# ABSTRACT

**Stephen R. Talley. Study of Long and Short Term Variation of Radon Concentration and Comparison of Sampling Methodologies in Public Drinking Water Supplies.**
**(Under the direction of Dr. James E. Watson, Jr.)**

Long term and short term sampling was performed to determine the radon concentration in well water at 11 sites in the piedmont region of North Carolina. Sampling was performed in anticipation of a possible future drinking water standard, to be proposed by the U. S. Environmental Protection Agency, for radon in public water supplies.

The goal of the long term sampling was to determine, at individual wells, how well grab samples can predict the annual average radon concentration for a particular well site. The results of the long term sampling supports the findings of previous UNC researchers that approximately 97 percent of the well water samples were within 30% of their associated sample mean.

Two short term sampling tests were also performed. The first short term test examined the variation in radon concentration over an eight hour period to determine the source of a trend observed by previous researchers at UNC while collecting sequential well water samples. The results of this test identified an association between well pump operation and well water sample radon concentration reduction, further research must be done to determine if the association is causal. The first short term test also identified an area of concern for sampling of public drinking water supply systems, that it is possible for water treatment chemicals to introduce sample artifacts by diluting the samples obtained for analysis. This dilution is possible if sampling locations are downstream of the water treatment chemical injection point and if the sample flow rate is low enough such that the water treatment chemical flow rate contributes a significant fraction of the sample volume, thus introducing a bias in the sample result.

The second short term test was performed to compare the slow-flow sampling method, developed at UNC, to the proposed EPA sampling method, EPA Method 913.0 (Draft), for determining the radon concentration in drinking water. Sample method comparison between the UNC slow-flow method and the EPA method resulted in the conclusion that no difference in the methods could be distinguished; this conclusion assumes that both methods minimize the amount of time that the filled sample vials are open and exposed to ambient air.

# ACKNOWLEDGMENTS

I wish to thank Dr. Watson for his encouragement for my returning to school and his expertise, both in the classroom and as my advisor, without which this research could not have been accomplished. I would like to extend my appreciation to Dr. Leith and Dr. Fong for serving as committee members and for their efforts in this research.

Thanks are also extended to William Drane for helping me to start this project and his expert advise in the conduct of the sampling operations. Special thanks go to the owners and operators of each well site for allowing the opportunity to perform the sampling tasks associated with this research effort. I also thank the North Carolina Division of Radiation Protection for their support in funding this project.

Most importantly, I wish to thank my parents for their support during my school career and their encouragement in my decision to return to school. This investigation was conducted as a part of graduate training program and was supported in part by a United States Public Health Service traineeship.

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# INTRODUCTION

This study continues the $^{222}$Rn public drinking water supply well water monitoring performed by previous researchers at the University of North Carolina at Chapel Hill (Hightower 1994, York 1995, Drane 1996). Eleven of 14 well sites sampled by Drane were sampled for an additional five months on five separate occasions. Two well sites were selected for additional sampling. Well Site #5 was selected to examine the variation in $^{222}$Rn within an eight hour period and was sampled on three separate occasions for this purpose. Well Site #10 was selected to compare the $^{222}$Rn sampling technique developed at UNC with a sampling technique developed by the EPA, EPA Method 913.0 (Draft). Well Site #10 was sampled on two separate occasions for this purpose.

The concentration of $^{222}$Rn in public drinking water supply well water is of interest because the 1996 amendment to the Safe Drinking Water Act (SDWA) requires that the Administrator of the Environmental Protection Agency (EPA) publish a maximum contaminant level goal and national primary drinking water regulation for radon within 36 months of the date of the enactment of the amendment. The 1996 amendment to the SDWA withdraws past proposed radon national primary drinking water regulations. At this time there is neither a radon limit nor a standard radon sampling methodology for public drinking water supplies.

Past proposed radon national primary drinking water regulation would have set the radon in water limit at 300 pCi/L. Along with the withdrawn 300 pCi/L limit, monitoring requirements would have required quarterly well water sampling. Annual sampling would be performed if the average of the first year's quarterly samples was below the limit, otherwise, quarterly sampling would be continued until the average of four consecutive samples was less than the limit. Several different sampling methodologies have been proposed by the EPA, including a method using a funnel and a syringe and the most current draft method using a beaker to simultaneously fill multiple vials (Federal Register 1991, EPA Method 913.0 (Draft)).

## Results of Previous UNC $^{222}$Rn Well Water Sampling

Drane 1996, in his research, consolidates his results with the results from the previous two studies (Hightower 1994, and York 1995). His conclusions as a result of examining 1,468 well water sample results were as follows:

> No individual sample varied by more than 55% from the mean $^{222}$Rn concentration for that well.
>
> 66% of the samples were within 10% of the well's grand mean, 91% were within 20% of the well's mean and 97% were within 30% of the well's grand mean.

Based on the results it was concluded that the proposed EPA sampling program, current at that time and now withdrawn, would have been adequate for determining whether an individual well site was within the compliance limit for $^{222}$Rn concentration in the well water. Noting that only wells having similar underlying geological formations in a specific region of the Piedmont area of North Carolina were sampled, thus possibly limiting the applicability of the conclusions therein, Drane provides a recommendation to utilize a reduced sampling program for those wells exhibiting a first sample at a set fraction below the applicable limit.

## Radon/Uranium Decay Chain

The uranium series consists of a decay chain starting with the long half-life nuclide $^{238}U$ and continuing through the series to the stable nuclide $^{206}Pb$. Figure 1 depicts the uranium series by plotting the atomic number Z on the vertical axis and the difference between the neutron number and the atomic number, N - Z, on the horizontal axis. This results in the depiction of the alpha decays as the vertically downward decays and the beta decays as the diagonally upward decays.

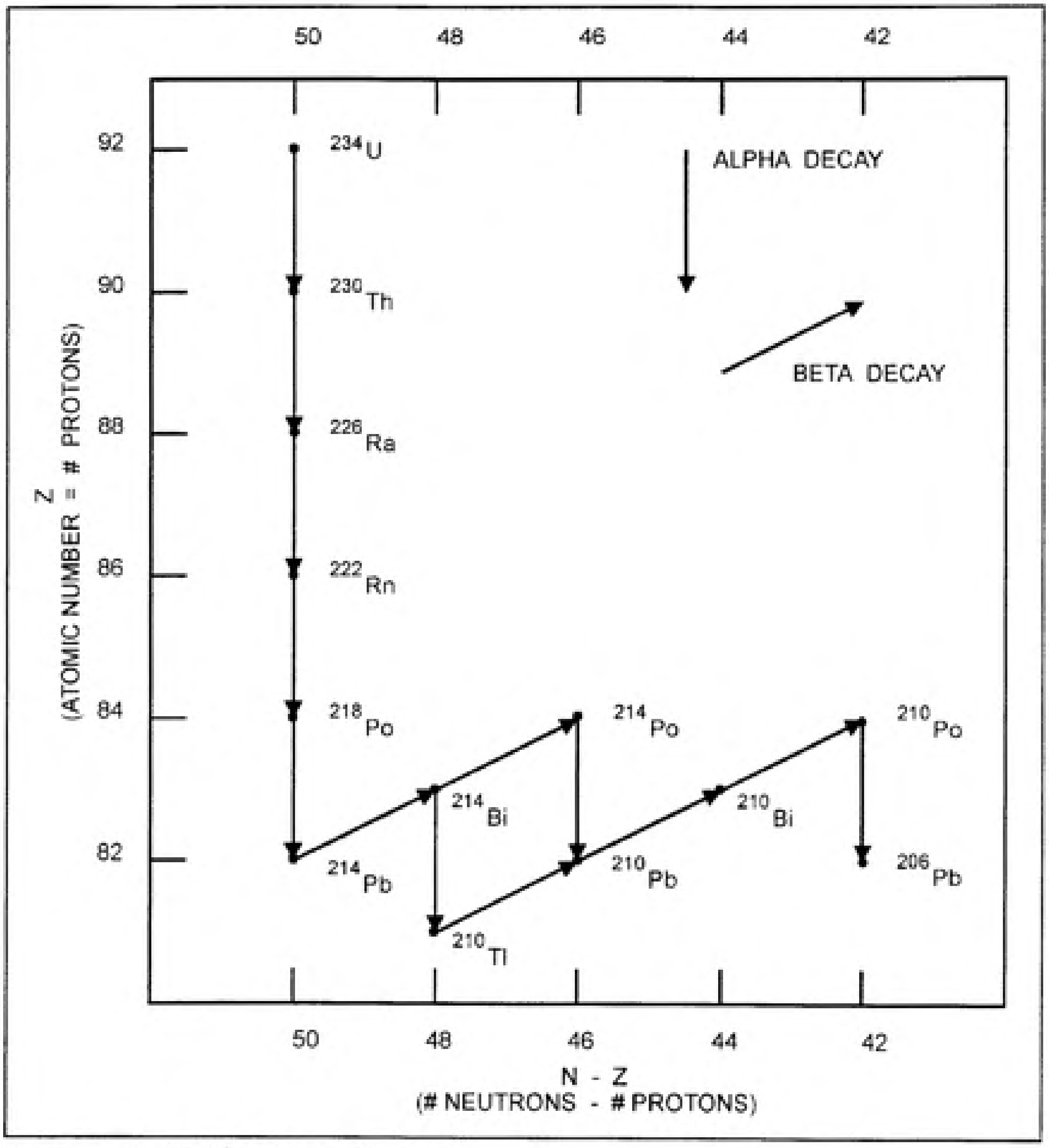


Figure 1: Uranium Decay Series

Table 1A, below, and Table 1B, following page, list the energies, half-lives and % branching between the alpha and beta decays and % gamma emission and associated gamma energy per disintegration for the uranium series. Table 1A lists values from $^{238}$U through $^{222}$Rn. Table 1B lists values from $^{218}$Po through $^{206}$Pb.

**Table 1A:** Simplified Uranium Series:
$^{238}$U Through $^{222}$Rn

| Nuclide | Half-life | Energy (MeV) | | |
|---|---|---|---|---|
| | | Alpha[a] | Beta[b] | Gamma[c] |
| Radon Production from Uranium-238 | | | | |
| $^{238}$U<br>92 | 4.468 x $10^9$ yr | 4.18 | | |
| $^{234}$Th<br>90 | 24. 10 d | | 0.193, 0.103 | 0.092(4%)<br>0.063(3%) |
| $^{234}$Pa<br>91 | 6.70 h | | 2.31 | 1.0(1.5%)<br>0.76(0.6%) |
| $^{234}$U<br>92 | 2.45 x $10^5$ y | 4.763 | | |
| $^{230}$Th<br>90 | 7.54 x $10^4$ y | 4.685 | | 0.068(0.60%) |
| $^{226}$Ra<br>88 | 1,600 y | 4.777 | | |
| $^{222}$Rn<br>86 | 3.8235 d | 5.486 | | 0.51(weak) |

a Only the highest alpha energy is listed,
percentage shown is for indicated decay path .

b Only the most prevalent beta maximum energy is listed,
percentage shown is for indicated decay path.

c Percentage shown is for gamma emissions per decay.

U - uranium, Th - thorium, Pa - protactinium, Ra - radium, Rn - radon

**Table 1B:** Simplified Uranium Series:
Radon Progeny

| Nuclide | Half-life | Energy (MeV) | | |
|---|---|---|---|---|
| | | Alpha[a] | Beta[b] | Gamma[c] |
| $^{218}$Po<br>84 | 3.11 m | 6.0026<br>(99.978%) | weak | 0.186 (3%) |
| $^{214}$Pb<br>82 | 26.8 m | | 0.67,0.73 | 0.35192(3.6%)<br>0.29522(2%)<br>0.24192 (7%) |
| $^{214}$Bi<br>83 | 19.8 m | 5.505<br>(0.04%) | 1.54,3.27,1.51<br>(99.96%) | 0.60932(29.5%)<br>1.12028 (13.1%) |
| $^{214}$Po<br>84 | 163.7 µs | 7.6871 | | |
| $^{210}$Pb<br>82 | 22.3 y | | 0.017, 0.061 | 0.046539(4.5%) |
| $^{210}$Bi<br>83 | 5.01 d | | 1.161 | |
| $^{210}$Po<br>84 | 138.38 d | 5.3044 | | 0.802 (0.001%) |
| $^{206}$Pb<br>82 | Stable | | | |

a Only the highest alpha energy is listed,
percentage shown is for indicated decay path .

b Only the most prevalent beta maximum energy is listed,
percentage shown is for indicated decay path.

c Percentage shown is for gamma emissions per decay.

Po - polonium, Pb - lead, Bi - bismuth

$^{238}$U was present at the formation of the earth's crust and because of it's long half-life, 4.468 x $10^9$ yr, it is present today. $^{238}$U is present in all rocks, between 1 and 3 ppm on average, and is present in soil to the same extent as it is present in the rock from which the soil was formed. Some volcanic rock, granite, dark shales, sedimentary rocks containing phosphate and metamorphic rocks derived from these rocks contain up to 100 ppm $^{238}$U. Further down the uranium series, $^{222}$Rn is formed by the alpha decay of $^{226}$Ra. The alpha decay of $^{226}$Ra imparts momentum to both the radon atom and the alpha particle. Depending upon the location of the $^{226}$Ra within the mineral grain, the radon atom may be ejected into the interstitial pore space between the mineral grains or it may remain embedded within the mineral grain (U.S. Geological Survey).

Since radon is a gas, once free from the mineral grain it can travel through the soil. The ability of the radon to travel is influenced by the moisture content of the soil, the porosity of the soil and the permeability of the soil to either air or water. Radon can travel much farther distances before decaying through fractures in the ground than would be possible through an equivalent porous media. Ground water velocities through fracture systems can range from meters to tens of meters per day allowing high $^{222}$Rn concentrations to persist downstream from $^{222}$Rn sources. It is the variation in the $^{222}$Rn distribution in the ground as well as the variation in flow through fracture systems supplying individual wells that contributes to the variation in $^{222}$Rn concentration observed between wells. Variation in the flow through fracture systems supplying individual wells contributes to the variation in $^{222}$Rn concentration observed at individual well sites (Folger et al. 1996).

## Safe Drinking Water Act

The national primary drinking water standard for radon proposed prior to the enactment of the Safe Drinking Water Act Amendment of 1996 has been withdrawn. The Safe Drinking Water Act Amendment of 1996 requires that a primary drinking water standard for radon be determined as follows:

1. A risk assessment for radon will be prepared by The National Academy of Sciences using the best available science. The peer reviewed assessment will consider the risks associated with exposure to radon from drinking water. Studies on the health effects of radon at residential exposure levels will be considered.

2. Examination of alternative methods of risk reduction, such as reduction of indoor air radon concentrations, will also be performed by The National Academy of Sciences.

Associated with the above two activities, analyses will be performed to determine the benefit from the health risk reduction and the cost required to comply with the maximum contaminant level being considered for radon. This analysis will be published and public comment will be sought. The analysis will include:

1. Health risk reduction benefits as a result of treatment to comply with the level and health risk reduction benefits as a result of reductions in co-occurring contaminants.
2. Cost for the compliance including monitoring, treatment and other costs.
3. Incremental costs and benefits associated with each alternative maximum contaminant level.
4. The effects of the contaminant on the general population and on groups within the general population identified as being at greater risk to the contaminant than the general population.
5. Determination of any increased health risks associated with compliance with the level.
6. An analysis of the health risk reduction benefits and costs associated with the treatment technique, as well as alternative treatment techniques.

## Study Objectives

The objectives of this study were to continue the long term, historical sampling of 11 of the 14 sites sampled by Drane. The goal of the long term sampling was to determine, at individual wells, how well individual grab samples can predict the annual average radon concentration for that well. The sites not sampled by this study were sites 1, 2 and 3 (Drane 1996). The 11 Drane sites were sampled 5 times over a 5 month period from February through June 1996. Results herein were compared with the previous results.

Two sets of specials tests were performed. Special Tests 1 through 3 examined the variation in $^{222}$Rn concentration over an eight hour period to determine, if possible, the source of a previously observed short term trend between the five sequential samples collected at Well Site #5. Special Tests 4 and 5 were performed to compare the slow-flow sampling method, used at UNC, to the proposed EPA sampling method, EPA Method 913.0 (Draft), for determining the $^{222}$Rn concentration in drinking water. As part of Special Test 5 the decrease in $^{222}$Rn concentration in uncapped scintillation vials was examined to begin to explore possible sources of $^{222}$Rn loss in the sampling process.

## LITERATURE REVIEW

### Well Studies and Temporal Variation

A literature review was performed to determine if other studies had been conducted to examine the long term variation in $^{222}$Rn concentration at individual well sites. Hightower (1994), York (1995) and Drane (1996) are three recent studies examining the temporal variation of $^{222}$Rn in well water and are the precursors to the work performed herein. Hightower's study examines the temporal variation in $^{222}$Rn concentration at four well sites in eastern North Carolina and five sites in western North Carolina over a seven month period. York's study examines the temporal variation in $^{222}$Rn concentration at ten well sites in Franklin, Wake, Orange and Chatham counties over an 11 month period. Drane consolidates the results of the two previous researchers, Hightower and York, and adds four additional well sites to the study, sampling the wells for periods of two to seven months. Drane concludes that of the 1,468 samples from the three studies 97 percent of the samples were within 30 percent of their associated mean.

Farai and Sanni (1992) reported small temporal variations in well water $^{222}$Rn concentrations in an individual well sampled three times a week, from November 1987 to October 1988. The average $^{222}$Rn concentration was reported to be 400 pCi/L with a standard deviation of 38 pCi/L. The authors attributed the $^{222}$Rn fluctuations to rainfall activity.

Watson and Mitsch (1987) examined the $^{222}$Rn concentration in well water samples from four research wells on a quarterly basis for nine months. No major changes in radium or radon concentrations were identified in the well water samples during the sample period. A recommendation was made to conduct sampling over a longer time period to seek to identify any long term variations in $^{222}$Rn well water concentration.

Simones et al. (1988) performed a study examining short term time variations in well water $^{222}$Rn concentrations. Monthly samples were obtained from 20 wells located in the Georgia Piedmont from December 1987 to February 1988. No pattern of variation in $^{222}$Rn concentrations were identified and the authors tentatively conclude "there may not be any short term time variation in radon activities in groundwaters."

Davis & Watson (1990) and Dillon et al. (1991) are two additional studies in which data are provided documenting the results of well water sampling from a number of wells sampled repetitively over time. It should be noted, however, that the stated objective of both studies was not to examine the temporal variation of the $^{222}$Rn concentration in well water. As such, neither study provided a conclusion about the temporal stability of the $^{222}$Rn concentration in the well water sample data. Davis & Watson's (1990) obtained well water samples from six different wells over a six month period from March through August of 1988. The six wells had been drilled in the same granite pluton. The sample results indicated that the $^{222}$Rn concentration in three of the six wells appeared to be fairly constant. The sampled $^{222}$Rn concentrations in the three remaining wells exhibited more variation, but with no consistent pattern of variation in the $^{222}$Rn concentration of the samples.

Dillon et al. (1991) measured the $^{222}$Rn concentration in well water samples from 283 wells located in the Georgia Piedmont. One grab sample was taken sometime between October 1987 and September 1988 from 278 of the 283 wells. Two samples were obtained from the remaining five wells, with three to thirteen months elapsed time between samples. Sample results from two of the five wells sampled twice exhibited identical well water $^{222}$Rn concentrations between the two samples. The remaining three wells had well water $^{222}$Rn concentrations that differed by as much as a factor of two between the two samples.

## Sampling Methods Comparison

A literature review was also performed to determine if other studies had been conducted to compare sampling methods for the determination of $^{222}$Rn concentration in well water. For the purposes of this review "sampling methods" includes the preparation of the scintillation vials in the laboratory, obtaining the liquid sample at the well site, and the processing of the sample upon return to the laboratory up until the point that the sample is placed in the LSC or other measurement device. Belloni et al. (1995) and Kitto et al. (1996) provide comparisons of sampling methodologies, however both compare methods to measure the activity once the sample has been obtained. Belloni et al. perform comparisons between liquid scintillation counting, Lucas cell alpha-scintillation counting and gamma counting of radon daughters in a Marinelli beaker. Kitto et al. perform comparisons between liquid scintillation counting, Lucas cell alpha-scintillation counting and alpha-scintillation counting using a portable instrument (Pylon). Neither study compares methods used to obtain samples at the sample source. No other relevant studies were identified.

## Types of Searches Conducted for Literature Review

In an effort to aid future researchers a brief description is provided of the two main scientific literature databases searched for the literature review performed herein, as follows:

GeoReF

GeoRef is produced by the American Geological Institute and the entire database contains entries from 1785 to the present date, although the disk containing data from 1988 to September 1995, GEOREF Disc 3, was used for the searches herein. GeoRef covers international literature on geology and geosciences, including the Bibliography of North

American Geology (1785-1970),
Bibliography of Theses in Geology (1965-1966), Bibliography and Index of Geology Exclusive of North America (1933-1968), Geophysical Abstracts (1966-1971), and the Bibliography and Index of Geology (1969 to date).

CARL UnCover

CARL UnCover is produced by the Colorado Alliance of Research Libraries and contains current article and table of contents information taken from 15,000 journals in many scientific disciplines. UnCover contains brief descriptive information about 5,000,000+ articles which have appeared since Fall 1988. Over 4000 current citations are added daily.

## METHODOLOGY

### Long Term Study of Variation of $^{222}$Rn Concentration in Well Water

Eleven wells were sampled for this study. This study continued the sampling of wells performed by Drane, with the exception of the wells in Franklin and Wake Counties (Drane wells 1, 2 and 3). This portion of the research examined the long term variation of the radon concentration by sampling the wells on approximately a monthly basis, although with some exceptions, as shown in Table 2, below:

**Table 2:** Sample Run Dates

| Sample Run Number | Date |
|---|---|
| 1 | 02/09/96 |
| 2 | 03/02/96 |
| 3 | 03/08/96 |
| 4 | 03/30/96 |
| 5 | 06/05/96 |

Five sequential samples were obtained at each well site during each sample run. Samples were obtained using the slow-flow method, described below, and then returned to the laboratory for analysis.

### Slow-flow Method

The objective of any sampling method is to obtain a representative sample in a reasonable cost-effective manner. Since the goal of $^{222}$Rn sampling of drinking water is to determine the $^{222}$Rn activity per unit volume of liquid, a representative sample is obtained by minimizing loss of radon gas from the liquid sample and preventing the dilution of the liquid sample by the addition of a non-representative liquid.

As discussed previously, the well is first purged for ten minutes to displace the volume of standing water in the well piping. It is assumed that the standing water contains a non-representative concentration of $^{222}$Rn because of the possibility of radon loss in the piping from decay, and de-gassing of the $^{222}$Rn from the well water. Once the piping has been purged the flow rate of the well water is adjusted at the sample collection point until a slowly flowing stream of water is obtained. It is desirable to obtain a flow rate that is steady, laminar and such that when the vial is filled neither scintillation fluid nor water is lost from the vial. Once the desired flow rate is established the vial is filled by holding the vial at approximately a 45° angle and allowing the flowing well water to flow down the inside wall of the vial and pool under the scintillation fluid. The vial is filled until the total volume of water and scintillation fluid reaches to just below the upper neck of the scintillation vial. The vial is then removed from the flowing water and capped. During cold weather care should be taken in tightening the cap onto the vial as the threaded portion of the vial may become brittle and break off.

