08	
Mean		2.20E-07	2.33E-07	1.19E-07	2.47E-08
Variance		3.17E-14	1.79E-13	5.47E-14	1.23E-16
Std Dev		1.78E-07	4.23E-07	2.34E-07	1.11E-08

Table A5 Zn-65 Parameters Used in Figure 1

Date	Sample #	Quantity	Zn-65	Zn%Error	(t)
16-Jan-86	86-01-16	500 cc	1.268E-07	8.32	0
20-Mar-86	86-03-12	500 cc	5.657E-08	22.75	63
20-Mar-86	86-03-13	500 cc	3.641E-08	28.41	63
27-Jun-86	86-06-25>26	Ave.	1.06E-07		162
18-Jul-86	86-07-14>15	Ave.	2.5E-08		183
31-Jul-87	87-07-25	592 cc	2.419E-07	5.83	561
29-Sep-88	88-09-46>51	Ave.	1.62E-07		987
29-Nov-88	88-11-40	450 cc	1.087E-07	16.28	1048
30-Apr-89	89-05-02	450 cc	4.439E-08	32.4	1200
10-May-89	89-05-09>11	Ave.	1.01E-07		1210
24-May-89	89-05-25>26	Ave.	5.67E-08		1224
30-Aug-89	89-08-33	450 cc	9.417E-08	34.93	1322
27-Oct-89	89-10-25	518 gm	3.15E-08		1380
01-Dec-89	89-12-01	450 ml	2.03E-08	40.53	1415
02-Jan-90	90-01-01	450 ml	2.313E-08	51.9	1447
29-Aug-90	90-08-28	450 ml	1.802E-08	64.27	1686
30-Oct-90	90-10-19	450 ml	5.431E-08	40	1748
28-Aug-91	91-08-10	450 ml	1.862E-08	76.96(<CL)	2050

Table-A6 Cooling Tower Data

Date	Sample#	Co-60	Ord	Cum%
24-May-89	89-05-25	ND	1	
29-Sep-88	88-09-48	ND	2	
16-Mar-93	93-03-29	ND	3	
29-Sep-88	88-09-51	ND	4	
29-Sep-88	88-09-50	ND	5	
29-Sep-88	88-09-49	ND	6	
29-Sep-88	88-09-47	ND	7	
29-Sep-88	88-09-46	ND	8	
15-Jan-91	91-01-05	ND	9	
30-Oct-90	90-10-19	ND	10	
30-Apr-89	89-05-02	ND	11	
31-Jul-87	87-7-25	ND	12	
03-Apr-87	87-4-2	1.73E-08	13	15.7
02-Oct-92	92-10-08	1.94E-08	14	16.9
29-Jan-91	91-01-11	2.12E-08	15	18.1
28-Dec-92	93-01-03	2.24E-08	16	19.3
28-Jan-93	93-01-36	2.32E-08	17	20.5
18-Jul-86	86-7-15	2.36E-08	18	21.7
03-Dec-90	90-12-01	2.43E-08	19	22.9
30-Nov-92	92-11-01	2.49E-08	20	24.1
01-Sep-87	87-9-1	2.63E-08	21	25.3
26-Aug-88	88-08-35	2.83E-08	22	26.5
15-Aug-86	86-8-2	2.88E-08	23	27.7
04-Jan-89	89-01-03	3.18E-08	24	28.9
28-Dec-92	92-12-13	3.20E-08	25	30.1
19-Nov-86	86-11-19	3.43E-08	26	31.3
18-Jul-86	86-7-14	3.71E-08	27	32.5
01-Mar-91	91-03-01	3.90E-08	28	33.7
26-Sep-86	86-9-16	3.98E-08	29	34.9
27-Jan-87	87-1-15	4.08E-08	30	36.1
29-Oct-91	91-10-08	4.17E-08	31	37.3
30-Oct-92	92-10-22	4.20E-08	32	38.5
16-Jan-86	86-1-17	4.47E-08	33	39.8
03-Mar-87	87-3-1	4.51E-08	34	41
03-Jan-92	92-01-02	5.07E-08	35	42.2
07-Apr-92	92-04-02	6.62E-08	36	43.3
16-Mar-93	93-03-24	6.80E-08	37	44.6
16-Mar-93	93-03-27	6.82E-08	38	45.8
29-Aug-85	85-8-41	6.82E-08	39	47