**Detailed Methodology**

The sampling sequence for each run consisted of the following steps:

Actions performed at radiological laboratory prior to Sample Run:

1. Obtain five 23 milliliter scintillation vials and caps for each well to be sampled.

   20 milliliter borosilicate glass vials
   white urea caps, cone shaped plastic liners
   Fisher 03-337-7

2. Fill each scintillation vial by pipette with 10 milliliters of mineral oil scintillation fluid and then cap the vial.

   High Efficiency Mineral Oil Scintillator Fluid
   Packard No. 6NE9579 (2.5 liters)
   20 milliliter REPIPET
   Fisher 13-687-21

3. Mark cap with unique numerical designator corresponding to well number and sequence number using permanent ink marker.

4. Weigh each filled and capped scintillation vial and record pre-weight on Sample Run Data Sheet.

   Note: The pre-weight is the weight of the scintillation vial, the cap and the 10 milliliters of scintillation fluid.

Actions performed at each well site during Sample Run:

1. On arrival at well site determine if well pump is running.

If well pump **is not** running then:

2. Start pump by manually actuating low pressure switch or by draining sufficient water to actuate low pressure switch automatically.

3. Once well pump has started, purge well for ten minutes.

4. Obtain five sequential samples using the slow-flow technique and record time at which each of the 5 samples are obtained on Sample Run Data Sheet.

   Note: At this point the vials contain 10 milliliters of scintillation fluid and approximately 10 milliliters of well water and are capped as the final step of the slow-flow technique. The vials are not opened again at any later time in the analysis procedure. This minimizes any potential loss of radon from the vials.

5. Restore well site to as-found condition, secure valves previously opened by closing them, turn off light, lock door.

6. Transport the samples to the radiological hygiene laboratory.

If upon arrival at well site well pump **is** running then:

2. If it is in the judgement of the researcher that the pump has been running longer than 10 minutes, perform above Steps 4, 5 and 6. This is determined by comparing the well water tank pressure with the low pressure switch setting that actuates the well pump.

   If it is in the judgement of the researcher that the pump has not been running longer than 10 minutes or it cannot be determined how long the pump has been running, perform above Steps 3, 4, 5 and 6.

Actions performed at radiological laboratory after Sample Run:

1. Weigh each scintillation vial and record post-weight on Sample Run Data Sheet.

   Note: The post-weight is the weight of the scintillation vial, the cap, the 10 milliliters of scintillation fluid and the approximately 10 milliliters of well water. The difference in the pre-weight and the post-weight of each vial is the mass of the well water in the vial. The corresponding well water volume is used once the activity of each sample is determined to calculate the radon concentration of the sample.

2. Clean each vial with a soft paper towel or tissue and shake the vial for 15 seconds to thoroughly dissolve the radon gas into the scintillation fluid.

3. Using the scintillator racks, place the four blanks and radon source in the first five slots of the first rack. Skip a slot and place the first set of five well sample vials in the next five slots, leaving the sixth and twelfth slot empty.

4. Fill the second and subsequent racks with five vials, skipping the sixth slot, and then filling with five more vials, skipping the twelfth slot, until all the vials have been placed in the racks. Thus each rack will have five vials, an empty sixth slot and then five more vials and an empty twelfth slot.

   Note: Leaving the sixth and twelfth slot empty will create a break in the results printout allowing for easier reading of the resultant data.

5. Record the unique numerical designator, corresponding to well number and sequence number, on the Scintillator Order Counting Sheet in the order that the vials are to be counted. This information is used later to associate the activity in the vial determined by the LSC with a specific well sample.

6. Place the appropriate protocol flag on the first rack, place a computer disk in the LSC disk drive, load the racks into the LSC and press the F2 button to start the counting of the activity in the vials.

### Scintillation Counting

Scintillation counting was performed using the same protocol as in the Drane and York studies with the exception that all of the sample runs herein were counted with the luminescence correction turned on. Luminescence is the production of photons not related to the counting of radioactive decay events. The LSC uses dual photo-multiplier tubes to discriminate between radioactive decay events and luminescence. Using coincident circuitry, which counts both radioactive and non-radioactive events, and delayed-coincident circuitry which counts only non-radioactive events, the radioactive counts are determined by the difference of the two counts. Table 3, below, describes the LSC protocol used for this study.

**Table 3:** Packard TRI-CARB 1900TR Preset Parameters

| | | | |
|---|---|---|---|
| Cycles: | 1 | | |
| Count Time: | 50.00 [minutes] | | |
| 2 Sigma Coincidence: | yes | | |
| #Counts/Vial: | 1 | | |
| Vials/Standard: | 1# | Vials/Sample: | 1 |
| 1st Vial Background: | no | | |
| Radionuclide: | Manual | | |

| | LL | UL | Bkg | 2Sigma% | LCR |
|---|---|---|---|---|---|
| Region A | 0.0 | 2000 | 0.00 | 20.0 | 0 |
| Region B | 5.0 | 1850 | 0.00 | 2.0 | 0 |
| Region C | 25.0 | 1000 | 0.00 | 20.0 | 0 |

| | | |
|---|---|---|
| Qip | TSIE | ES Terminator 15 sec |
| % of Reference | no | |
| Data Mode | cpm | |

| | | |
|---|---|---|
| Half Life | A: 0.00 | B: 0.00 |
| Ref Date | A: 1/1/93 | B: 1/1/93 |
| Ref Time | A: 0:0 | B: 0:0 |

| | |
|---|---|
| Single Photon Count | no |
| Colored Samples | no |
| RS232 Computer Output | no |

| | |
|---|---|
| Luminescence Correction | yes |
| High Sensitivity Mode | no |

| | |
|---|---|
| Data/Application Drive & Path | |
| Save Data | (variable) |
| Save Spectrum | yes |
| Run User Application | no |
| Static Controller | on |

## Data Analysis

$^{222}$Rn concentration is determined using the following relationship for activity per unit volume:

$$C\ (\frac{pCi}{L}) = \frac{(CPM_{channel\ B} - CPM_{background})(\exp^{\lambda t})}{(V_{sample})(CF)}$$

$C\ (\frac{pCi}{L})$ = *222 Rn Concentration*

$CPM_{channel\ B}$ = *counts per minute channel B*

$CPM_{background}$ = *average of four background counts*

$\exp^{\lambda t}$ = *decay correction factor*

$\lambda$ = *radon decay constant* $1.259 \times 10^{-4}\ \text{min}^{-1}$

$t$ = *time in minutes from sample collection to midpoint of LSC count*

$V_{sample}$ = *volume of water sample in Liters*

$CF$ = *calibration factor*

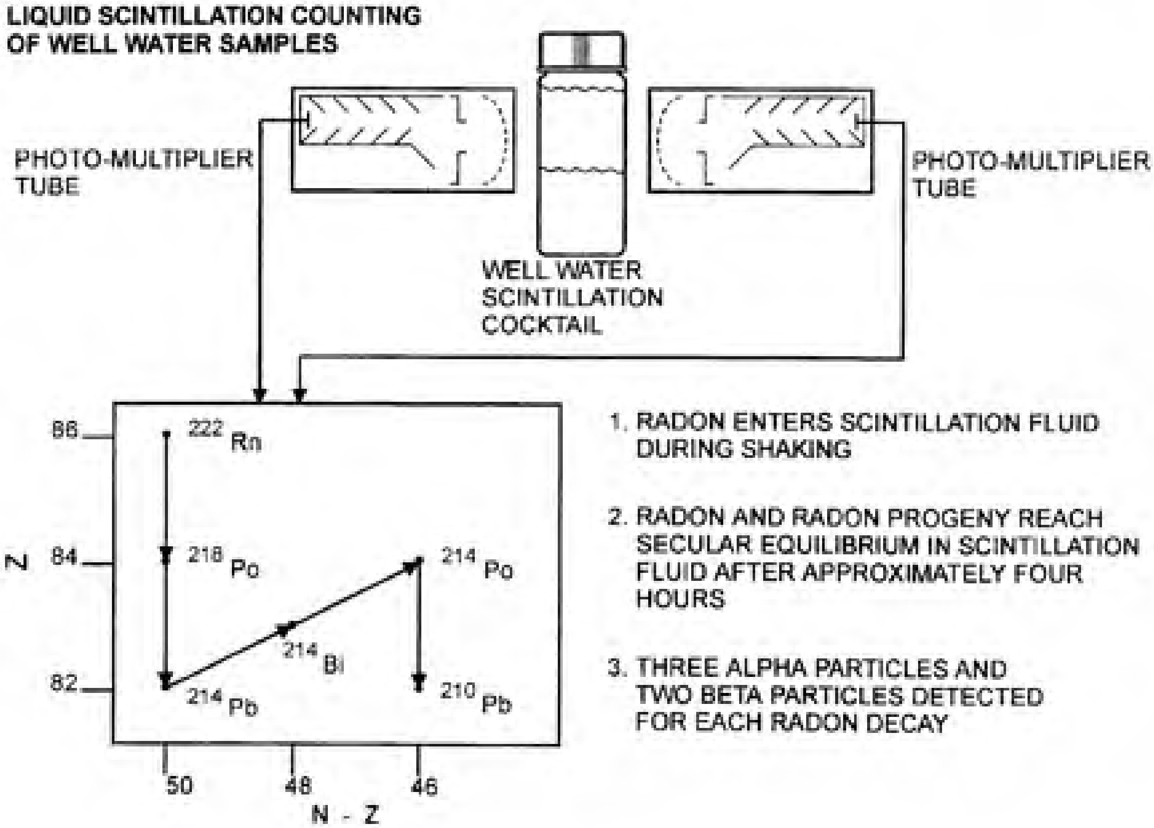
$$CF = \frac{\text{counts per minute in channel B for radon source}}{\text{activity of radon source}}$$

**Well Water Sample Counting**

The $^{222}$Rn activity of an individual well water sample is determined by "counting" the sample in the LSC. The activity of the sample is determined by comparison of the sample counts to the counts obtained from a source of known activity. The well water sample activity is determined by dividing the counts per minute above background of the sample by a calibration factor. The calibration factor is calculated by first counting the $^{222}$Rn source of known activity in the LSC and is the ratio of the counts per minute above background to the activity of the source. The background count is obtained by counting four vials containing 20 milliliters of demineralized water and then averaging the counts.

As described on the previous page, the activity at the time of sample collection is obtained by decay correcting the above sample activity by the decay correction factor. The $^{222}$Rn concentration is then determined by dividing the decay-corrected activity by the sample volume. This study used a counting window from 5 to 1850 keV, designated as channel B, for the counting of the sample, source and background vials. Figure 2A, below, is a schematic depiction of the counting of the well water sample using the LSC:

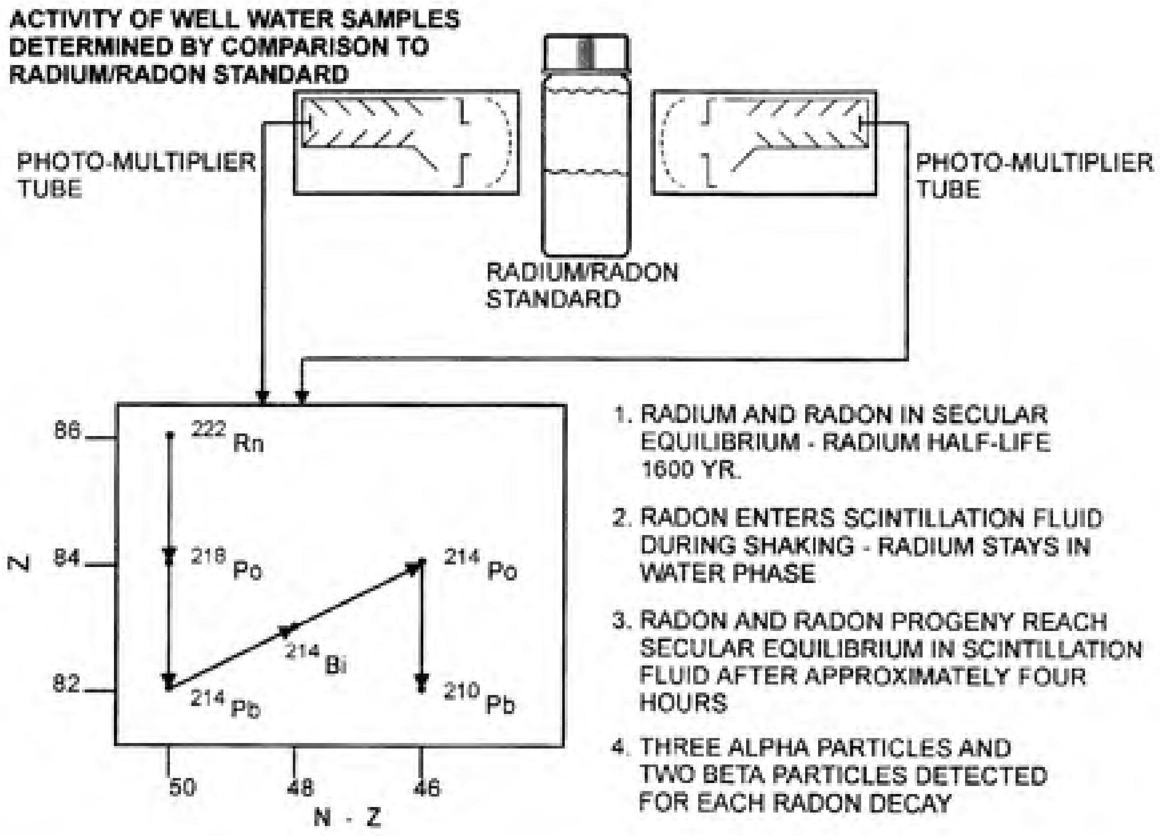
**Figure 1A:**


LIQUID SCINTILLATION COUNTING OF WELL WATER SAMPLES

### Radon Source Counting

The radon source is made by placing a known amount of $^{226}$Ra in a scintillation vial along with scintillation fluid and water. The $^{226}$Ra decays and after approximately seven half-lives of the daughter product, $^{222}$Rn (3.2385 day half-life), the $^{226}$Ra is in secular equilibrium with the $^{222}$Rn. Secular equilibrium is where the activity of the parent radionuclide is equal to the daughter radionuclide. Upon shaking the vial, the $^{222}$Rn gas enters the scintillation fluid and the $^{226}$Ra remains in the water. Thus the $^{226}$Ra produces a source of $^{222}$Rn that is at a relatively constant activity over a long period of time, since the half-life of the $^{226}$Ra is 1600 years. This study used a radon source of 714 pCi. Figure 2B, below, is a schematic depiction of the counting of the radon source using the LSC:

**Figure 1B:**



1. RADIUM AND RADON IN SECULAR EQUILIBRIUM - RADIUM HALF-LIFE 1600 YR.
2. RADON ENTERS SCINTILLATION FLUID DURING SHAKING - RADIUM STAYS IN WATER PHASE
3. RADON AND RADON PROGENY REACH SECULAR EQUILIBRIUM IN SCINTILLATION FLUID AFTER APPROXIMATELY FOUR HOURS
4. THREE ALPHA PARTICLES AND TWO BETA PARTICLES DETECTED FOR EACH RADON DECAY

## Short Term Studies of Variation of $^{222}$Rn Concentration in Well Water

This portion of the study examined the short term variation in the $^{222}$Rn concentration at an individual well. In the York study, Well #5 was identified as having a consistently lower first vial $^{222}$Rn concentration and a consistently higher last vial $^{222}$Rn concentration within a sample run. York concludes that inadequate purging of the well prior to the commencement of sampling might be an explanation for the observed trend within individual sample runs.

In the Drane study, Well #5 was identified as having frequently a higher first vial $^{222}$Rn concentration followed by a decreasing concentration of $^{222}$Rn concentration to the last vial within a sample run. Drane concludes that possibly water was being drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continued water was then drawn from areas of lower $^{222}$Rn concentration, further away. Based on the decreasing trend observed in $^{222}$Rn concentration within the sample runs for Well #5, Drane concluded that the explanation of inadequate purging of the well, provided by York, was not supported.

Based on the possible explanation for the trend observed by Drane, that water was drawn from areas of differing $^{222}$Rn concentration over the sample period, the short term tests were designed to attempt to determine if this was occurring. Additional factors considered, that might influence the $^{222}$Rn concentration, included well pump operation, such as starting and stopping the pump versus continuous operation of the well pump over an extended period.

Studies to examine well purging were not explored as the Drane data and the 1996 data show a decreasing trend in the Well #5 $^{222}$Rn concentration over individual sample runs, suggesting that inadequate purging was not occurring. Since the standing water in the well drop pipe is at a lower $^{222}$Rn concentration due to radioactive decay than the freely flowing ground water, inadequate purging of the well prior to sampling would show an increasing trend in the $^{222}$Rn concentration as the standing water in the well drop pipe is sampled first and then replaced by the ground water at the higher equilibrium $^{222}$Rn groundwater concentration.

### Well Selection Criteria

Tabulated below, Table 4, are the well site average $^{222}$Rn concentrations and standard deviation of the concentration through the end of 1995 as recorded by Drane. In the examination of the short term variation, in addition to the observations described above, it was felt necessary to select a well that had a relatively high average $^{222}$Rn concentration and a relatively large standard deviation of the $^{222}$Rn concentration. Well Site #5 ranked as follows:

1. Fourth highest $^{222}$Rn concentration of the 11 well sites.
2. Third highest standard deviation.

Additionally, practical factors also contributed to the decision to select Well Site #5. Because the site supplies a single user it was possible to coordinate with the owner to obtain permission to operate the well pump continuously for eight hour periods.

**Table 4:** Well Site Average Concentrations and Standard Deviations Through the End of 1995

| Well Site # | Average $^{222}$Rn Concentration (pCi/L) | Standard Deviation (pCi/L) |
|---|---|---|
| 5 | 1868 | 232 |
| 6 | 183 | 24 |
| 7 | 515 | 35 |
| 8A | 3280 | 356 |
| 8B | 1081 | 149 |
| 9 | 2242 | 248 |
| 10 | 2670 | 133 |
| 11A | 354 | 32 |
| 11B | 136 | 13 |
| 12 | 1066 | 98 |
| 13 | 406 | 24 |

## Sampling Methodology

The examination of the short term variation in $^{222}$Rn concentration was performed in a tiered approach. Two tests were performed, each over an eight hour period, but with a different pattern of pump operation. Based on the results of the two tests the methodology for the third test was devised. All samples were taken using the slow-flow method and processed as described in the methodology section for the long term sampling study.

## Special Test #1

This test was performed over an eight hour period. The well pump was operated continuously during the first 2 hours of the test and then operated for a twenty minute period at the fourth hour, the sixth hour and the eighth hour. Sixty samples were taken, with half the samples taken during the first two hours and the other half taken in equal numbers at the fourth hour, the sixth hour and the eighth hour. All samples were taken with the pump in operation. The following figure illustrates diagrammatically the sampling sequence and the pump operation during the eight hour sampling period:

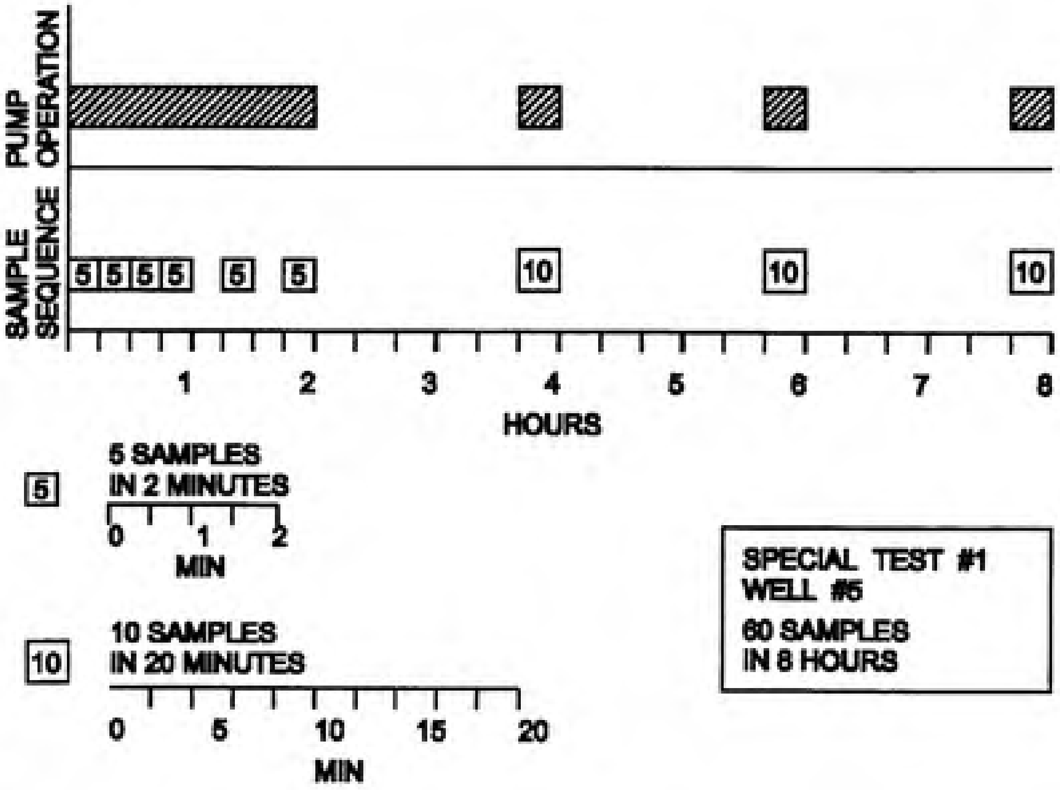


**Figure 2:** Special Test #1 Sampling Sequence

**Special Test #2**

This test was performed over an eight hour period. The well pump was operated continuously during the 8 hours of the test. Sixty samples were taken, with half the samples taken during the first two hours and the other half taken in equal numbers on the hour for the third through eighth hour. The following figure illustrates diagrammatically the sampling sequence and the pump operation during the eight hour sampling period:

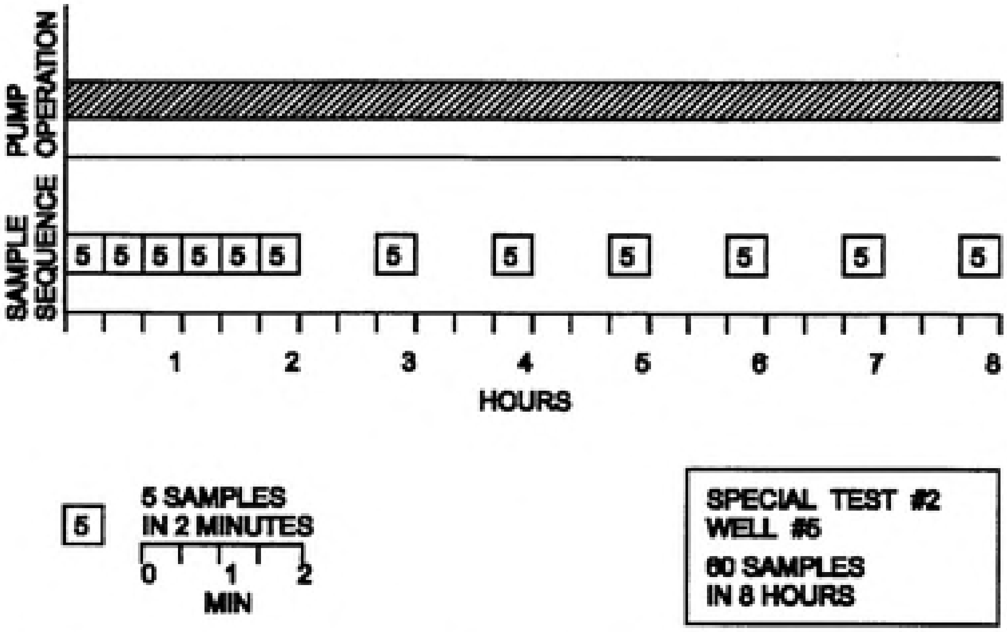


**Figure 3:** Special Test #2 Sampling Sequence

**Special Test #3**

The results of the two previous short term tests were examined and it was decided to design the third test to try to identify the cause of the unusual decrease in $^{222}$Rn concentration seen at the end of the fourth, sixth and eighth hour sample sequences of Special Test #1. Ninety samples were taken in six 15 sample increments, with half the samples taken during the first two hours. The samples taken during the first two hours were sequenced to increase the number of samples taken at the beginning of the sample sequence. The sample sequence for the samples taken during the first two hours started with five samples taken during the first two minutes and the next ten samples taken over the next twenty minutes of the sample sequence.

The remaining 45 samples were taken at the fourth hour, the sixth hour and the eighth hour. The samples taken during the last six hours were sequenced to increase the number of samples taken at the end of the sample sequence. The sample sequence for the three sets of samples taken during the last six hours started with ten samples taken over the first twenty minutes and then five samples taken during the last two minutes of the sample sequence. The last three sets of 15 samples each were taken in reverse order from the first three sets in order to concentrate the number of samples at the end of the sample sequence. All samples were taken with the pump in operation. The following figure illustrates diagrammatically the sampling sequence and the pump operation during the eight hour sampling period:

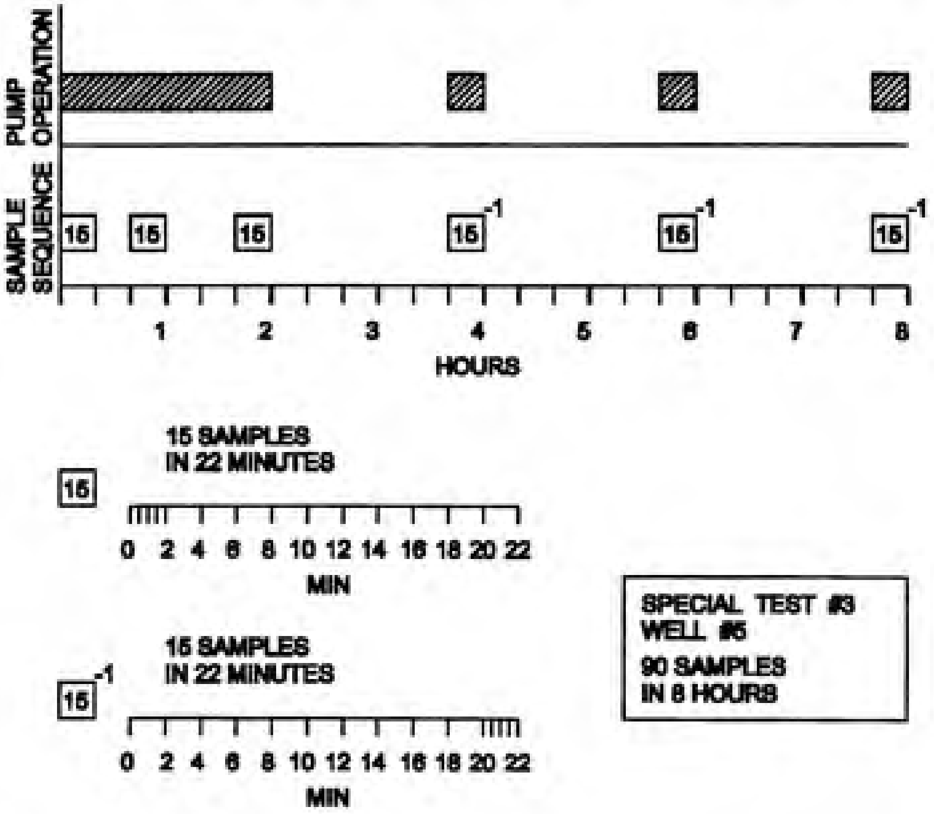


**Figure 4:** Special Test #3 Sampling Sequence

## EPA vs. UNC Comparison of $^{222}$Rn Sampling Methodologies

Presently no standardized sampling methodology has been established for obtaining drinking water samples to determine $^{222}$Rn concentration in water. For this study "sampling methodology" included the preparation of the scintillation vials in the laboratory, obtaining the liquid sample at the well site, and processing the sample upon return to the laboratory up until the point that the sample was placed in the LSC. It was not within the scope of the tests performed herein to examine LSC optimization nor to examine sample volumes versus scintillation fluid volumes within the scintillation vial.

Special Test #4 and Special Test #5 were performed to compare the slow-flow sampling methodology developed at UNC versus the proposed EPA sampling methodology, EPA Method 913.0 (Draft). To analyze for a contaminant concentration in drinking water two parameters are determined:

1. The amount of the contaminant in the sample;

2. The volume of the drinking water sample.

Important differences exist between the UNC and the proposed EPA sampling methodology; these differences lie in the way the sample is collected and the way the volume of the drinking water sample is determined. The LSC processing in the two methods to determine the activity of the $^{222}$Rn was identical in this comparison. The UNC method requires that the scintillation fluid be added to the vial at the laboratory, then vial, fluid and vial cap are pre-weighed. The drinking water sample is then obtained with scintillation fluid already present in the scintillation vial. Once the sample is obtained and capped it is not opened again and need only be weighed a second time to determine the volume of water obtained for the sample. The proposed EPA sampling method requires that the scintillation vial be filled completely with the sample water, at the well site, and then capped. The vial is then uncapped upon return to the laboratory and a known volume of water is then removed and discarded and a measured volume of scintillation fluid is added to the remaining water in the vial. The volume of the water sample obtained using the EPA sampling method can be determined by either:

1. Assuming the vial is a fixed, constant volume and subtracting the volume of water removed from this volume to determine the sample volume, or;

2. The water sample volume can be determined by pre-weighing the empty scintillation vial and cap and then weighing the scintillation vial, cap and remaining water sample once the fixed volume of water has been extracted.

Special Test #4 and Special Test #5 compared the two sample collection methods, UNC versus EPA, and also compared two possible methods of handling the EPA samples once collected, herein designated EPA Method "A" and EPA Method "B," corresponding to #1 and #2 above, respectively.

### Well Selection Criteria

In the UNC versus EPA comparison it was decided to select a well that had a relatively high average $^{222}$Rn concentration and a small standard deviation of the $^{222}$Rn concentration. This was done to select a well site that would have a small variation in concentration between samples. Well Site #10 was chosen for the following reasons:

1. Second highest average $^{222}$Rn concentration of the 11 well sites.
2. Lowest standard deviation of the five highest average $^{222}$Rn concentration sites.

### Special Test #4

This test compared the sample collection methodology developed at UNC versus the proposed EPA sampling methodology. UNC samples were collected and processed as described in the slow-flow method section. EPA samples were collected as described in the following detailed methodology section. The EPA samples were processed using EPA Method "B" for this test. This test differs from Special Test #5 only in how the samples for the EPA method were handled to determine the sample volume. Special Test #4 collected 20 UNC samples and 20 EPA samples in 50 minutes in the sequence, as shown below:

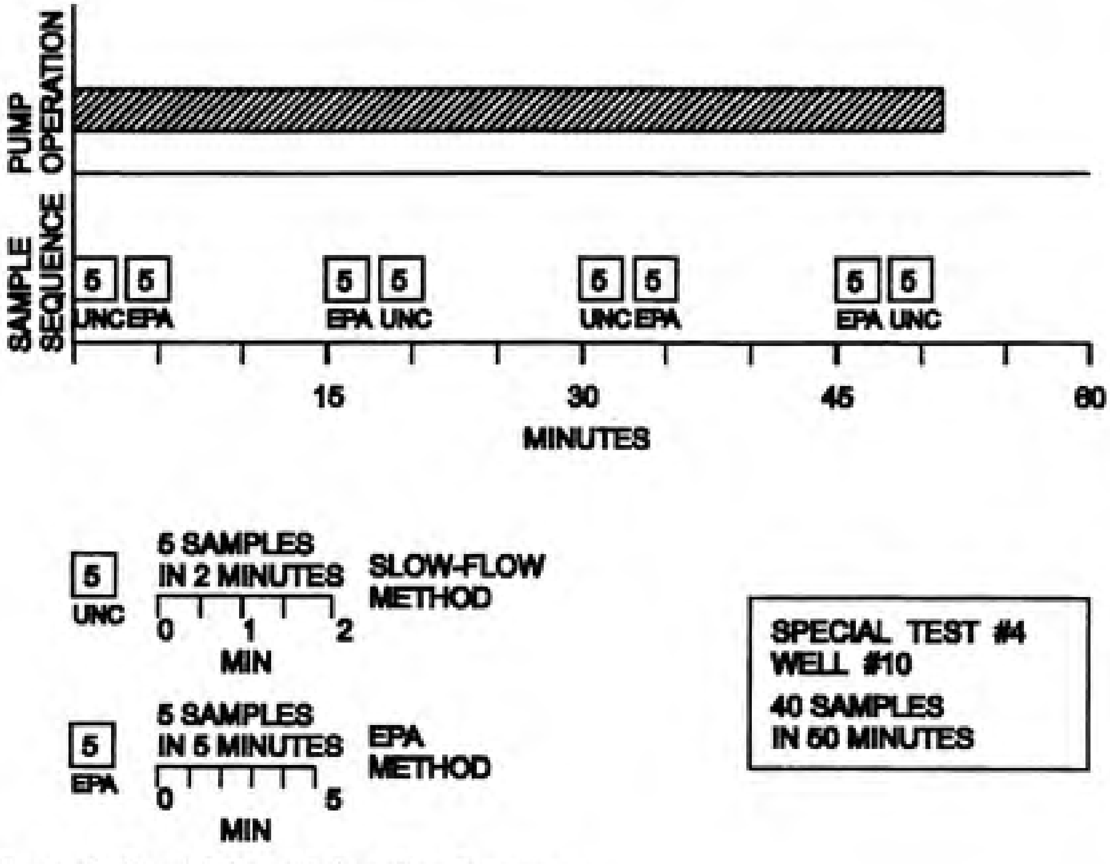


**Figure 5:** Special Test #4 Sampling Sequence

**Special Test #5**

This test was a follow-up test to Special Test #4. Special Test #5 was designed to determine if the additional handling of the sample in EPA Method "B" contributed to the lower $^{222}$Rn concentration observed in Special Test #4 versus the UNC samples. EPA Method "A" was proposed to process the samples without the extra handling associated with weighing the samples to determine the sample volume. UNC samples were collected and processed as described in the slow-flow method section. Two sets of EPA samples were collected as described in the following detailed methodology section. The EPA samples were processed using EPA Method "A" and EPA Method "B" for this test. EPA samples were all collected using the same sample collection method, as described in the following detailed methodology section. The differences in EPA Sample Method "A" and EPA sample Method "B" lie only in how the sample volumes were determined upon return to the laboratory. Special Test #5 collected 20 UNC samples and 40 EPA samples, 20 for Method "A" and 20 for Method "B," in 50 minutes in the sequence, as shown below:

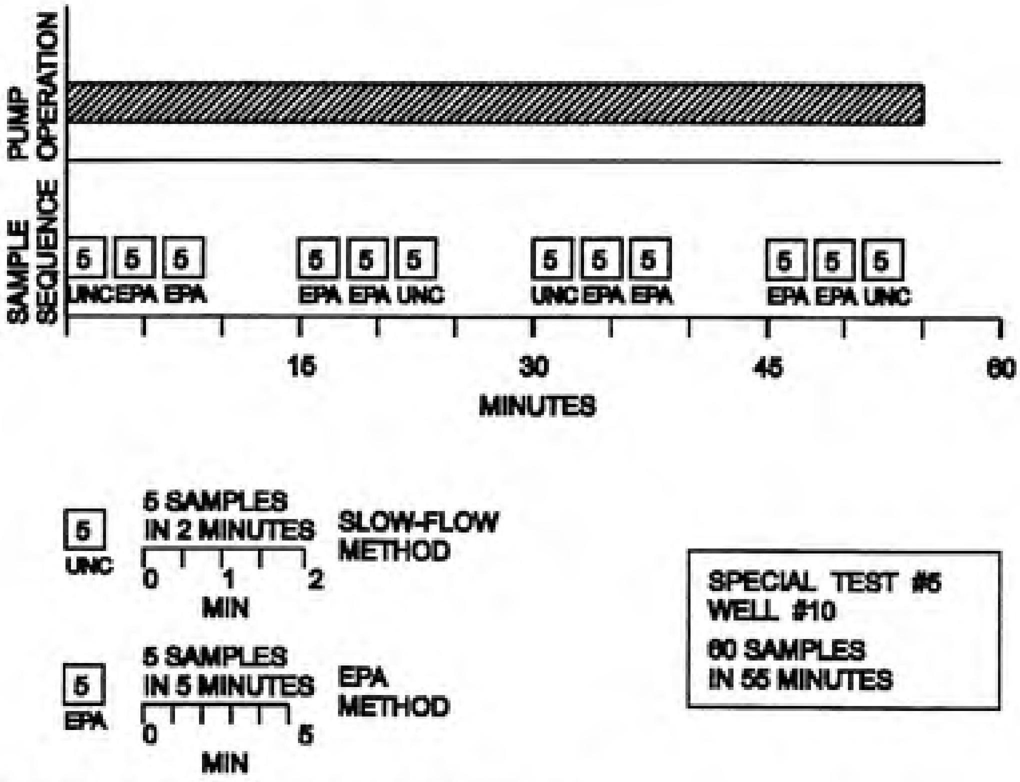


**Figure 6:** Special Test #5 Sampling Sequence

As an adjunct to the comparison of sampling methodologies an additional test was performed during Special Test #5 to demonstrate the loss of $^{222}$Rn from open sample vials. For this test 10 additional samples were collected using the EPA sample collection method. Upon return to the radiological hygiene laboratory the 10 sample vials were uncapped, the excess liquid was removed and the 10 vials were allowed to remain open for differing lengths of time. After five minutes the first vial was weighed and 10 milliliters of scintillation fluid was added to the vial and then the vial was capped. Every five minutes another vial was similarly processed until 50 minutes had elapsed and the last vial had been processed. The vials were then cleaned, shaken and counted in the same manner as all of the other vials in this study.

## Sampling Methodology

The proposed EPA method to determine the $^{222}$Rn concentration in drinking water, EPA Method 913.0 (Draft), was compared with the slow-flow method used in this research and used by previous UNC researchers (Hightower 1994, York 1995, Drane 1996). The proposed EPA method provides a brief description of the sample collection procedure and from this description two detailed procedures were developed for comparison to the slow-flow method, EPA Method "A" and EPA Method "B," described below.

The sample collection methodologies of the two EPA methods described herein were identical. They differ in the method of determining the volume of water remaining in the scintillation vials when counted in the LSC. In EPA Method "A" a fixed volume of 10.5 milliliters was assumed to be in the scintillation vials after the excess sample water was extracted and in EPA Method "B" the remaining sample water was determined by weighing the vial when empty and then after the excess liquid was extracted. As will be described in the following section, EPA Method "B" samples were handled more and the vials were open to the air longer than samples processed using EPA Method "A". As discussed previously, in seeking a representative sample to determine the $^{222}$Rn in drinking water, loss of $^{222}$Rn should be minimized. Perhaps EPA Method "A" more closely resembled the methodology intended by the EPA because of the lower potential for loss of $^{222}$Rn from the sample associated with less sample handling.

## Detailed Sampling Methodology

The sampling sequence for EPA Method "A" consisted of the following steps:

Actions performed at radiological laboratory prior to Sample Run (EPA Method "A").

1. Obtain five 23 milliliter scintillation vials and caps for each sample sequence.

20 milliliter borosilicate glass vials
white urea caps, cone shaped plastic liners
Fisher 03-337-7

2. Cap each vial and mark caps, each with a unique numerical designator, corresponding to the sample sequence number and method designator using permanent ink marker.

Sample collection methodology (EPA Method "A"):

1. Start well pump and purge well as described previously.

2. Attach sampling hose to the well sample spigot threaded connection.

3/8" inner diameter x 1/2" outer diameter
Tygon tubing - 1 meter in length
Hose connection with 3/8" hose barb
1/2" hose clamp

3. Remove caps from five sample vials and place vials in a 1000 milliliter beaker.

1000 milliliter beaker
Kimax
No. 14000

4. Slowly open valve at sample spigot and adjust valve to create a steady water stream sufficient to fill beaker and vials in the following steps. Allow water to flow and purge sample hose by directing water stream onto the floor for 30 seconds.

5. Introduce sample stream into each of the five vials in the beaker sequentially so that they do not start to float when beaker is filled. Continue to fill beaker from sample hose while being careful not to knock over the vials. Vials should remain upright during sampling procedure.

6. Once beaker is full, introduce the tip of the sample hose into each submerged vial and purge each vial with flowing water sufficiently to displace 50 to 100 milliliters of volume; usually 2 to 3 seconds will be sufficient.

7. Secure sample flow by closing sample spigot valve.

8. Place filled beaker and vials on stable surface.

9. Cap each vial one at a time by submerging the cap in the water in the beaker with the

cap threads facing upwards to displace any air in the cap. Turn the cap so that the threaded portion is downwards and screw the cap onto the vial as much as possible and then remove vial and cap together. Tighten cap completely and invert the vial and check for air bubbles. Discard the sample if any bubbles are detected.

10. Repeat procedure as required to obtain a sufficient number of samples.

11. Place each sample sequence set of vials in a plastic bag, no more than five to a bag, and close plastic bag such that the bag is partially full with air to provide some shock absorption during transport. Place the bagged vials in a cooler to prevent temperature excursions.

12. Transport the samples to the radiological hygiene laboratory.

<u>Actions performed at radiological laboratory after Sample Run (EPA Method "A"):</u>

1. If the outdoor temperature or temperature during transport was such that the samples were transported with ice and are cool upon arrival at the laboratory it is then necessary to let the vials warm up to ambient temperature and allow any condensation to drain off of the exterior of the vials. This can be done by removing the vials from the bags and placing them upright on absorbent paper such as paper towels.

2. Once the vials are at ambient temperature and the vial exteriors are determined to be dry they are ready for further processing.

   Note: Vials should be opened and processed singly and then closed. To reduce any potential loss of $^{222}$Rn it is strongly recommended **<u>not to</u>** process the vials in batches containing multiple vials. Processing the vials singly will minimize the length of time that the vials are open to the ambient air and should result in a minimization of potential loss of $^{222}$Rn from the sample.

3. Open the first vial and using a syringe or pipette remove 13 milliliters of water.

4. Fill the vial by pipette with 10 milliliters of mineral oil scintillation fluid and then cap the vial.

High Efficiency Mineral Oil Scintillator Fluid
Packard No. 6NE9579 (2.5 liters)
20 milliliter REPIPET
Fisher 13-687-21

5. Clean each vial with a soft paper towel or tissue and shake the vial for 15 seconds to thoroughly dissolve the radon gas into the scintillation fluid.

6. Continue processing the vials in the LSC as described in the slow-flow method.

The sampling sequence for EPA Method "B" consists of the following steps:

Actions performed at radiological laboratory prior to Sample Run (EPA Method "B"):

1. Obtain five 23 milliliter scintillation vials and caps for each sample sequence.

> 20 milliliter borosilicate glass vials
> white urea caps, cone shaped plastic liners
> Fisher 03-337-7

2. Cap each vial and mark caps, each with a unique numerical designator, corresponding to the sample sequence number and method designator using permanent ink marker.

3. Weigh each capped and marked scintillation vial and record pre-weight on Sample Run Data Sheet.

   Note: The pre-weight is the weight of the scintillation vial and the cap.

Sample collection methodology (EPA Method "B"):

1. Identical to EPA Method "A"

Actions performed at radiological laboratory after Sample Run (EPA Method "B"):

1. If the outdoor temperature or temperature during transport was such that the samples were transported with ice and are cool upon arrival at the laboratory it is then necessary to let the vials warm up to ambient temperature and allow any condensation to drain off of the exterior of the vials. This can be done by removing the vials from the bags and placing them upright on absorbent paper such as paper towels.

2. Once the vials are at ambient temperature and are determined to be dry they are ready for further processing.

   Note: Vials should be opened and processed singly and then closed. To reduce any potential loss of $^{222}$Rn it is strongly recommended **not to** process the vials in batches containing multiple vials. Processing the vials singly will minimize the length of time that the vials are open to the ambient air and should result in a minimization of potential loss of $^{222}$Rn from the sample.

3. Open the first vial and using a syringe or pipette remove 13 milliliter of water.

4. Weigh the scintillation vial and cap and record post-weight on Sample Run Data Sheet.

   Note: The post-weight is the weight of the scintillation vial, the cap, and the approximately 10 milliliters of well water remaining in the vial. The difference in the pre-weight and the post-weight of each vial is the mass of the well water in the vial. The corresponding well water volume is used once the activity of each sample is determined to calculate the radon concentration of the sample.

5. Fill the vial by pipette with 10 milliliters of mineral oil scintillation fluid and then cap the vial.

   High Efficiency Mineral Oil Scintillator Fluid
   Packard No. 6NE9579 (2.5 liters)
   20 milliliter REPIPET
   Fisher 13-687-21

6. Clean each vial with a soft paper towel or tissue and shake the vial for 15 seconds to thoroughly dissolve the radon gas into the scintillation fluid.

7. Continue processing the vials as described in the slow-flow method in the LSC

The proposed EPA method also describes methodology to prepare radium solutions to be used as calibration sources and quality control check samples, record keeping, and scintillation counting. Only the sample collection procedures were compared herein. In order to remove the possibility of confounding results the existing radon standard and existing scintillation counting methodology were used in the comparison of the slow-flow sample collection technique to the proposed EPA sample collection technique.

# RESULTS

## Long Term Study of Variation of $^{222}$Rn Concentration in Well Water

Presented below, Table 5A, is a comparison of the Drane and York average well concentration and associated standard deviation data with the 1996 average well concentration and associated standard deviation data determined in this study. Following Table 5B, next page, are Figures 7 and 8 comparing the Table 5A data in a graphical fashion. Following Figures 7 and 8 are the results of the long term sampling of the individual well sites, Figures 9 through 19.

**Table 5A:** Comparison of Well Site Average Concentrations and Standard Deviations 1995 versus 1996

| | 1995 | | 1996 | |
|---|---|---|---|---|
| Well Site # | Average $^{222}$Rn Concentration (pCi/L) | Standard Deviation (pCi/L) | Average $^{222}$Rn Concentration (pCi/L) | Standard Deviation (pCi/L) |
| 5 | 1868 | 232 | 1937 | 468 |
| 6 | 183 | 24 | 174 | 20 |
| 7 | 515 | 35 | 566 | 38 |
| 8A | 3280 | 356 | 3441 | 433 |
| 8B | 1081 | 149 | 1257 | 160 |
| 9 | 2242 | 248 | 2050 | 102 |
| 10 | 2670 | 133 | 2686 | 60 |
| 11A | 354 | 32 | 360 | 32 |
| 11B[1] | 136 | 13 | 225 | 21 |
| 12 | 1066 | 98 | 1126 | 63 |
| 13 | 406 | 24 | 385 | 35 |

[1] Drane sampled Well 11B at the well head on four occasions in October and November of 1995 when the well cover was removed by the well maintenance personnel. This sample point was not accessible at other times. The 1996 samples were obtained further downstream at a point where the Well 11A flow had entered the piping system. The 1996 results for Well 11B are approximately equal to the average of the Well 11A and 11B 1995 values, indicative of nearly equal contributions to the sample stream from Well 11A and 11B.