Table-A6 Cooling Tower Data

Date	Sample#	Co-60	Ord	Cum%
30-Aug-89	89-08-33	6.85E-08	40	48.2
27-Oct-89	89-10-25	6.85E-08	41	49.4
02-Feb-90	90-02-04	7.77E-08	42	50.6
30-Sep-88	88-09-52	7.79E-08	43	51.8
28-Aug-85	85-8-35	8.04E-08	44	53
28-Feb-92	92-03-13	8.21E-08	45	54.2
14-Feb-86	86-2-3	8.40E-08	46	55.4
20-Sep-85	85-9-31	8.69E-08	47	56.6
02-Jan-90	90-01-01	9.40E-08	48	57.83
05-Sep-85	85-9-2	9.61E-08	49	59
03-Oct-85	85-10-4	9.77E-08	50	60.2
28-Aug-85	85-8-36	1.05E-07	51	61.4
30-Aug-85	85-8-49	1.08E-07	52	62.6
16-Mar-93	93-03-25	1.12E-07	53	63.9
27-Jun-86	86-6-26	1.12E-07	54	65.1
29-Nov-88	88-11-40	1.18E-07	55	66.3
20-Mar-86	86-3-12	1.19E-07	56	67.5
01-Aug-85	85-8-2	1.33E-07	57	68.7
29-Aug-90	90-08-28	1.38E-07	58	69.9
16-Oct-85	85-10-24	1.39E-07	59	71.1
27-Jun-86	86-6-25	1.39E-07	60	72.3
20-Mar-86	86-3-13	1.46E-07	61	73.5
28-Aug-91	91-08-10	1.47E-07	62	74.7
10-May-89	89-05-11	1.50E-07	63	75.9
16-Jan-86	86-1-16	1.51E-07	64	77.1
16-Mar-93	93-03-26	1.55E-07	65	78.3
22-Apr-91	91-04-12	1.75E-07	66	79.5
30-Dec-86	86-12-18	1.77E-07	67	80.7
04-Feb-92	92-02-01	1.81E-07	68	81.9
03-May-89	89-05-15	2.15E-07	69	83.1
10-May-89	89-05-10	2.30E-07	70	84
22-Jun-90	90-06-11	2.33E-07	71	85.5
31-Jul-87	87-07-25	2.34E-07	72	86.7
10-May-89	89-05-09	2.43E-07	73	87.9
29-Sep-88	88-09-49	2.87E-07	74	89.2
29-Sep-88	88-09-51	3.08E-07	75	90.4
29-Sep-88	88-09-50	3.27E-07	76	91.6
29-Sep-88	88-09-48	3.65E-07	77	92.8
29-Sep-88	88-09-46	4.00E-07	78	94

Table-A6 Cooling Tower Data

Date	Sample#	Co-60	Ord	Cum%
29-Sep-88	88-09-47	4.92E-07	79	95.2
30-Oct-90	90-09-17	5.07E-07	80	96.4
24-May-89	89-05-25	5.27E-07	81	97.6
24-May-89	89-05-26	6.84E-07	82	98.8
04-Nov-88	88-11-06	7.44E-07	83	100
Mean		1.23E-07		
Variance		2.24E-14		
Standard Deviation		1.50E-07		

Table-A7 Date	Raw Loc	Co-60 Conc	Data Order	River Cum%	Population
19-Jun-88	GP-6.1	ND	1		
19-Jun-88	GP-6.3	ND	2		
17-Jul-88	GP-22.6	ND	3		
26-Jun-88	GP-14.6	ND	4		
17-Jul-88	GP-22.6	ND	5		
17-May-88	WA-23	ND	6		
17-May-88	WA-01	ND	7		
14-Aug-88	GP-4.1	ND	8		
19-Jun-88	GP-6.2	ND	9		
14-Aug-88	GP-4.1	ND	10		
17-Jul-88	GP-24.8	ND	11		
10-Jul-88	GP-10.2	ND	12		
26-Jun-88	GP-15.75	ND	13		
10-Jul-88	GP-7.9	ND	14		
10-Jul-88	GP-8.6	ND	15		
26-Jun-88	GP-15.1	ND	16		
10-Jul-88	GP-6.5	ND	17		
10-Jul-88	GP-14.7	ND	18		
10-Jul-88	GP-8.3	ND	19		
14-Aug-88	GP-6.5	ND	20		
17-May-88	WA-21	ND	21		
25-Jun-86	WP-33	ND	22		
06-Sep-88	GP-26.5	ND	23		
06-Sep-88	GP-22.6	ND	24		
25-Jun-86	WP-33	ND	25		
11-Apr-89	WA-33-01	ND	26		
10-Apr-91	WP-33-04	ND	27		
31-Oct-91	WP-33-10	ND	28		
16-Apr-86	WP-33	ND	29		
16-Oct-90	WP-33-90	ND	30		
14-Aug-88	GP-10.8	ND	31		
14-Aug-88	GP-6.5	ND	32		
14-Aug-88	GP-6.1	ND	33		
14-Aug-88	GP-18.8	ND	34		
14-Aug-88	GP-21.5	ND	35		
14-Aug-88	GP-6.5	ND	36		
14-Aug-88	GP-11.4	ND	37		
14-Aug-88	GP-4.1	2.58E-09	38	46.9	
26-Jun-88	GP-17.8	2.87E-09	39	48.1	