Table 5B presents for comparison, for all samples taken in 1995 and 1996, the percentage of samples that fell within the given range about the sample's well site sample mean. In each sample mean range the 1996 cumulative percentages are larger than the 1995 cumulative percentages, thus in each range more 1996 samples were closer to the well site sample mean than in 1995. This indicates that an individual 1996 well sample would be as likely or better at estimating the well site's average $^{222}$Rn concentration than an individual 1995 well sample. Based on the comparison of the 1995 data with the 1996 data the conclusion of the Drane study remains valid that the proposed EPA sampling program, current at that time and now withdrawn, would have been adequate for determining whether the $^{222}$Rn concentration was within the compliance limit.

**Table 5B:** Cumulative Percentage Difference from the Mean
1995 versus 1996

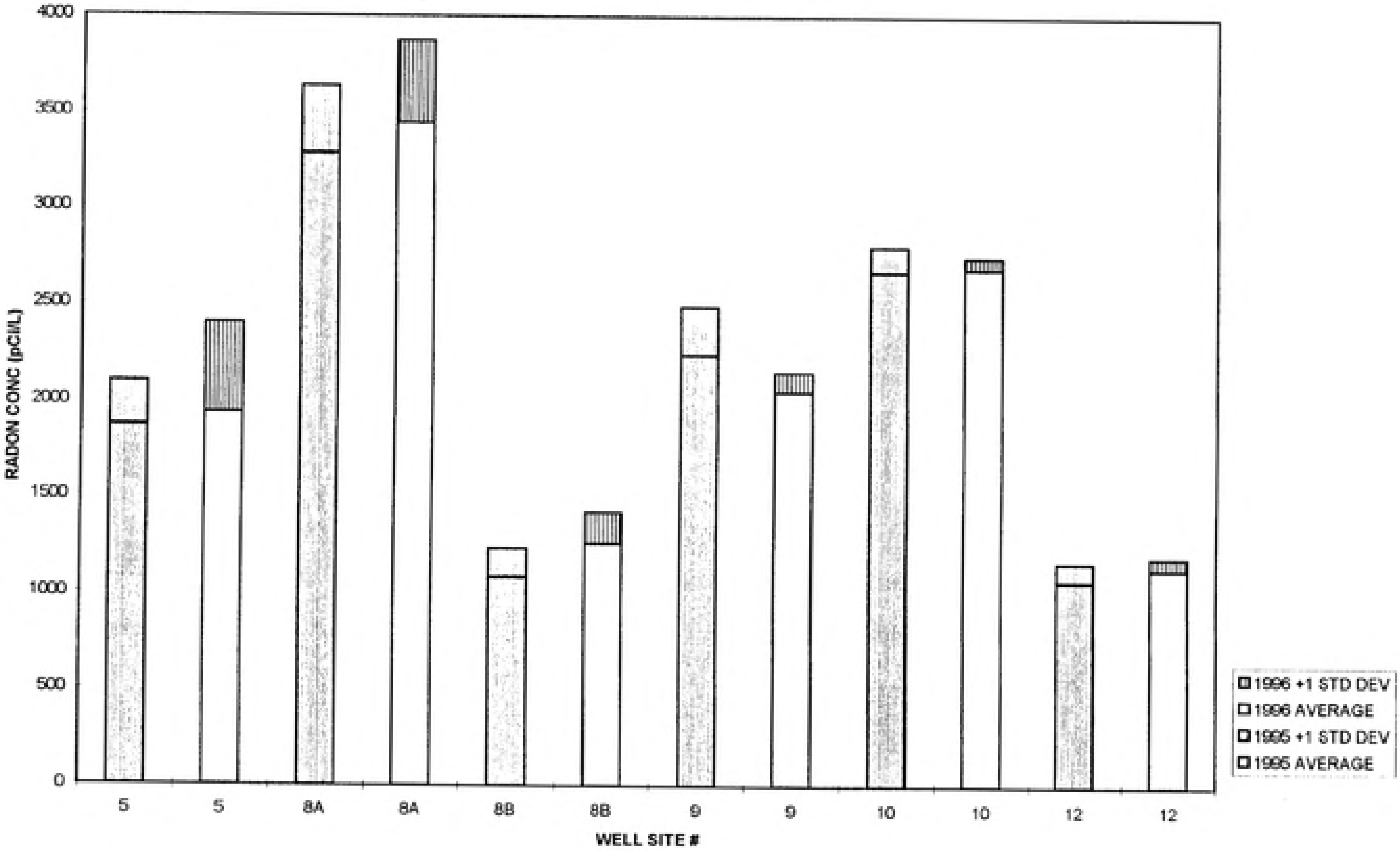
1995 Data (from Drane)

| WELL SITE # | WELL AVERAGE (pCi/L) | WELL STD DEV (pCi/L) | SAMPLES PER WELL | PERCENTAGE OF SAMPLES AT INDIVIDUAL WELL SITE WITHIN SPECIFIED PERCENTAGE OF MEAN | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | ± 10% | ± 20% | ± 30% | ± 40% | ± 50% |
| 5 | 1868 | 232 | 113 | 66.40% | 24.80% | 5.30% | 3.50% | |
| 6 | 183 | 24 | 126 | 73.00% | 17.50% | 7.10% | 0.80% | 0.80% |
| 7 | 515 | 35 | 115 | 85.20% | 14.80% | | | |
| 8A | 3280 | 356 | 118 | 53.40% | 43.20% | 3.40% | | |
| 8B | 1081 | 149 | 29 | 41.40% | 48.30% | 10.30% | | |
| 9 | 2242 | 248 | 84 | 64.30% | 29.70% | 6.00% | | |
| 10 | 2670 | 133 | 119 | 95.00% | 5.00% | | | |
| 11A | 354 | 32 | 70 | 72.90% | 24.20% | 2.90% | | |
| 11B | 136 | 13 | 20 | 75.00% | 20.00% | 5.00% | | |
| 12 | 1066 | 98 | 69 | 71.00% | 26.10% | 2.90% | | |
| 13 | 406 | 24 | 50 | 94.00% | 6.00% | | | |
| CUMULATIVE PERCENTAGES | | | | 65.70% | 90.70% | 96.80% | 98.40% | 99.70% |

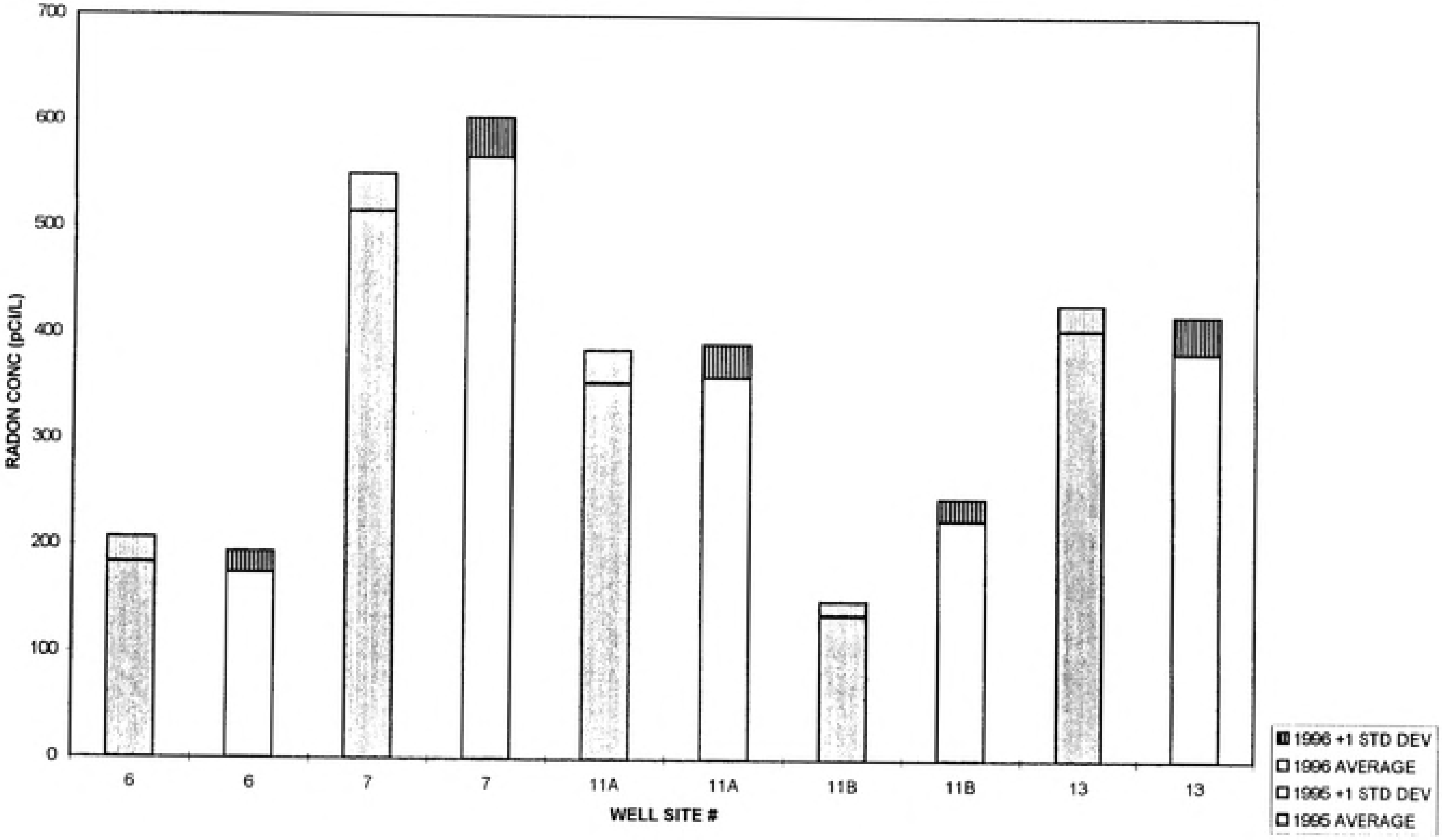
1996 Data

| WELL SITE # | WELL AVERAGE (pCi/L) | WELL STD DEV (pCi/L) | SAMPLES PER WELL | PERCENTAGE OF SAMPLES AT INDIVIDUAL WELL SITE WITHIN SPECIFIED PERCENTAGE OF MEAN | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | ± 10% | ± 20% | ± 30% | ± 40% | ± 50% |
| 5 | 1937 | 468 | 25 | 36.00% | 20.00% | 12.00% | 28.00% | 4.00% |
| 6 | 174 | 20 | 25 | 68.00% | 20.00% | 12.00% | | |
| 7 | 566 | 38 | 25 | 84.00% | 16.00% | | | |
| 8A | 3441 | 433 | 25 | 40.00% | 56.00% | 4.00% | | |
| 8B | 1257 | 160 | 25 | 56.00% | 32.00% | 12.00% | | |
| 9 | 2050 | 102 | 25 | 100.00% | | | | |
| 10 | 2686 | 60 | 25 | 100.00% | | | | |
| 11A | 360 | 32 | 25 | 68.00% | 32.00% | | | |
| 11B | 225 | 21 | 25 | 72.00% | 24.00% | 4.00% | | |
| 12 | 1126 | 63 | 25 | 96.00% | 4.00% | | | |
| 13 | 385 | 35 | 25 | 68.00% | 32.00% | | | |
| CUMULATIVE PERCENTAGES | | | | 71.64% | 93.09% | 97.09% | 99.64% | 100.00% |

## Figure 7: Comparison of Well Site Average Concentrations and Standard Deviations - 1995 vs. 1996 (Concentrations > 1000 pCi/L)



## Figure 8: Comparison of Well Site Average Concentrations and Standard Deviations 1995 vs. 1996 (Concentration < 1000 pCi/L)



## Figure 9: Well 5 Results

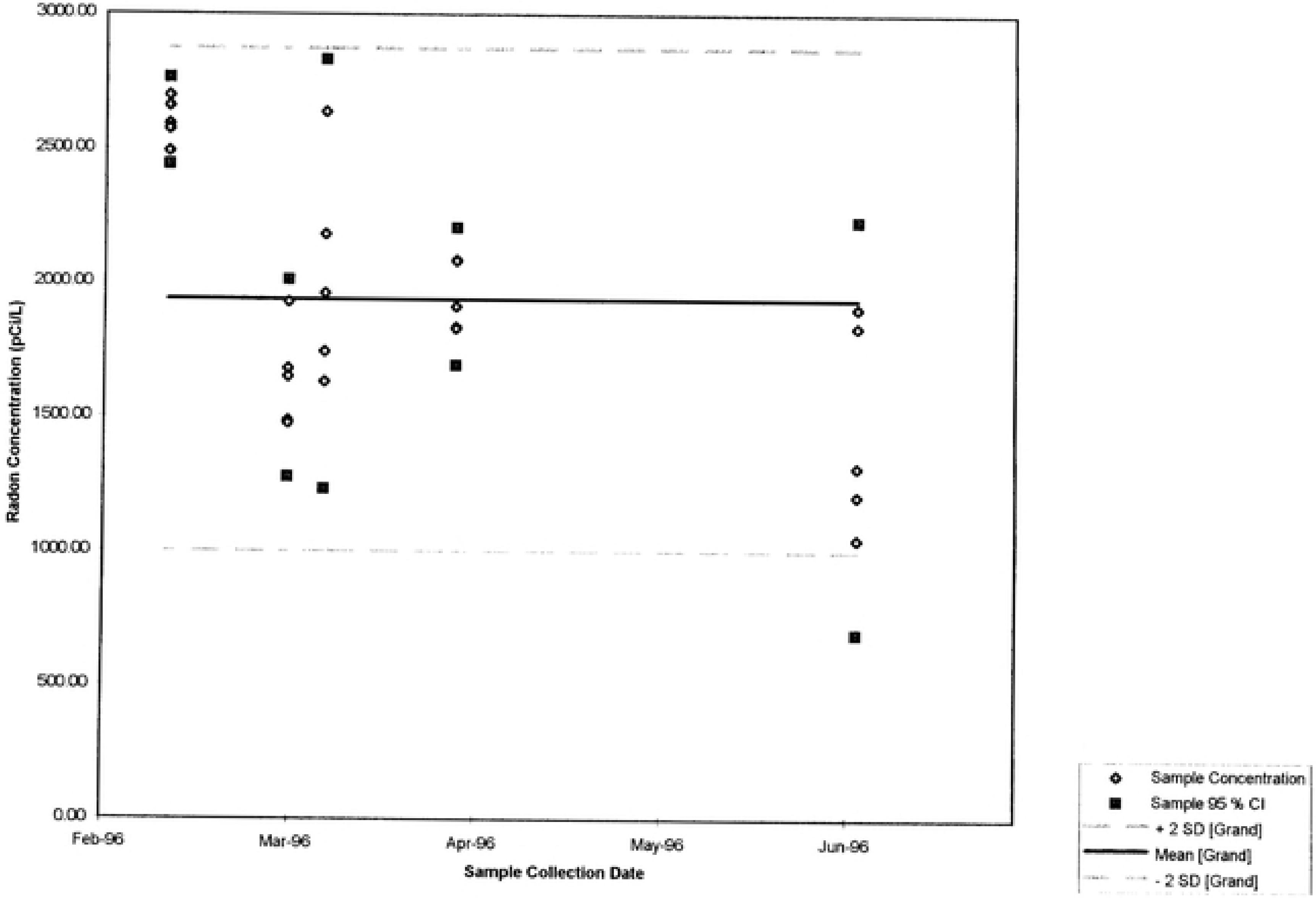
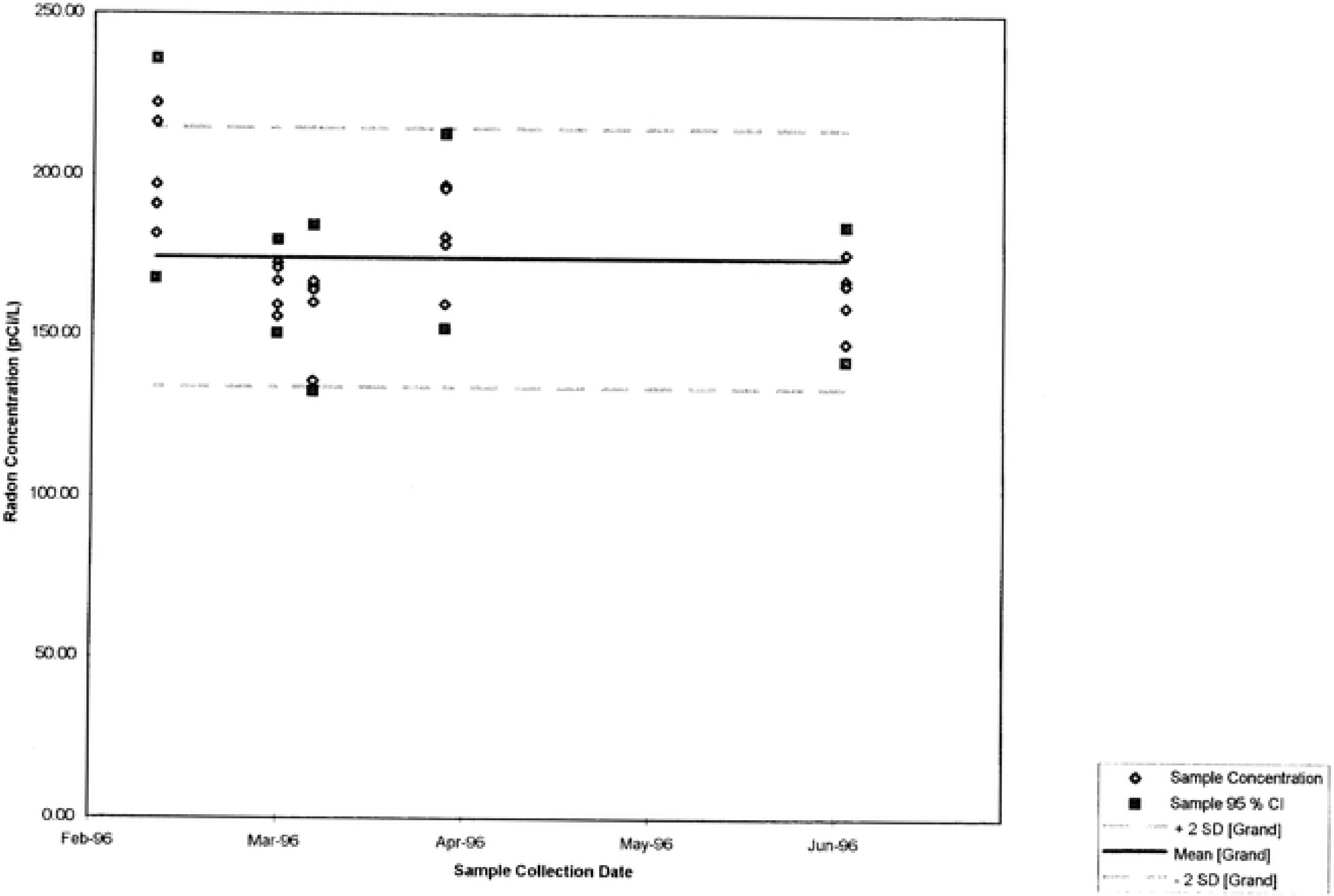
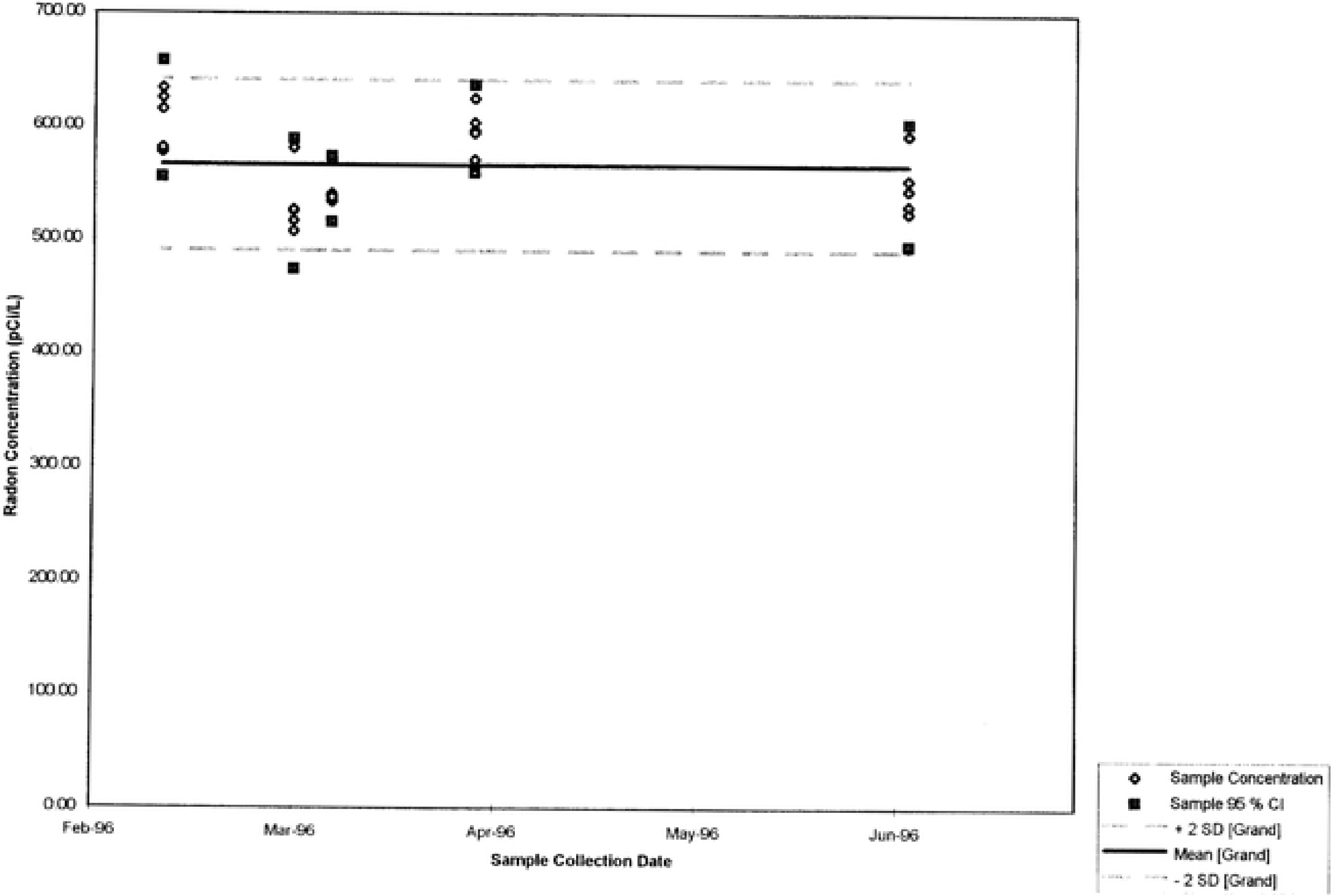


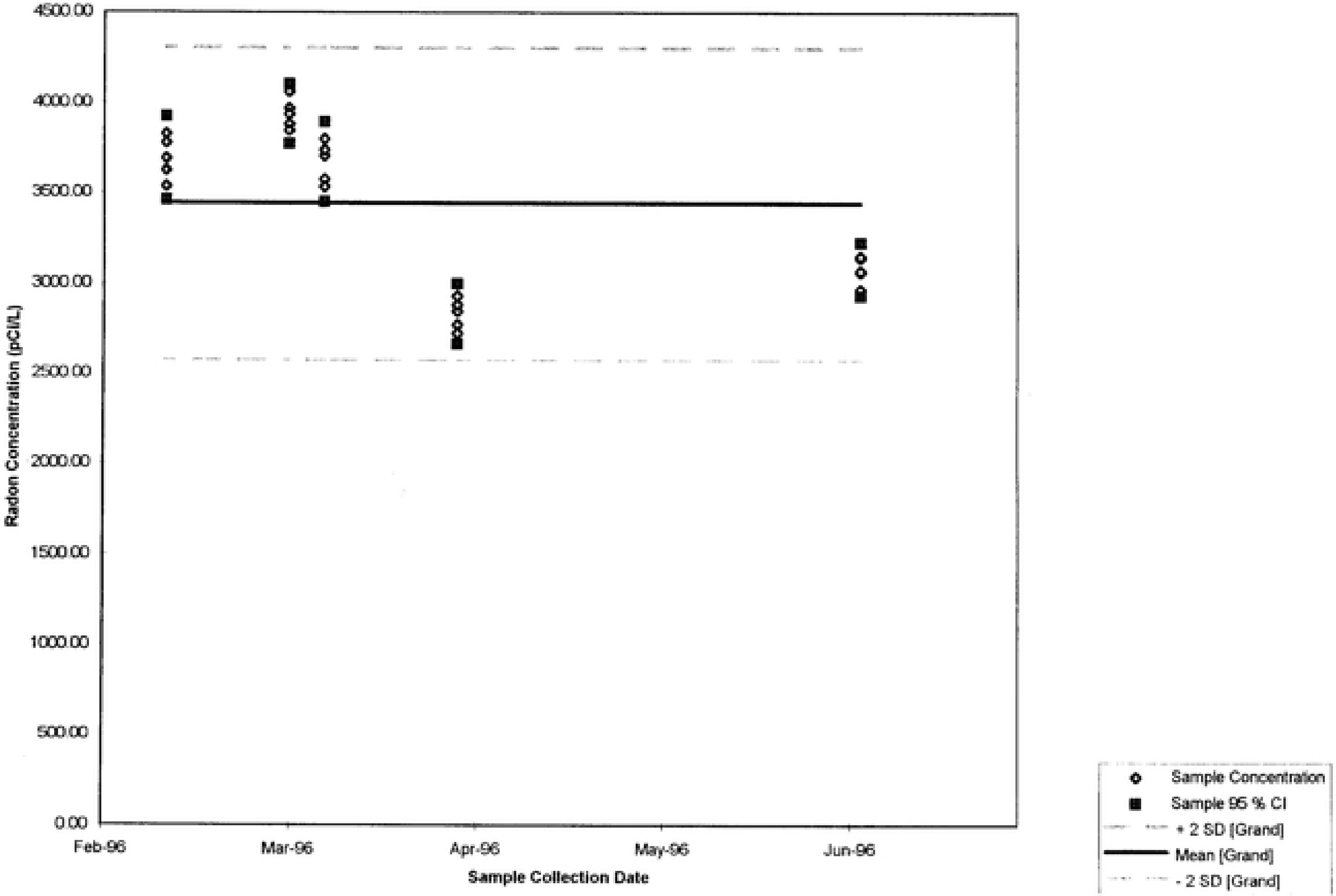
Figure 10: Well 6 Results



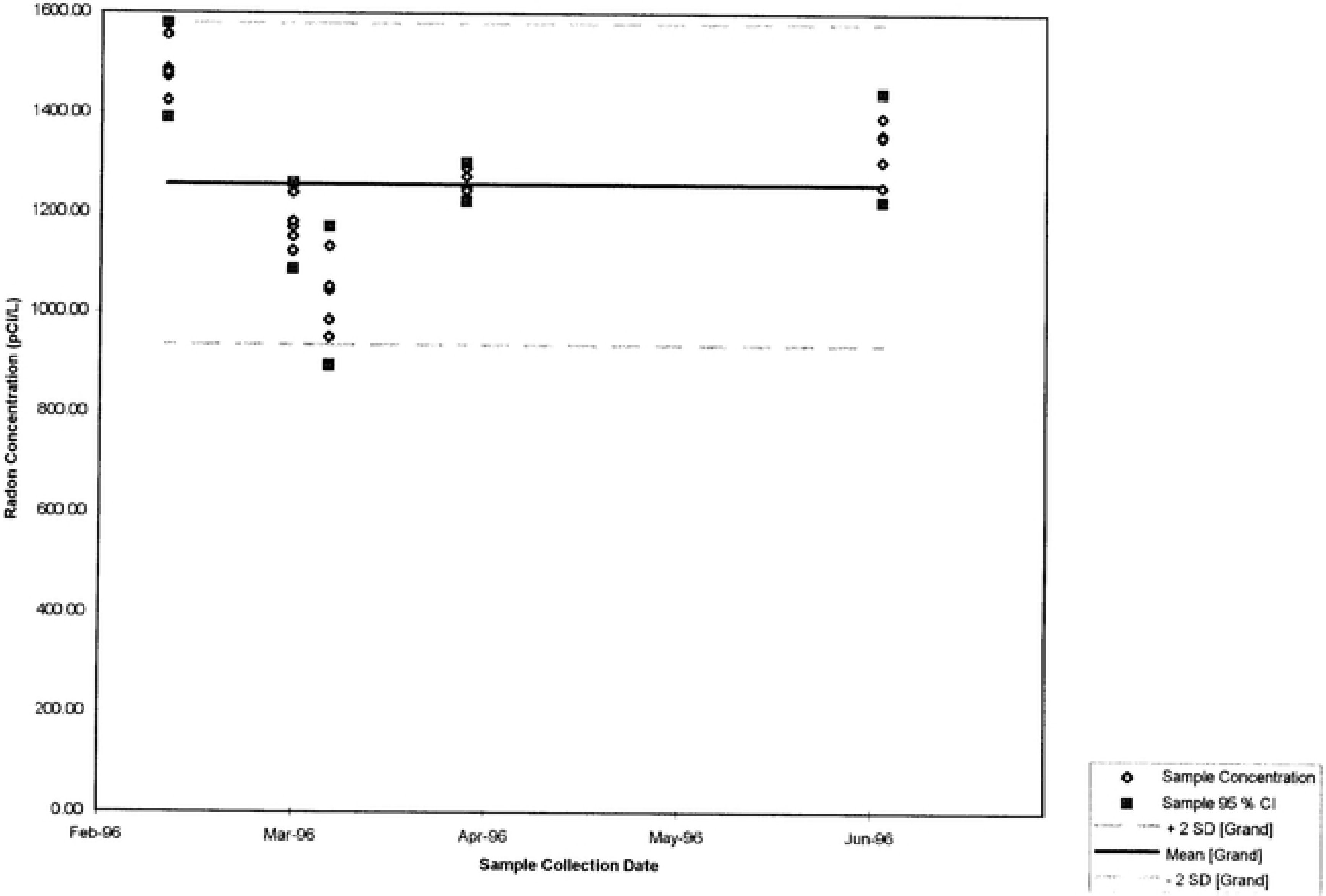
## Figure 11: Well 7 Results



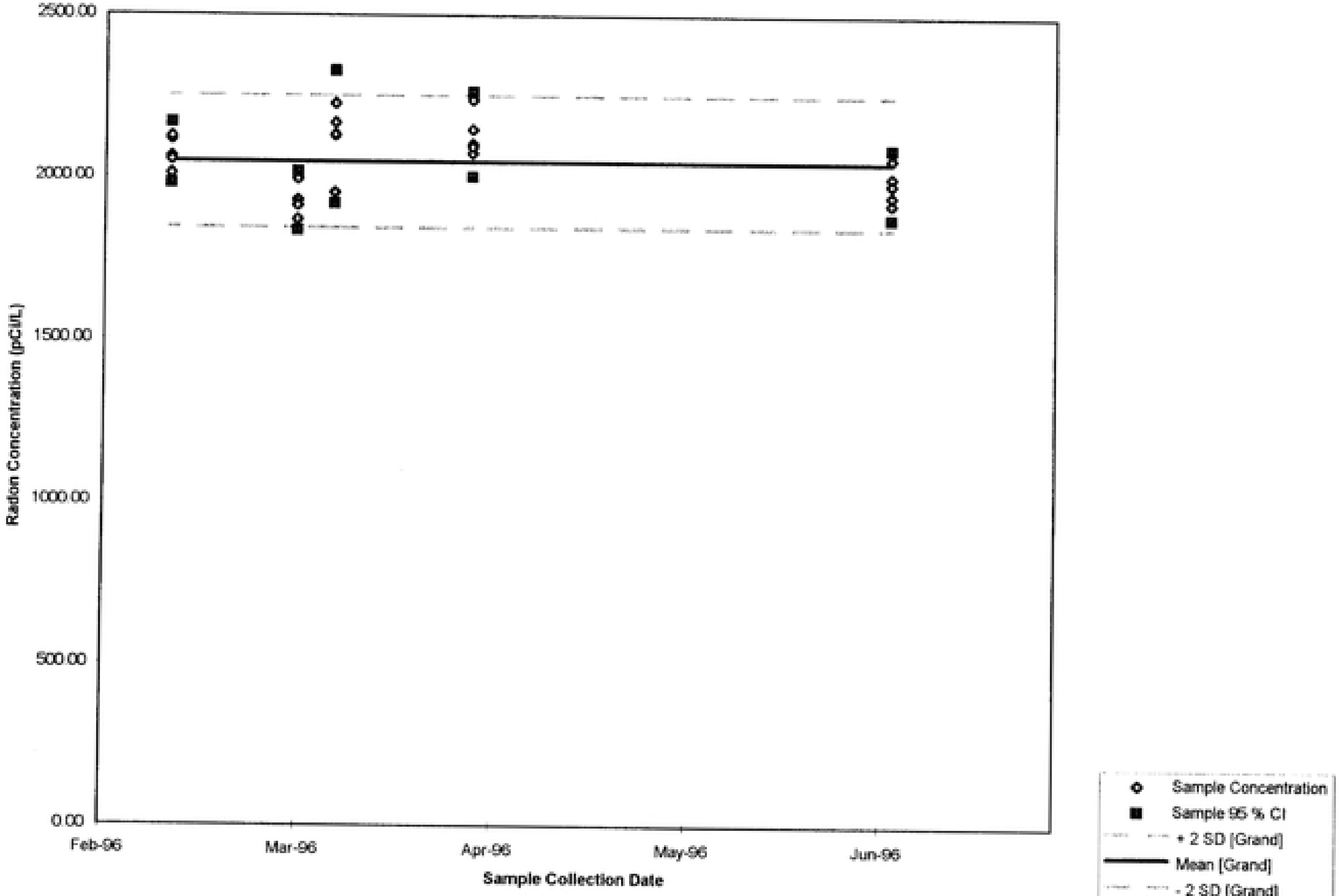
## Figure 12: Well 8A Results



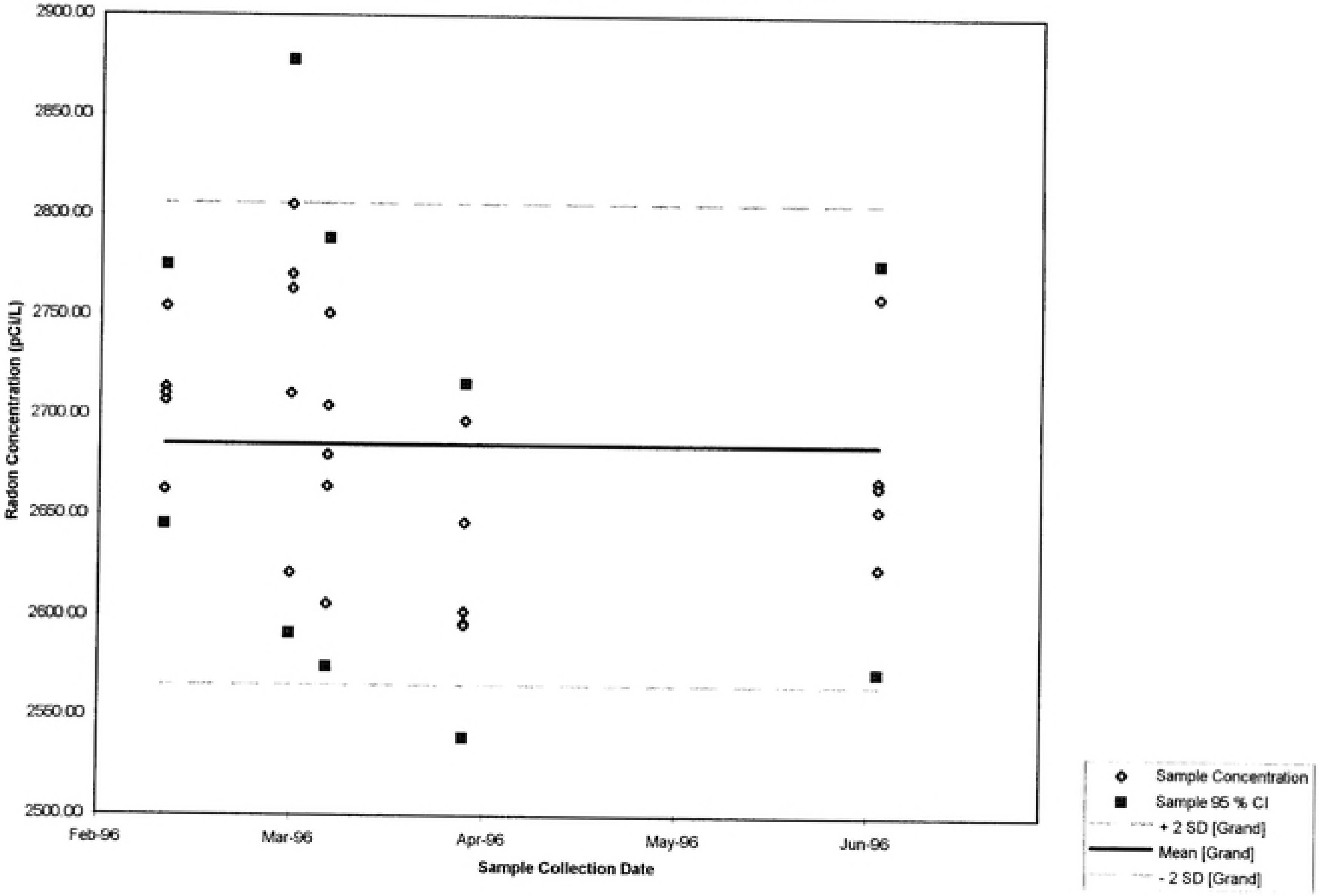
## Figure 13: Well 8B Results



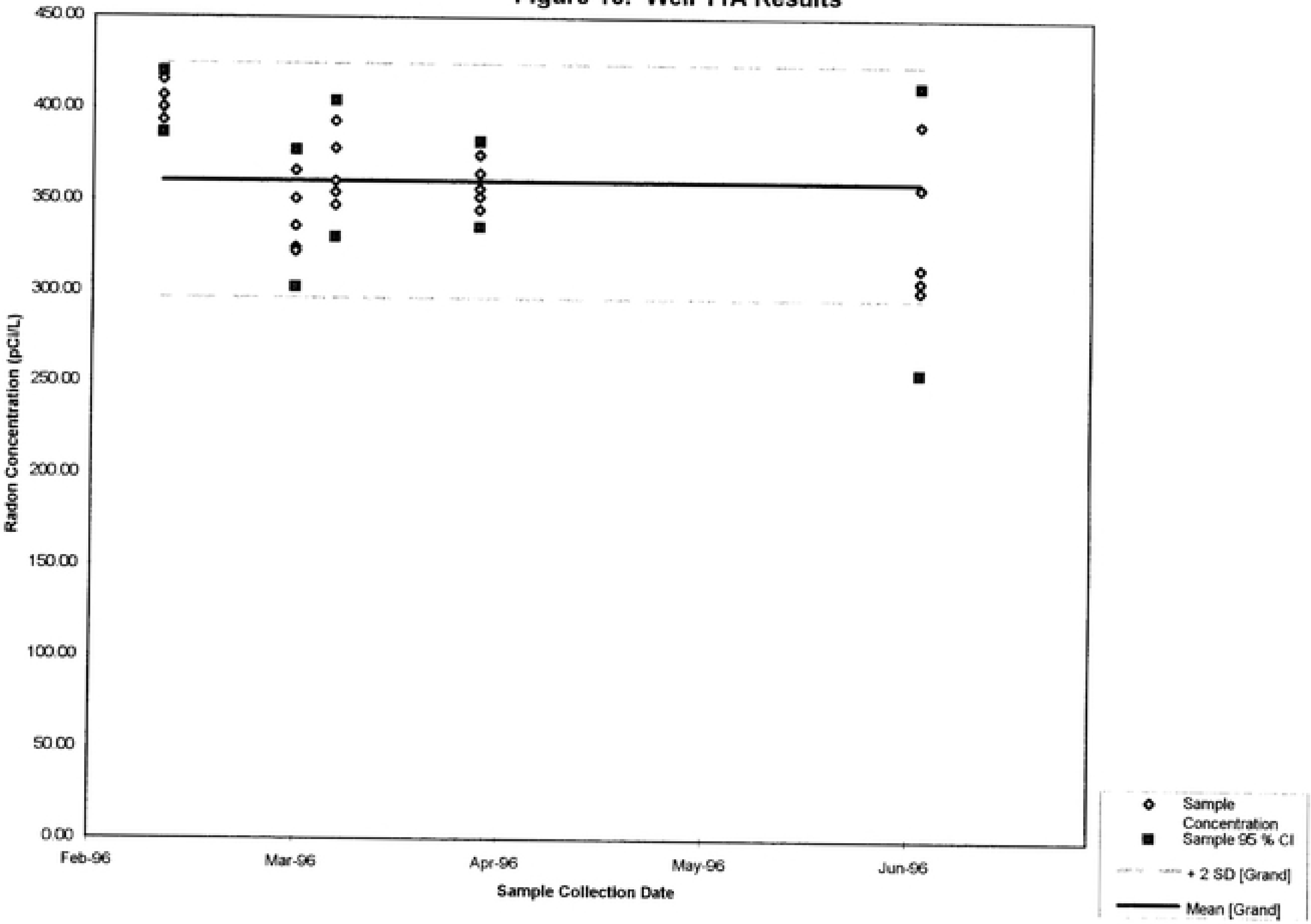
## Figure 14: Well 9 Results



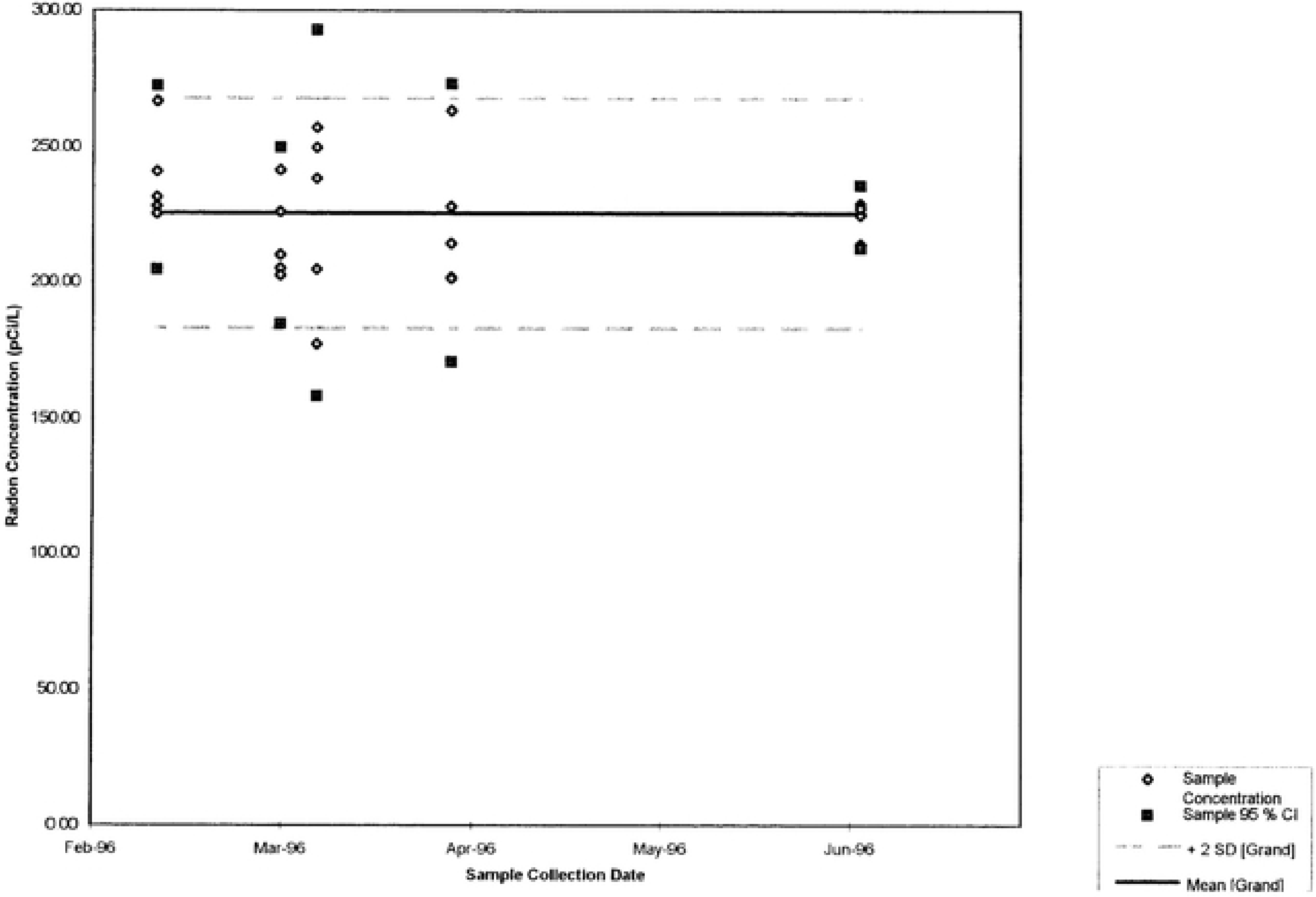
## Figure 15: Well 10 Results



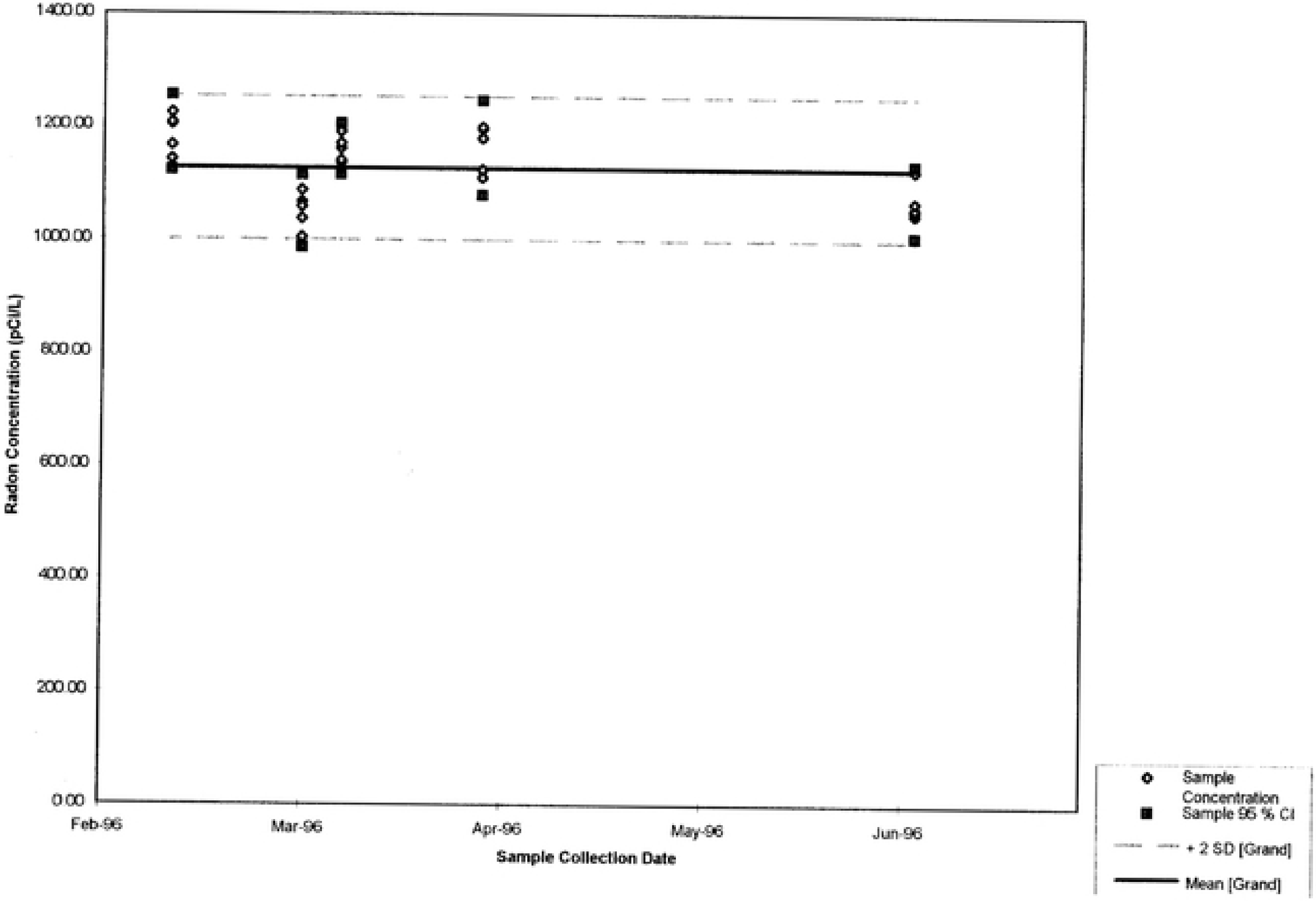
# Figure 16: Well 11A Results



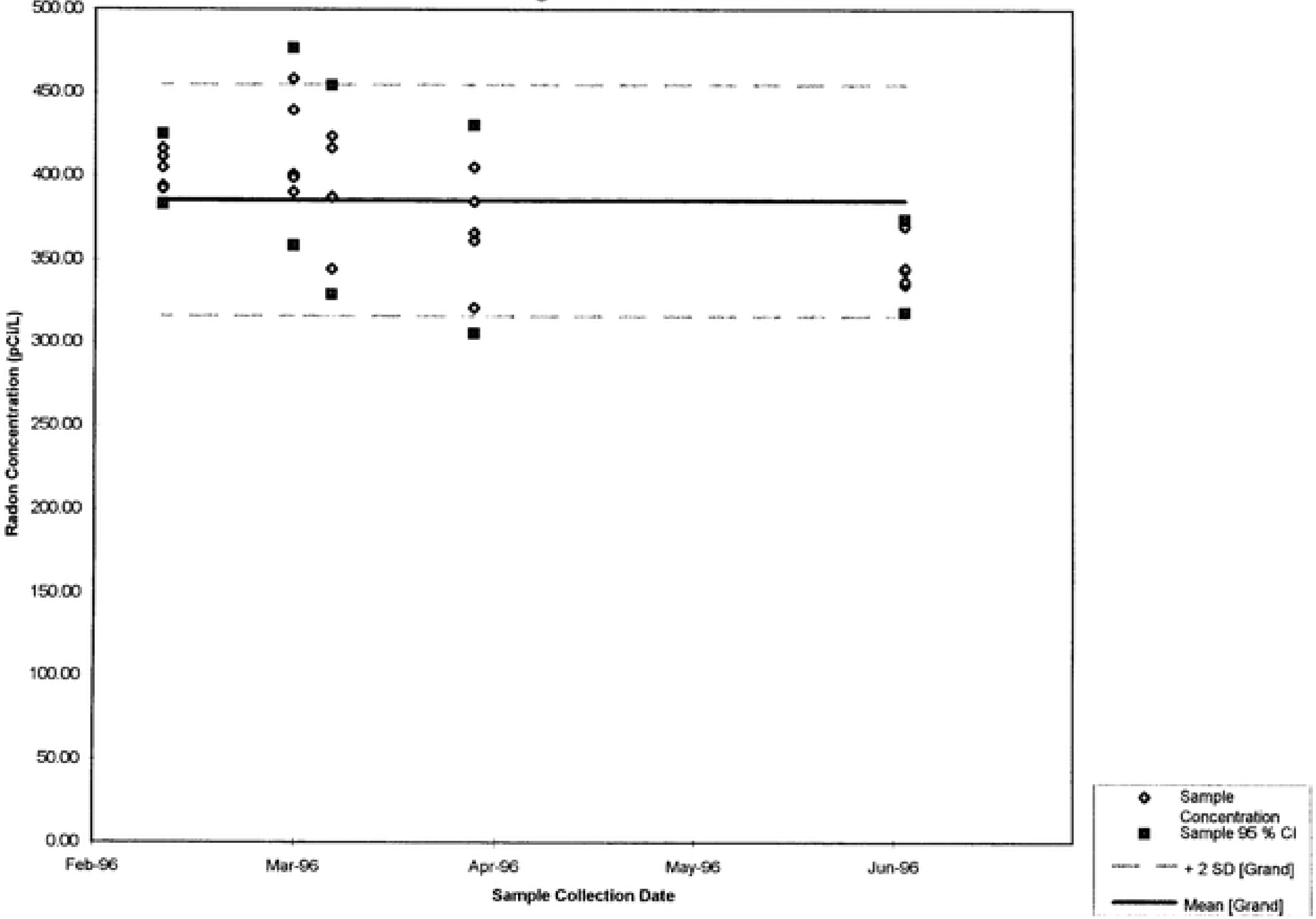
## Figure 17: Well 11B Results



## Figure 18: Well 12 Results



## Figure 19: Well 13 Results



## Short Term Studies of Variation of $^{222}$Rn Concentration in Well Water

Special Tests #1, #2 and #3 sought to determine if pump operation had an effect on the measured $^{222}$Rn concentration at a well site. Well Site #5 was chosen because of the previously described trends, both increasing and decreasing, observed in the measured $^{222}$Rn concentration within individual sample runs. Previous researchers had speculated that the observed trends in the Well Site #5 sample concentration during an individual sample run might be explained by inadequate purging (York) or that possibly water was being drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continued water was then drawn from areas of lower $^{222}$Rn concentration, further away (Drane). The high variation in $^{222}$Rn concentration in Well Site #5 samples taken in 1995 and 1996 and the well's relatively high average $^{222}$Rn concentration were two additional factors in choosing Well Site #5.

### Special Test #1

In this test the well pump was operated for two hours and then operated for twenty minutes at two hour intervals over the total sampling period of eight hours. This was done to see if the sample $^{222}$Rn concentration would decrease during the initial two hours of pump operation and then perhaps recover, or increase with the pump not operating in the intervals between sampling. If this type of pattern, decreasing then increasing, were to be observed it would support the theory that possibly water was being drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continued water was then drawn from areas of lower $^{222}$Rn concentration.

Sixty samples were obtained over the eight hour sampling period in the sequence as shown on Figure 2. Figure 20 shows the measured $^{222}$Rn concentration of each of the sixty samples. The four hour, six hour and eight hour samples show a decrease in $^{222}$Rn concentration during the ten samples of the individual sample sequences, whereas the samples taken during the first two hours of pump operation do not show as pronounced a pattern.

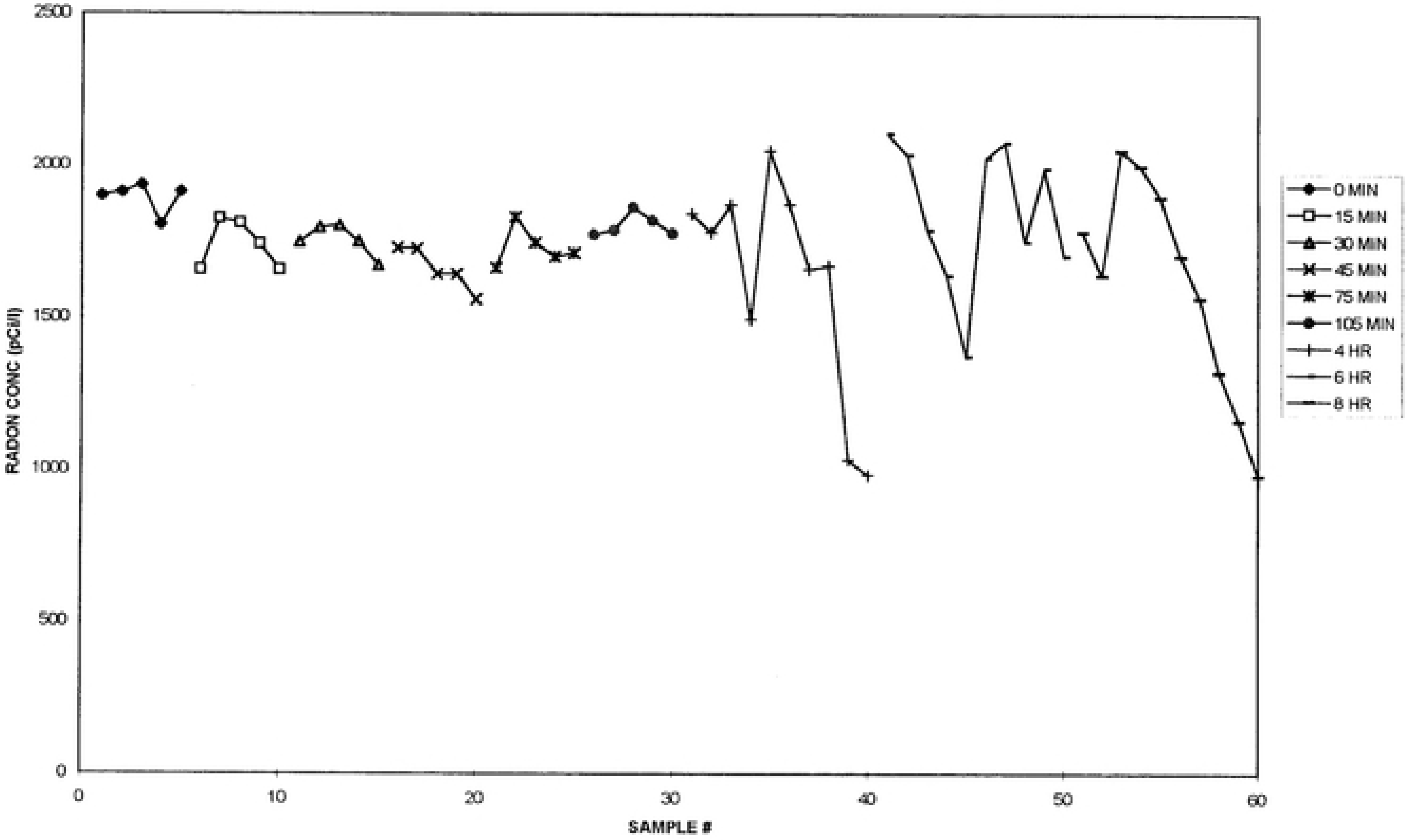
Linear regression analysis of the thirty samples taken during the first two hours of pump operation does not show a decreasing $^{222}$Rn concentration at a 95% level of confidence ($p = 0.34$); at a 95% level of confidence there is not sufficient evidence to reject the hypothesis that there is zero slope or no decrease in the $^{222}$Rn concentration over the first two hours. Therefore, examination of the first two hours of data, as a whole, does not provide sufficient evidence to support the theory that sustained pump operation would first draw water from areas of higher $^{222}$Rn concentration near the pump suction and then draw water from areas of lower $^{222}$Rn concentration further away.

Examination of Figure 20 seems to show a decreasing $^{222}$Rn concentration over the first hour followed by an increasing trend over the second hour. Linear regression analysis of the first twenty samples taken during the first hour of pump operation does show a decreasing $^{222}$Rn concentration at a greater than 99.99% level of confidence ($p < 0.0001$); at a 99.99% level of confidence there is sufficient evidence to reject the hypothesis that there is zero slope or no decrease in the $^{222}$Rn concentration over the first hour. Using the regression line as a predictor it can be estimated that over the one hour period that the $^{222}$Rn concentration would be reduced by 275 pCi/L, equivalent to a rate of -4.6 pCi/L per minute. Therefore, examination of the first hour of data does provide some evidence to support the theory that sustained pump operation would first draw water from areas of higher $^{222}$Rn concentration near the pump suction and then draw water from areas of lower $^{222}$Rn concentration further away.

Examination of Figure 20 seems to show an increasing trend over the second hour. Linear regression analysis of the ten samples taken during the second hour of pump operation does not show an increasing $^{222}$Rn concentration at a greater than 95% level of confidence ($p = 0.06$); at a 95% level of confidence there is not sufficient evidence to reject the hypothesis that there is zero slope or no change in the $^{222}$Rn concentration over the second hour, but at a 94% level of confidence there is sufficient evidence to state that there is an increasing trend in the $^{222}$Rn concentration. Using the regression line as a predictor it can be estimated that over the one hour period that the $^{222}$Rn concentration would increase by 144 pCi/L, equivalent to a rate of 2.4 pCi/L per minute.