Table-A7 Date	Raw Loc	Co-60 Conc	Data Order	River Cum%	Population
17-Jul-88	GP-24.8	2.87E-09	40	49.4	
17-Jul-88	GP-35.5	3.9E-09	41	50.6	
01-May-91	HRPRDAM	1E-08	42	51.8	
01-May-89	HRPRDAM	1E-08	43	53.1	
01-May-90	HRPRDAM	1E-08	44	54.3	
10-Jul-88	GP-7.1	1.05E-08	45	55.6	
06-Sep-88	GP-28.05	1.57E-08	46	56.8	
19-Apr-90	WA-33-01	1.7E-08	47	58	
14-Aug-88	GP-21.5	2.29E-08	48	59.3	
28-May-85	WHBLUFF	2.41E-08	49	60.5	
09-Apr-87	WP-33	2.6E-08	50	61.73	
14-Aug-88	GP-11.1	2.76E-08	51	63	
10-Jul-88	GP-8.2	3.17E-08	52	64.2	
21-Apr-88	WA-33-01	3.6E-08	53	65.4	
10-Jul-88	GP-9.9	4.87E-08	54	66.7	
25-Jun-86	WP-33	4.9E-08	55	67.9	
26-Jun-88	GP-18.5	6.11E-08	56	69.1	
06-Sep-88	WA-100F	6.7E-08	57	70.4	
10-Dec-86	WHBLUFF	7.1E-08	58	71.6	
06-Sep-88	GP-22.6	7.14E-08	59	72.8	
25-Jun-86	WP-33	8.3E-08	60	74.1	
28-May-85	MKR-19	8.46E-08	61	75.3	
26-Jun-88	GP-15.1	8.7E-08	62	76.5	
25-Jun-86	WP-33	8.8E-08	63	77.8	
10-Dec-86	WHBLUFF	1E-07	64	79	
14-Aug-88	GP-28	1.02E-07	65	80.25	
17-Jul-88	GP-28	1.16E-07	66	81.5	
28-May-85	HNFRD2	1.3E-07	67	82.7	
10-Dec-86	OLDHNFD	1.3E-07	68	83.9	
14-Aug-88	GP-10.2	1.56E-07	69	85.2	
28-May-85	HNFRD1	1.82E-07	70	86.4	
10-Dec-86	WHBLUFF	2.6E-07	71	87.6	
14-Aug-88	GP-10.2	2.73E-07	72	88.9	
10-Dec-86	WHBLUFF	2.8E-07	73	90.1	
10-Dec-86	WHBLUFF	2.9E-07	74	91.4	
26-Jun-88	GP-14.7	2.98E-07	75	92.6	
10-Jul-88	GP-9.3	3.24E-07	76	93.8	
02-Jun-85	HNFRDW	5.91E-07	77	95.1	
06-Sep-88	GP-9.3	7.73E-07	78	96.3	

Table-A7	Raw	Co-60	Data	River	Population
Date	Loc	Conc	Order	Cum%	
10-Dec-86	OLDHNFD	1.1E-06	79	97.5	
10-Jul-88	GP-9.0	1.6E-06	80	98.8	
14-Aug-88	GP-9.0	2.04E-06	81	100	
Mean		1.20E-07			
Variance		1.04E-13			
Standard Deviation		3.22E-07			