Based on the observation in the four hour, six hour and eight hour samples of a pronounced decrease in $^{222}$Rn concentration, over each of the twenty minute sampling intervals, Special Test #3 was designed to identify the explanation for the decrease.

## FIGURE 20: SPECIAL TEST #1 RESULTS
## TWO HOUR PUMP OPERATION



**Special Test #2**

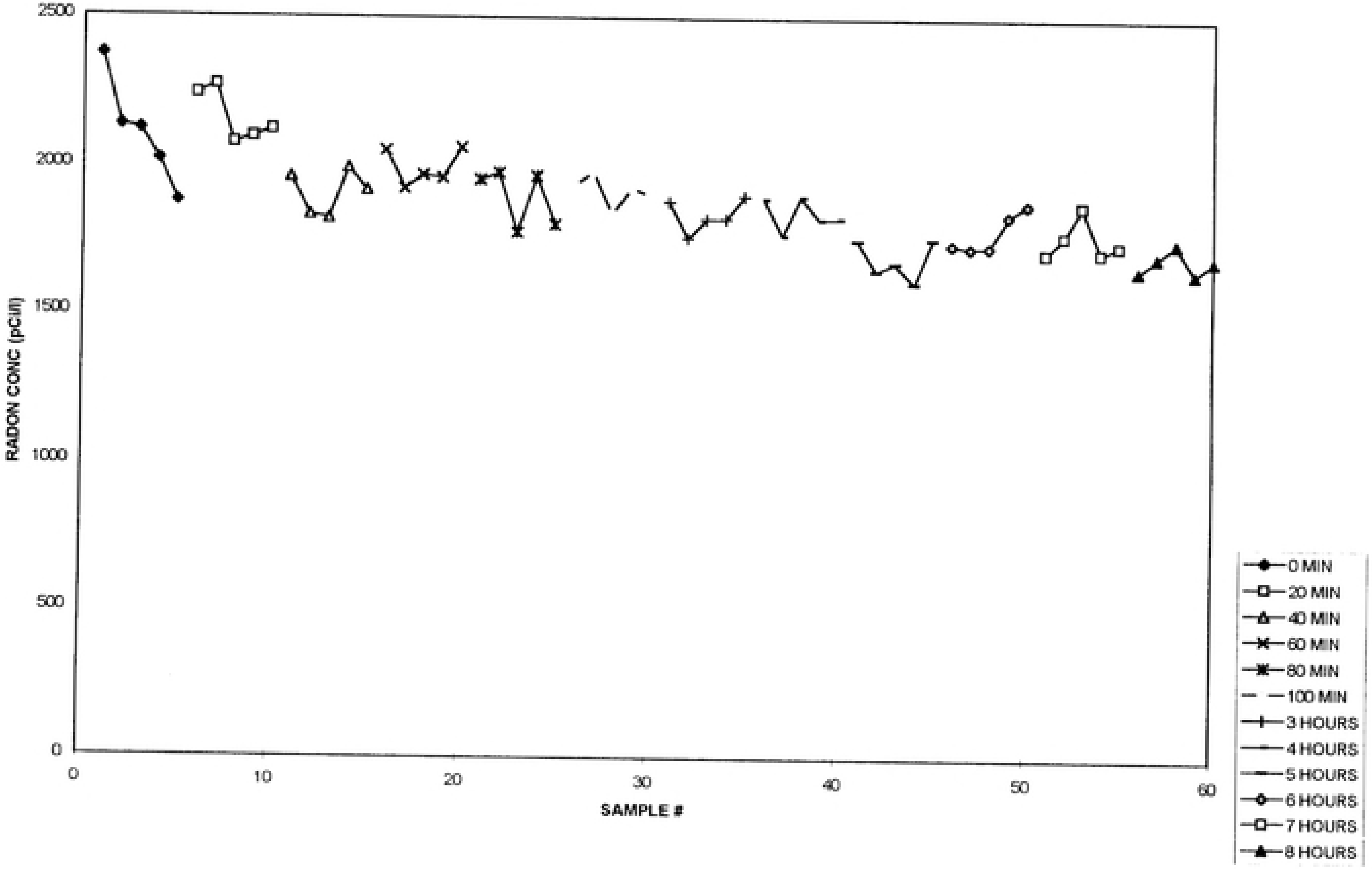
In this test the well pump was operated for eight hours. Sixty samples were obtained over the eight hour sampling period in the sequence as shown on Figure 3. This was done to see if the sample $^{222}$Rn concentration would decrease over an eight hour period of continuous pump operation. Similar to the rationale for Special Test #1, if a decreasing trend were to be observed in $^{222}$Rn concentration it would support the theory that possibly water was being drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continued water was then drawn from areas of lower $^{222}$Rn concentration.

Figure 21 shows the measured $^{222}$Rn concentration of each of the sixty samples. Linear regression analysis of the data yields the conclusion that the sample $^{222}$Rn concentration decreased as a function of pump run time, this conclusion is reached with a greater than 99.99% confidence level ($p < 0.0001$). Using the regression line as a predictor it can be estimated that over an eight hour period that the $^{222}$Rn concentration would be reduced by 380 pCi/L, equivalent to a rate of -0.8 pCi/L per minute. Well Site #5 had a 1996 average $^{222}$Rn concentration of 1937 pCi/L, thus the eight hour trend would represent almost a 20% reduction in $^{222}$Rn concentration.

It is the variation in the $^{222}$Rn distribution in the ground as well as the variation in flow through fracture systems supplying individual wells that contributes to the variation in $^{222}$Rn concentration observed between wells. Variation in the flow through fracture systems supplying individual wells contributes to the variation in $^{222}$Rn concentration observed at individual well sites (Folger et al. 1996). Assuming that the in-ground $^{222}$Rn distribution does not change appreciably over eight hours, the change in $^{222}$Rn concentration observed in Special Test #2 might possibly be explained by the change in the water flow rate through the underground fracture system supplying the well caused by the operation of the well pump. This explanation can only suggest a reason for a change in the $^{222}$Rn concentration observed in the well water samples, the explanation for the decreasing trend in the concentration is as yet unexplained.

It should be noted that previous sampling of this well, conducted for the purposes of the long term sampling program, obtained five samples at a time in a two or three minute period (York 1995, Drane 1996). It is unlikely that a 0.8 pCi/L per minute downward trend could have been identified with five samples in three minutes considering that the standard deviation for Well Site #5 in 1996 was 468 pCi/L. Although it can be concluded with a high confidence level ($p < 0.0001$) that the Well Site #5 Special Test #2 results show an unexplained downward trend in the sample $^{222}$Rn concentration as a function of pump run time, this trend is not large enough to have been observed by previous researchers. Special Test #1 did identify a large downward short term trend, as much as 76 pCi/L per minute at the eighth hour of sampling. Special Test #3 was designed to attempt to identify the source of the large short term trend seen in Special Test #1, as discussed on the following page.

## FIGURE 21: SPECIAL TEST #2 RESULTS
## EIGHT HOUR PUMP OPERATION



**Special Test #3**

To determine if the apparent reduction in radon concentration observed in the samples collected during the fourth, sixth and eighth hour of Special Test #1 was real or some sort of sampling artifact, the pattern of Special Test #1 was repeated with the number of samples increased from sixty to ninety. Additional samples were added to the end of each individual sample sequence at the fourth, sixth and eighth hour to provide better resolution, since the downward trend observed in Special Test #1 was more pronounced at the end of the sample sequences at the fourth and eighth hour. Similar to Special Test #1, in Special Test #3 the well pump was operated for two hours and then the pump was operated for twenty minutes at two hour intervals for a total sampling period of eight hours. Ninety samples were obtained over the eight hour sampling period in the sequence as shown on Figure 4. Figure 22 shows the measured $^{222}$Rn concentration of each of the ninety samples.

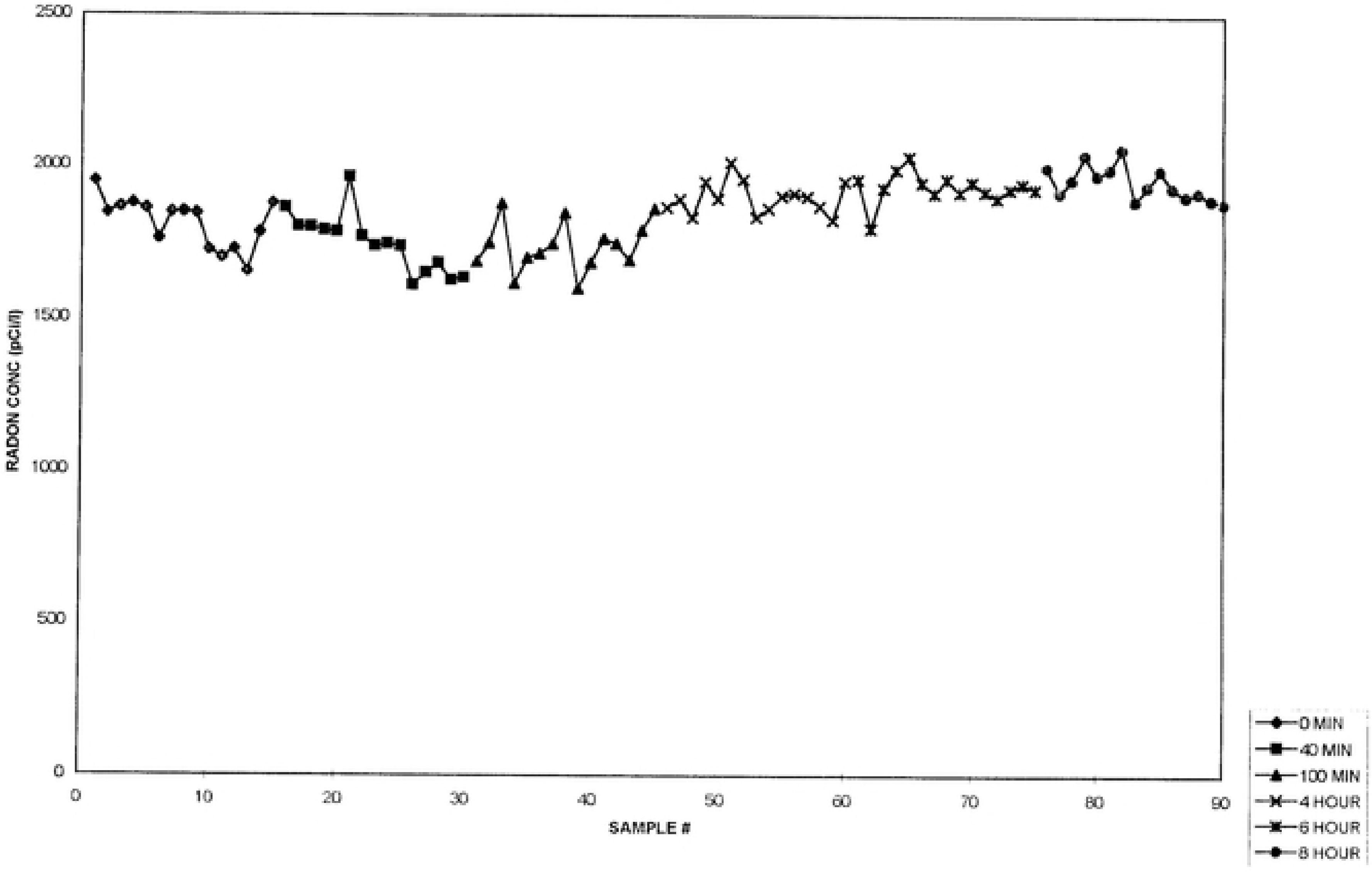
The sample flow rate was varied in Special Test #3 to determine if the sampling method was influencing the observed $^{222}$Rn concentration. The difference in the sample flow rates between Special Test #1 and Special Test #3 was as follows:

1. In Special Test #1 the sample valve was adjusted to achieve a suitable sample flow and, once adjusted, was left at that position for the time required to obtain either the five or ten samples in the individual sample sequence.

2. In Special Test #3 the sample valve was continuously adjusted to achieve a suitable sample flow during the time period required to obtain the 15 samples in the individual sample sequence.

This adjustment in the sample procedure was made because it was observed during Special Test #1 that as the sample sequence progressed the sample flow rate diminished. Additionally, it was observed that the chemical metering point into the well water distribution system was upstream of the sample point and it was postulated that the reduction in sample flow rate might cause some of the metered water treatment chemical solution to dilute the sample, thus lowering the sample concentration. Well Site #5 uses a sodium hypochlorite solution mixed with water in a 50 gallon plastic trash can and a positive-displacement chemical metering pump to inject the solution into the potable water system, upstream of the sample point.

**Figure 22: SPECIAL TEST #3 RESULTS**
**TWO HOUR PUMP OPERATION**



Linear regression analysis was performed on the Special Test #3 data to determine if there is an increase or decrease in the sample $^{222}$Rn concentration over the eight hour test period. The regression line was also tested against the hypothesis that the slope of the line is zero. The data was tested in three parts:

Analysis of all 90 data points - eight hours:

Special Test #3 was performed similarly to Special Test #1, the well pump was operated for two hours and then the pump was operated for twenty minutes at two hour intervals at the fourth, sixth and eighth hour for a total sampling period of eight hours. Ninety samples were taken, 45 in the first two hours and 45 over the next six hours as shown on Figure 4. Linear regression analysis of the data over the eight hour period yields the conclusion that the sample $^{222}$Rn concentration increased as a function of time, this conclusion is reached with a greater than 99.99% confidence level ($p < 0.0001$), the hypothesis that the slope of the line is zero was rejected. Using the eight hour regression line as a predictor it can be estimated that over the eight hour period that the $^{222}$Rn concentration increased by 210 pCi/L, equivalent to a rate of +0.44 pCi/L per minute.

Analysis of first 45 data points - first two hours of eight hour period:

Special Test #3 obtained 45 samples in the first two hours, during which time the well pump was in continuous operation. Linear regression analysis of the data over the two hour period yields the conclusion that the sample $^{222}$Rn concentration decreased as a function of time while the pump was in operation. This conclusion is reached with a greater than 98.8% confidence level ($p = 0.0114$), the hypothesis that the slope of the line is zero was rejected. Using the regression line for the first two hours as a predictor it can be estimated that over the first two hours of the eight hour test that the $^{222}$Rn concentration decreased by 96 pCi/L, equivalent to a rate of -0.8 pCi/L per minute. Note that this is the same rate observed during the entire eight hour period of Special Test #2 in which the well pump was in continuous operation.

Analysis of second 45 data points - last six hours of eight hour period:

Special Test #3 also obtained 45 samples in the last six hours of the test, during which time the well pump was operated only during the three 20 minute periods every two hours when samples were taken. Linear regression analysis of the data over the six hour period yields the conclusion that the sample $^{222}$Rn concentration increased as a function of time. This conclusion is reached with a greater than 99.99% confidence level ($p < 0.0001$), the hypothesis that the slope of the line is zero was rejected. Using the regression line for the last six hours as a predictor it can be estimated that over the last six hours of the eight hour test that the $^{222}$Rn concentration increased by 80 pCi/L, equivalent to a rate of +0.22 pCi/L per minute.

The theory that the sample flow rate was diluted in Special Test #1 by the water treatment solution, is borne out by the lack of a large downward trend in the sample concentration in Special Test #3, as can be seen in Figure 22. The decreasing trend observed in Special Test #1 was not observed in Special Test #2 because the individual sample sequence in Special Test #2 only consisted of five samples in a two minute time period. The trend was only observed in Special Test #1 when the sample sequence shifted from five samples in two minutes to 10 samples in 20 minutes for the fourth, sixth and eighth hour samples. The longer time at a constant valve setting in Special Test #1 for the 20 minute sample sequences resulted in enough reduction in sample flow for the dilution effect of the water treatment chemical flow to be easily seen.

Previous researchers had speculated that the observed trends in the Well Site #5 sample concentration during an individual sample run might be explained by inadequate purging (York) or that possibly water was being drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continued water was then drawn from areas of lower $^{222}$Rn concentration, further away (Drane). Considering that the water treatment chemical injection point is upstream of the sample point for Well Site #5 and the results of Special Tests #1, #2 and #3, evidence strongly suggests that the previously observed trends are due to a sampling artifact associated with sample dilution and not due to inadequate purging or variation in groundwater $^{222}$Rn concentrations in the vicinity of the pump suction. This is of particular significance as it illustrates how the drinking water system configuration and the sample technique can influence the sample concentration.

Although previous researchers reported observing trends in the Well Site #5 data, these trends were observed in sample sequences that were performed over a two to three minute time period. Linear regression analysis and hypothesis testing of the data do show clear trends, decreasing $^{222}$Rn concentration while the well pump is in operation and increasing $^{222}$Rn concentration while the well pump is intermittently operated. However, the observed trend is at a slow enough rate, less than 1.0 pCi/L per minute, that the trends could not have been observed in a sample sequence taken over a two to three minute interval. It is concluded that pump operation appears to change the well water sample $^{222}$Rn concentration at a rate less than 1.0 pCi/L per minute, although the mechanism is not known. By comparison of the difference in the sample methods and the sample results between Special Test #1 and Special Test #3 it is concluded that, at low sample flow rates, the water treatment chemical injection can dilute the well water sample and create an apparent reduction in sample $^{222}$Rn concentration that would be observable in a two to three minute sample sequence.

## EPA vs. UNC Comparison of $^{222}$Rn Sampling Methodologies

Special Test #4 and Special Test #5 were performed to compare the slow-flow sampling methodology developed at UNC versus the proposed EPA sampling methodology.

### Special Test #4

The results of this test seem to indicate that the EPA method results in some sample loss versus the UNC slow-flow method. This can be seen by the consistently higher $^{222}$Rn concentration of the 20 UNC samples versus the 20 EPA samples, in Figure 23. The null hypothesis that the two groups of data have the same population mean is tested against the alternate hypothesis that the two groups have different population means. This test was performed by a one-way analysis of variance using an F test to examine the variance within the groups versus the variance between groups. The results of the one-way analysis of variance indicate that there is sufficient evidence to reject the null hypotheses ($p < 0.0001$). It can be stated that the two groups have different population means, at a confidence level of approximately 99.99%.

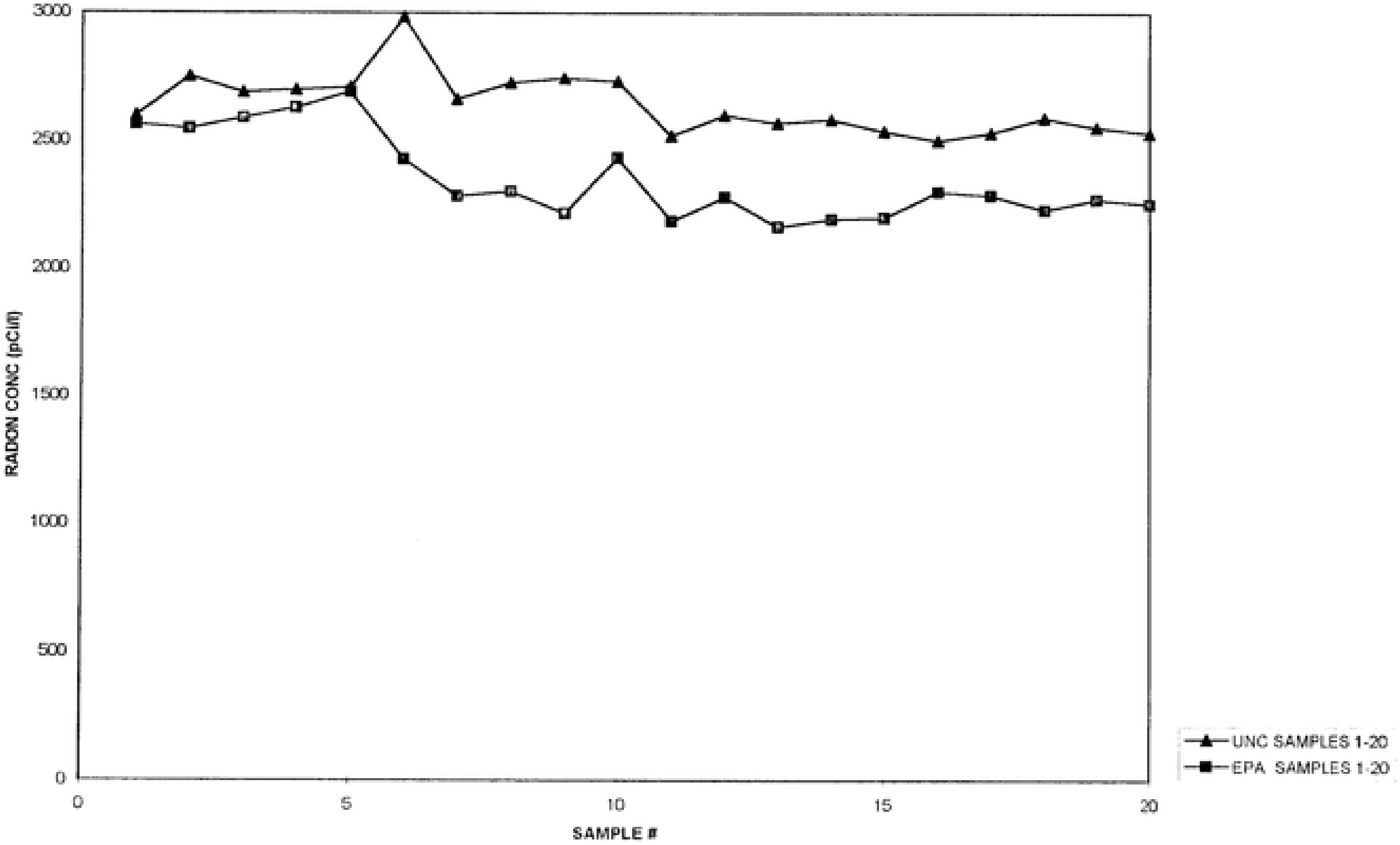
The 20 EPA samples were obtained and processed using a detailed sampling procedure based on the guidelines contained in EPA Method 913.0 (Draft). Review of the sample procedure used for this test identified the following possible sources of sample loss:

1. The empty sample vials in the EPA method were pre-weighed and then post-weighed once the excess water sample had been removed from the vial. This was done to determine the sample volume.

2. The samples in the EPA method were processed five-at-a-time, thus the individual vials were open for a longer length of time than had the vials been processed one-at-a-time.

EPA Method 913.0 (Draft) was reviewed based on the above and it was concluded that the sample volumes could also be determined based on the volume of water withdrawn from a full vial, assuming the full vial contained 23 milliliters of water. It was also decided that the vials should be processed one-at-a-time. From this re-examination of the detailed sample procedure developed herein and review of the EPA method guidelines it was determined that the method that would result in the minimization of the loss of the contaminant would be one that resulted in less handling of the sample with the vial open.

Figure 23: SPECIAL TEST #4 RESULTS
EPA vs. UNC SAMPLE METHOD COMPARISON



Based on the results of Special Test #4 the detailed sampling procedure designated EPA Method "A" was developed. EPA Method "A" minimized the length of time that the sample vial was open to the air by determining the sample volume through removing a known volume of water by syringe from the sample vial and assuming the total sample vial volume was 23 milliliters. EPA Method "B" determined the sample volume through pre-weighing the empty sample vials and then post-weighing the sample vials once the excess water sample had been removed from the vial. In both methods the vials are processed one-at-a-time. The EPA method used for Special Test #4 was therefore a variant of EPA Method "B" since the EPA method vials were processed five-at-a-time in Special Test #4.

**Special Test #5**

The results of this test seem to indicate that there was little difference between the UNC method and EPA Methods "A" and "B". This can be seen by the nearly identical results for the three methods as shown in Figure 24. The null hypothesis that the three groups of data all have the same population mean is tested against the alternate hypothesis that at least two groups have different population means. This test was performed by a one-way analysis of variance using an F test to examine the variance within the groups versus the variance between groups. The results of the one-way analysis of variance indicate that there is insufficient evidence to reject the null hypotheses ($p=0.49$). Alternatively, it could be stated that at least two groups have different population means, but at only a confidence level of approximately 50%.

In Special Test #4 there was an apparent difference for the two sets of results, between the UNC slow-flow method and the variant of EPA Method "B". Special Test #5 did not show any apparent difference between either the UNC method and EPA Method "A" or the UNC method and EPA Method "B." One possible conclusion may be that by reducing the length of time that the sample vials were open to the air by handling the EPA method vials one-at-a-time in Special Test #5 versus five-at-a-time in Special Test #4 contributed the most in reducing the loss of the $^{222}$Rn in the sample vials.

To further demonstrate the effect of loss of $^{222}$Rn from the sample vials being open and exposed to air, as part of Special Test #5, ten samples were obtained using the EPA sample collection method. Once in the laboratory the ten sample vials were opened and then processed sequentially over a 50 minute period using the EPA Method "B." Figure 25 depicts the sample $^{222}$Rn concentration as a function of the length of time that the sample vials were open.

Linear regression analysis of the data over the 50 minute period yields the conclusion that the sample $^{222}$Rn concentration decreased as a function of the time that the vials were open, this conclusion is reached with a greater than 99.99% confidence level ($p < 0.0001$), the hypothesis that the slope of the line is zero was rejected. Using the 50 minute regression line as a predictor, it can be estimated that over the 50 minute period that the last vial was open, that the $^{222}$Rn concentration decreased by 510 pCi/L, equivalent to a rate of -10.25 pCi/L per minute.

## FIGURE 24: SPECIAL TEST #5 RESULTS
## EPA vs. UNC SAMPLE METHOD COMPARISON

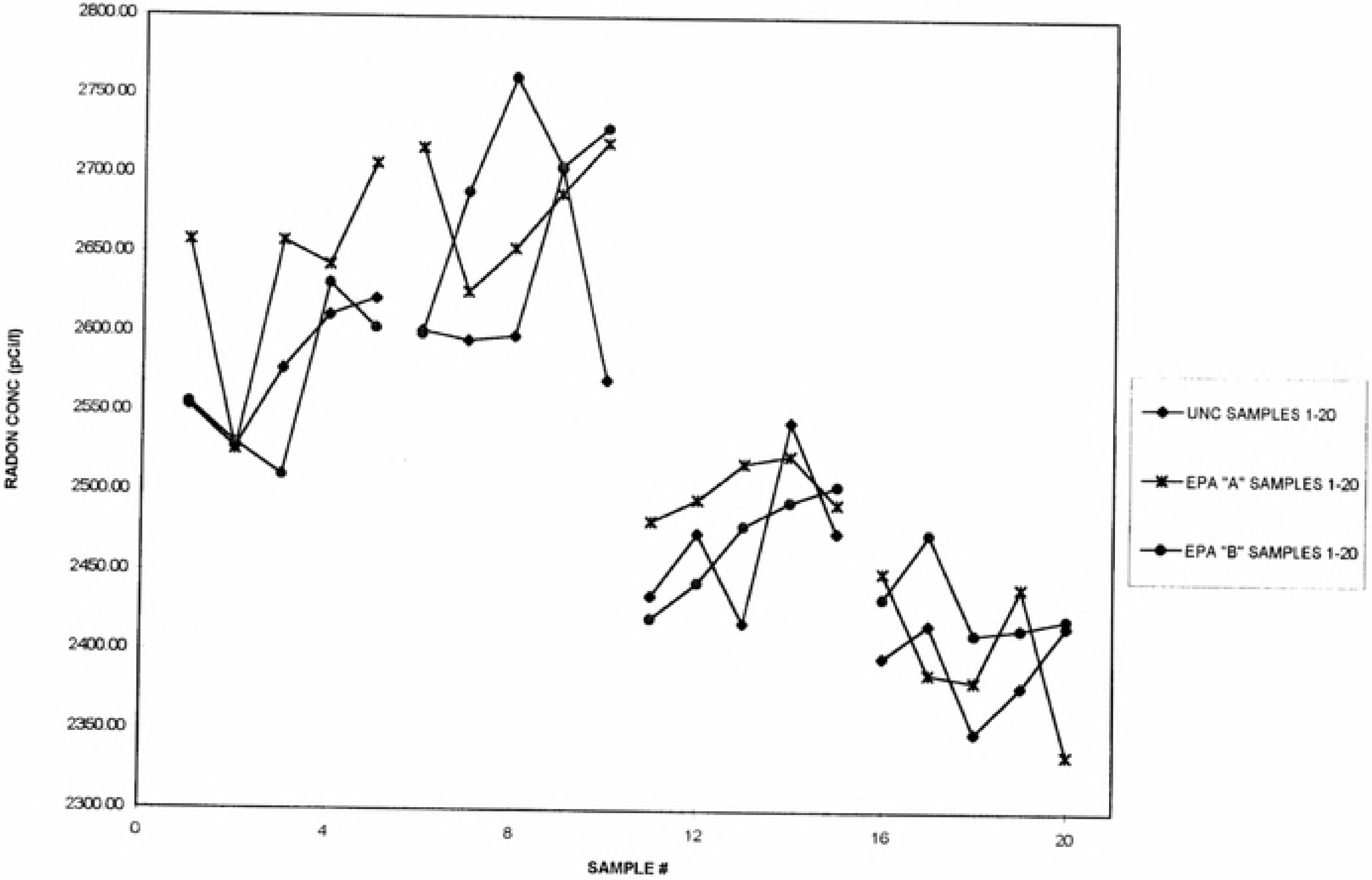
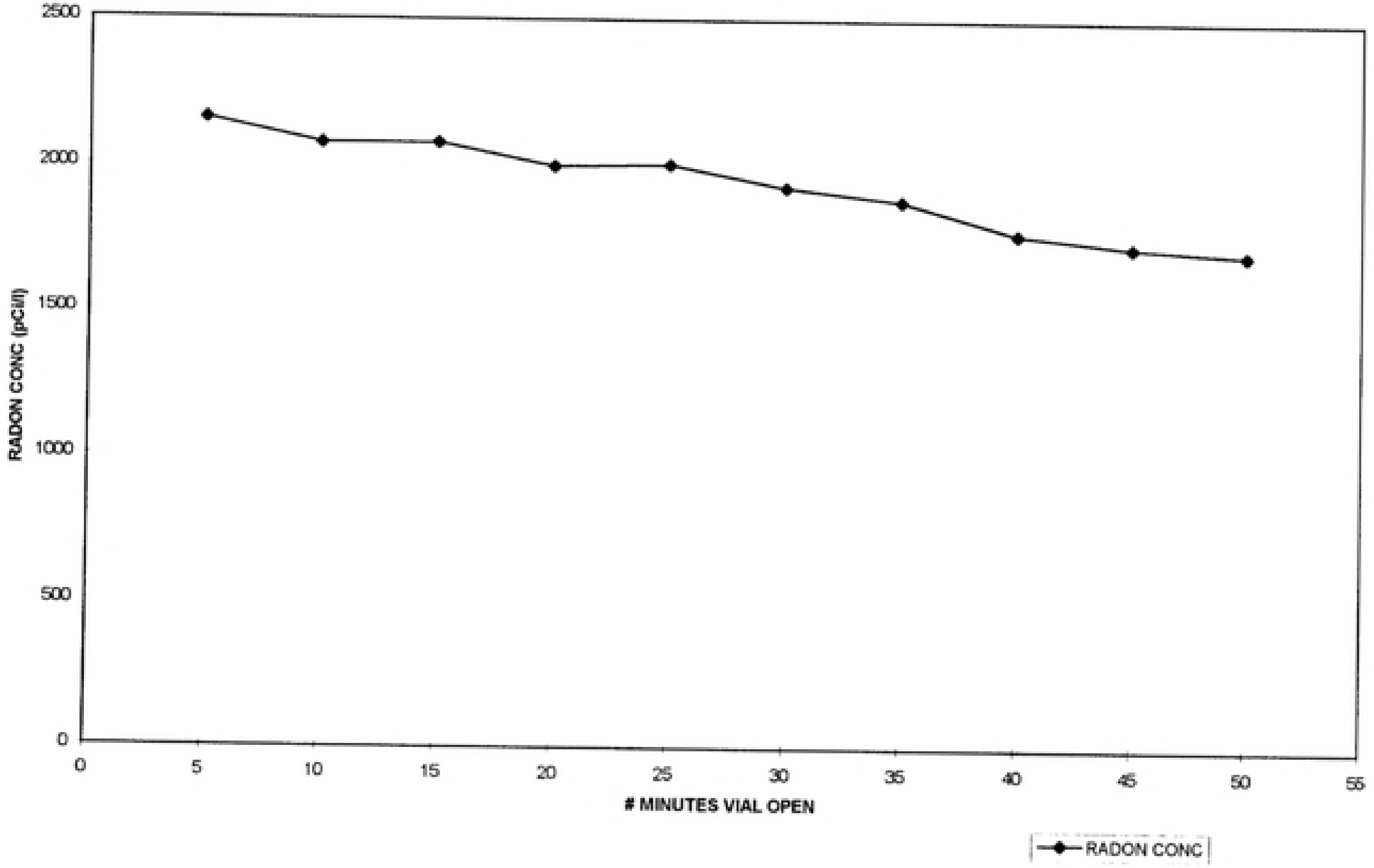


Figure 25: SPECIAL TEST #5 RESULTS
RADON CONCENTRATION
VERSUS VIAL OPEN TIME



# CONCLUSIONS

## Long Term Study of Variation of $^{222}$Rn Concentration in Well Water

Based on the results reported herein, no evidence was found to diminish the following conclusions of the Drane study:

1. No individual sample varied by more than 55% from the mean $^{222}$Rn concentration for that well.

2. 66% of the samples were within 10% of the well's grand mean, 91% were within 20% of the well's mean and 97% were within 30% of the well's grand mean.

3. The proposed EPA sampling program, current at that time and now withdrawn, would have been adequate for determining whether an individual well site was within the compliance limit for $^{222}$Rn concentration in the well water.

This assessment is based on comparison of the samples taken in 1995 with those taken in 1996. Comparison of the percentage of samples that fell within the given range about the sample's well site sample mean was conducted. In each sample mean range the 1996 cumulative percentages are larger than the 1995 cumulative percentages, thus in each range more 1996 samples were closer to the well site sample mean than in 1995. This indicates that an individual 1996 well sample would be as likely or better than an individual 1995 well sample at estimating the well site's average $^{222}$Rn concentration.

## Short Term Studies of Variation of $^{222}$Rn Concentration in Well Water

Special Tests #1, #2 and #3 sought to determine if pump operation had an effect on the measured $^{222}$Rn concentration at a well site. Well Site #5 was chosen based on previous researchers' reported trends, both increasing and decreasing, observed in the measured $^{222}$Rn concentration within individual sample runs. The following conclusions may be drawn from the results of the subject tests:

1. Operation of the well pump appears to cause the sample $^{222}$Rn concentration to be reduced by approximately 0.8 pCi/L per minute. This conclusion is drawn from the results of Special Test #2 in which the $^{222}$Rn concentration decreases at 0.8 pCi/L per minute over the eight hour test period during which the pump was in operation, and from Special Test #3 in which the $^{222}$Rn concentration also decreases at 0.8 pCi/L per minute during the first two hours of the eight hour test period while the pump was in operation. However, it should be noted that Special Test #1 did not show a similar pattern during pump operation. The results of Special Test #1 show a decrease in $^{222}$Rn concentration for the first hour of pump operation followed by an increase in

$^{222}$Rn concentration for the second hour of pump operation, without a significant change over the two hour period. The mechanism by which the sample $^{222}$Rn concentration is apparently reduced is not known at this time.

2. Special Test #3 results show an increasing trend in sample $^{222}$Rn concentration as the well pump is intermittently operated. In this eight hour test, after the first two hours of continuous pump operation, the pump was only operated during the three twenty minute sampling sequences, every two hours. Assuming that pump operation causes a reduction in sample $^{222}$Rn concentration, it would be logical to assume that cessation of pump operation would cause an increase or recovery in sample $^{222}$Rn concentration.

3. Based on an examination of the well water distribution system at Well Site #5 and the results of Special Tests #1 and #3, evidence strongly suggests that the trends observed by previous researchers are due to a sampling artifact associated with sample dilution and not due to inadequate purging or variation in groundwater $^{222}$Rn concentrations in the vicinity of the pump suction.

   At Well Site #5 the chemical metering point into the well water distribution system was upstream of the sample point and evidence suggests that the reduction in sample flow rate over an individual sample sequence might cause some of the metered sodium hypochlorite and water solution to dilute the sample, thus lowering the sample concentration. This is of particular significance as it illustrates how the drinking water system configuration and the sample technique can influence the sample concentration.

   Although previous researchers reported observing trends in the Well Site #5 data, these trends were observed in sample sequences that were performed over a two to three minute time period. Linear regression analysis and hypothesis testing of the data do show clear trends, decreasing $^{222}$Rn concentration while the well pump is in operation and increasing $^{222}$Rn concentration while the well pump is intermittently operated. However, the observed trend is at a slow enough rate, less than 1.0 pCi/L per minute, that the trends could not have been observed in a sample sequence taken over a two to three minute interval.

## Discussion of Possible Causal Association Between Pump Operation and $^{222}$Rn Concentration Change

Borrowing from epidemiological guidelines for judging whether an association is causal (Gordis, 1996) to establish if pump operation is causally associated with the reduction in $^{222}$Rn concentration, the following points from Gordis, in **bold** letters below, are addressed:

The **temporal relationship** between pump operation and $^{222}$Rn concentration reduction must be examined. Disease causal factors such as exposure typically precede the onset of disease; in this case the simultaneous temporal relationship between pump operation and $^{222}$Rn concentration reduction strongly suggests an association between the two. Clearly this is not sufficient by itself. It is possible that sampling occurred simultaneously with $^{222}$Rn concentration fluctuations associated with some other cause.

The **strength of association** between a suspected causal factor and the effect can be measured by a risk ratio or odds ratio. In this case the strength of association between pump operation and $^{222}$Rn concentration reduction is less than 1.0 pCi/L per minute of operation, while not large, it has been shown that it is not zero in Special Tests #2 and #3 with a high confidence level ($p < 0.0001$).

The **dose-response relationship** is important in establishing causal relationships for many types of disease. If an increase in the pump flow rate (dose) were accompanied by an increase in the rate of change of the $^{222}$Rn concentration reduction (response) then the relationship between pump operation and $^{222}$Rn concentration reduction would be more firmly established. This type of test was not done for this study and may be difficult to do depending on the suitability of the well pumps used and the well water distribution piping and sampling locations.

**Replication of findings** is important in establishing causal relationships. If the relationship between pump operation and $^{222}$Rn concentration reduction is causal, then it would be expected to be seen at other wells and to be able to be repeated at Well Site #5. This has not been done at this time. In order to more firmly establish the relationship between pump operation and $^{222}$Rn concentration reduction it would be necessary to repeat the types of tests done at Well Site #5 and to perform similar test at other well sites.

**Biological plausibility** is important in disease causal relationships by comparing the current body of knowledge with epidemiological or other findings. Establishing a relationship between pump operation and $^{222}$Rn concentration reduction is difficult without understanding the physical mechanisms by which this is occurring. Lacking a physical mechanism, it may be difficult to interpret the results of the tests and to make recommendations as to whether or not sampling strategies support regulatory requirements.

**Consideration of alternate explanations** is required to fully understand whether or not pump operation is associated with $^{222}$Rn concentration reduction. The theory that water is drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continues water is then drawn from areas of lower $^{222}$Rn concentration is one explanation. Another explanation is that the pumping of the water itself reduces the $^{222}$Rn concentration as a result of the pressure changes induced upon the fluid in order to cause the fluid to flow. Another explanation is that the ground water $^{222}$Rn concentration varies, perhaps sinusoidally, and that the performance of the tests coincided with natural variations in the ground water $^{222}$Rn concentration.

**Consideration of alternate explanations** is also required to establish that there is not some confounding effect associated with the pump operation that would cause the decrease in $^{222}$Rn concentration. A confounding effect is one associated with the suspected cause, pump operation, that would lead to the effect, $^{222}$Rn concentration reduction, but that is not a direct result of the suspected cause. An example of a confounder associated with pump operation, which might cause loss of dissolved $^{222}$Rn in the pumped fluid, would be elevated pumped fluid temperature in the pump casing. Although not directly related to the actual pumping of the fluid, it could be associated with the pumping and might result from improper pump or motor selection at a specific site. Further testing would be required in order to fully explore the possible explanations for the observed phenomena.

Reduction of disease incidence is often associated with **cessation of exposure** to the suspected causal factor. Special Test #3 demonstrates that as the operation of the pump is changed from continuous to intermittent that the sample $^{222}$Rn concentration shifts from decreasing to increasing. This is a strong argument for the association of pump operation and $^{222}$Rn concentration reduction.

Identification of a **specificity of association** would link the cause and effect in an exclusive way. For the purposes discussed herein, if pump operation was the only known cause of a change in the well sample $^{222}$Rn concentration, that would be a strong argument linking pump operation and well sample $^{222}$Rn concentration change. Absence of specificity does not negate a causal relationship, and variation in $^{222}$Rn concentration has been reported to be associated with changes in temperature, pressure, rainfall, $^{222}$Rn emission from rocks, and earthquake activity (York, 1995).

Similar to biological or physical plausibility, **consistency with other knowledge** must be evaluated when trying to establish a causal relationship. The theory that water is drawn from areas of higher $^{222}$Rn concentration near the pump suction and that as the pumping continues water is then drawn from areas of lower $^{222}$Rn concentration must be evaluated with the equally likely expectation that water could be drawn from areas of lower $^{222}$Rn concentration near the pump suction and that as the pumping continues water is then drawn from areas of higher $^{222}$Rn concentration. Lacking any physical explanation at this time the association of pump operation and sample $^{222}$Rn concentration change could be a positive or increasing association rather than negative and decreasing.

Summarizing the above discussion, arguments strongly supporting the association of pump operation and sample $^{222}$Rn concentration reduction are as follows:

> The temporal relationship between pump operation and $^{222}$Rn concentration reduction strongly suggest an association, $^{222}$Rn concentration reduction appears to occur while the pump is in operation. The change in $^{222}$Rn concentration from decreasing to increasing upon termination of continuous pump operation also strongly suggests an association. Although the $^{222}$Rn concentration reduction is not rapid during pump operation, less than 1.0 pCi/L per minute of operation, it has been shown to be non-zero with a high degree of confidence ($p < 0.0001$).

Information not yet obtained that would add support to the association of pump operation and sample $^{222}$Rn concentration reduction would be as follows:

> The establishment of a relationship between several different pump flow rates and a change in the rate of $^{222}$Rn concentration reduction at a specific well site would add support to the association of pump operation and sample $^{222}$Rn concentration reduction. This could be done by throttling the pump discharge and varying the total pump flow rate, in a step-wise fashion, over a sufficiently long enough time period to show different rates of $^{222}$Rn concentration change corresponding to different pump flow rates. It should be verified that the pump and valves to be used are suitable for this type of throttled operating mode. Replication of the observed phenomena at Well Site #5 and at other sites would also add support to the association of pump operation and sample $^{222}$Rn concentration reduction.
>
> Identifying a physical mechanism that explains the observed trend of decreasing $^{222}$Rn concentration as a function of pump operation would add to the plausibility of the observed findings. Understanding the physical mechanism would also allow a better interpretation of the results of the tests and allow more specific recommendations as to whether or not sampling strategies support regulatory requirements. Any explanations supporting the association of pump operation and sample $^{222}$Rn concentration reduction must also evaluate alternate explanations, possibly through further testing at well sites.

Information that would suggest that there is no association between pump operation and sample $^{222}$Rn concentration reduction, is as follows:

> Special Test #1 did not show a decreasing $^{222}$Rn concentration over the entire two hour period of continuous pump operation. Examination of the first two one hour segments of pump operation shows a decreasing trend the first hour followed by an increasing trend the second hour. This suggests that pump operation may not always

lead to a decrease in $^{222}$Rn concentration. Possibly pumping history at the well site prior to the conduct of the tests may have influenced the outcomes.

In light of the above discussion, it is necessary to also examine the conclusion that the proposed EPA sampling program would have been adequate for determining whether an individual well site was within the compliance limit for $^{222}$Rn concentration in the well water with respect to the possibility that as water is drawn from the well the $^{222}$Rn concentration measured in the well water samples decrease. Because the conclusion that the proposed EPA sampling program would have been adequate is based on whether or not an individual sample can estimate the well's average $^{222}$Rn concentration, the conclusion is independent of the phenomena of increasing or decreasing $^{222}$Rn concentration over a short term period, whatever the mechanism. As shown by the Drane 1995 data and the long term data from 1996, in comparison to the well's average $^{222}$Rn concentration, an individual sample is a good estimator of the well's average $^{222}$Rn concentration.

Even if the well's measured average $^{222}$Rn concentration is suppressed by the phenomenon of decreasing $^{222}$Rn concentration as the well pump is operated, it should be noted that the average delivered well water $^{222}$Rn concentration to the individual user would also be suppressed to the same proportion with respect to the average groundwater $^{222}$Rn concentration. If an association exists between $^{222}$Rn concentration reduction and pump operation then both the sampled $^{222}$Rn concentration and the delivered to the user $^{222}$Rn concentration would be reduced by the same proportion. Therefore, if the well's average sampled $^{222}$Rn concentration is a sufficient estimator of the average drinking water $^{222}$Rn concentration and if the formerly proposed EPA sampling program would have been adequate to characterize a well's average $^{222}$Rn concentration, then the conclusion remains valid that:

> The proposed EPA sampling program, current at that time and now withdrawn, would have been adequate for determining whether an individual well site was within the compliance limit for $^{222}$Rn concentration in the well water.

## EPA vs. UNC Comparison of $^{222}$Rn Sampling Methodologies

Special Tests #4 and #5 sought to determine if differences existed in sampling methodologies being considered for use in determining drinking water $^{222}$Rn concentration in well water samples. Three methodologies were compared, the UNC slow-flow method and two EPA methods, described previously. The following conclusions may be drawn from the results of the subject tests:

1. If sample vials are processed one-at-a-time and the length of time that the sample vials are open during processing is minimized, then there is no difference between the UNC slow-flow method and the EPA Method "A" and EPA Method "B".

This conclusion is reached by comparison of the results of Special Test #4 and Special Test #5. In Special Test #4, which compared the UNC slow-flow method, in which the vials are not reopened at the laboratory, and the EPA Method "B", in this test vials were opened five-at-a-time and processed at the laboratory, results show that there are differences in the measured $^{222}$Rn concentration between the two methods. In Special Test #5, which compared the UNC slow-flow method and the EPA Method "A" and EPA Method "B", in this EPA Method test vials were opened one-at-a-time during processing at the laboratory, results show that there were no differences in the measured $^{222}$Rn concentration between the three methods examined.

2. The $^{222}$Rn concentration decreases as a function of time that the sample vial is open and exposed to ambient air. It is estimated that at typical room temperatures, 20 - 22 °C (68 - 72 °F), that the rate of $^{222}$Rn concentration reduction is approximately 10.0 pCi/L per minute.

This is not surprising since the physical mechanism by which this is occurring is quite well understood, that of molecular diffusion. This is both a time-dependent process and temperature-dependent. Therefore it can also be concluded that as the temperature of the sample is increased the rate of loss of $^{222}$Rn would also be increased.

Based on the above two conclusions the following recommendation is made:

> In adopting a final sampling methodology for compliance to the possible future requirements of the Safe Drinking Water Act, consideration should be given to a methodology that minimizes the amount of time that the sample is exposed to ambient air and also minimizes exposure of the open sample vials to elevated temperatures.

## RECOMMENDATIONS FOR FUTURE STUDIES

1. Consideration should be given to performing additional short term tests in which the total pump flow rate is varied in a step-wise fashion, over a sufficiently long enough time period, to attempt to identify different rates of $^{222}$Rn concentration change corresponding to the different pump flow rates. This would strengthen the association between $^{222}$Rn concentration change and pump operation. It should be verified that the pump and valves to be used are suitable for this type of throttled operating condition. Additionally, further testing should include the exploration of an increase in $^{222}$Rn concentration associated with the cessation of continuous pump operation.

2. It is recommended that further literature reviews be performed to attempt to identify a physical mechanism by which $^{222}$Rn concentration change and pump operation are linked. References associated with Folger et al., 1996, might be a productive source of materials with which to begin a review. Further short term testing could be designed to further confirm any physical mechanisms identified and evaluate any alternate explanations under consideration.

3. For well sites with a high variation in sampled $^{222}$Rn concentration it is recommended that a review of well site equipment configurations be conducted. This would determine if the variation in sample concentration can be explained by equipment considerations, such as the location of the water treatment injection piping causing a dilution of the sample obtained at the sample point. It is recommended that other possible means of sample dilution be evaluated, such as the lack of a check valve between sample point and drinking water tank, causing dilution of the sample through back-flow of liquid from the tank to the sample point. Alter sample collection methods, as necessary, and determine if variation can be reduced.

4. Loss of contaminant may be caused by other factors such as high ambient air temperature causing sample vials and scintillation fluid to be at elevated temperature when sample is collected. Compare sample collection using vials and scintillation fluid at elevated temperatures versus using vials and scintillation fluid at well water temperature.

5. Elevated temperatures encountered in the shipping and transport of the EPA method vials may effect the ability of the sample to retain the dissolved $^{222}$Rn once opened at the laboratory. A possible comparison would be to examine any differences in shipping and transport temperatures affecting the EPA method vials once the sample is collected. Since the UNC slow-flow method vials are not opened after the sample is collected at the well site it would not be expected to lose any $^{222}$Rn due to elevated temperatures encountered in the shipping and transport of the UNC method vials. Hightower demonstrated that there was no significant difference in the results of mailed samples versus non-mailed samples collected by the UNC slow-flow method.

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# APPENDIX A

Table A1: Sample Run #1 - Raw Data

| SAMPLE DESIGNATION | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 32.06 | | 50.00 | 2/11/96 15:45 | 2/11/96 15:20 | | |
| BACK | | | | | 31.24 | | 50.00 | 2/11/96 16:36 | 2/11/96 16:11 | | |
| BACK | | | | | 32.38 | | 50.00 | 2/11/96 17:27 | 2/11/96 17:02 | | |
| BACK | | | | | 32.42 | | 50.00 | 2/11/96 18:19 | 2/11/96 17:54 | | |
| RADONSTD | | | | | 7075.35 | | 1.42 | 2/11/96 18:21 | 2/11/96 18:20 | | |
| 5-1 | 25.26 | 36.19 | 10.93 | 2/11/96 11:35 | 227.76 | 195.74 | 43.92 | 2/13/96 11:31 | 2/13/96 11:09 | 1.98 | 2569.12 |
| 5-2 | 25.49 | 37.85 | 12.36 | 2/11/96 11:35 | 261.16 | 229.14 | 38.29 | 2/13/96 12:11 | 2/13/96 11:51 | 2.01 | 2694.76 |
| 5-3 | 25.37 | 37.55 | 12.18 | 2/11/96 11:36 | 253.54 | 221.52 | 39.45 | 2/13/96 12:52 | 2/13/96 12:32 | 2.04 | 2656.80 |
| 5-4 | 25.36 | 37.45 | 12.09 | 2/11/96 11:36 | 243.72 | 211.70 | 41.03 | 2/13/96 13:34 | 2/13/96 13:13 | 2.07 | 2571.24 |
| 5-5 | 25.43 | 37.19 | 11.76 | 2/11/96 11:37 | 230.28 | 198.26 | 43.43 | 2/13/96 14:19 | 2/13/96 13:57 | 2.10 | 2488.95 |
| 6-1 | 25.27 | 35.77 | 10.50 | 2/10/96 15:07 | 45.98 | 13.96 | 50.00 | 2/12/96 18:30 | 2/12/96 18:05 | 2.12 | 197.15 |
| 6-2 | 25.40 | 36.28 | 10.88 | 2/10/96 15:07 | 47.78 | 15.76 | 50.00 | 2/12/96 19:22 | 2/12/96 18:57 | 2.16 | 216.22 |
| 6-3 | 25.35 | 36.26 | 10.91 | 2/10/96 15:07 | 48.16 | 16.14 | 50.00 | 2/12/96 20:13 | 2/12/96 19:48 | 2.20 | 222.25 |
| 6-4 | 25.36 | 36.56 | 11.20 | 2/10/96 15:08 | 46.16 | 14.14 | 50.00 | 2/12/96 21:04 | 2/12/96 20:39 | 2.23 | 190.86 |
| 6-5 | 25.32 | 36.32 | 11.00 | 2/10/96 15:08 | 45.16 | 13.14 | 50.00 | 2/12/96 21:56 | 2/12/96 21:31 | 2.27 | 181.77 |
| 7-1 | 25.41 | 37.71 | 12.30 | 2/10/96 14:21 | 84.38 | 52.36 | 50.00 | 2/12/96 14:13 | 2/12/96 13:48 | 1.98 | 614.65 |
| 7-2 | 25.44 | 36.86 | 11.42 | 2/10/96 14:21 | 81.10 | 49.08 | 50.00 | 2/12/96 15:05 | 2/12/96 14:40 | 2.01 | 624.82 |
| 7-3 | 25.52 | 37.56 | 12.04 | 2/10/96 14:22 | 79.52 | 47.50 | 50.00 | 2/12/96 15:56 | 2/12/96 15:31 | 2.05 | 577.19 |
| 7-4 | 25.23 | 36.86 | 11.63 | 2/10/96 14:23 | 82.08 | 50.06 | 50.00 | 2/12/96 16:47 | 2/12/96 16:22 | 2.08 | 633.73 |
| 7-5 | 25.44 | 37.47 | 12.03 | 2/10/96 14:23 | 79.16 | 47.14 | 50.00 | 2/12/96 17:39 | 2/12/96 17:14 | 2.12 | 580.71 |
| 8A-1 | 25.46 | 37.12 | 11.66 | 2/9/96 16:00 | 294.70 | 262.68 | 33.95 | 2/12/96 2:39 | 2/12/96 2:22 | 2.43 | 3534.09 |
| 8A-2 | 25.37 | 37.77 | 12.40 | 2/9/96 16:00 | 322.37 | 290.35 | 31.03 | 2/12/96 3:11 | 2/12/96 2:56 | 2.46 | 3688.76 |
| 8A-3 | 25.29 | 38.86 | 13.57 | 2/9/96 16:01 | 343.05 | 311.03 | 29.15 | 2/12/96 3:41 | 2/12/96 3:26 | 2.48 | 3624.44 |
| 8A-4 | 25.44 | 36.86 | 11.42 | 2/9/96 16:01 | 307.18 | 275.16 | 32.57 | 2/12/96 4:15 | 2/12/96 3:58 | 2.50 | 3825.64 |
| 8A-5 | 25.37 | 37.17 | 11.80 | 2/9/96 16:02 | 311.36 | 279.34 | 32.13 | 2/12/96 4:48 | 2/12/96 4:31 | 2.52 | 3773.97 |
| 8B-1 | 25.44 | 36.27 | 10.83 | 2/9/96 16:04 | 137.18 | 105.16 | 50.00 | 2/12/96 5:40 | 2/12/96 5:15 | 2.55 | 1555.98 |
| 8B-2 | 25.46 | 37.53 | 12.07 | 2/9/96 16:04 | 143.42 | 111.40 | 50.00 | 2/12/96 6:31 | 2/12/96 6:06 | 2.58 | 1488.51 |
| 8B-3 | 25.34 | 35.90 | 10.56 | 2/9/96 16:04 | 127.82 | 95.80 | 50.00 | 2/12/96 7:22 | 2/12/96 6:57 | 2.62 | 1472.52 |
| 8B-4 | 25.41 | 37.00 | 11.59 | 2/9/96 16:05 | 137.10 | 105.08 | 50.00 | 2/12/96 8:14 | 2/12/96 7:49 | 2.66 | 1481.12 |
| 8B-5 | 25.37 | 36.65 | 11.28 | 2/9/96 16:05 | 129.78 | 97.76 | 50.00 | 2/12/96 9:05 | 2/12/96 8:40 | 2.69 | 1424.93 |
| 9-1 | 25.48 | 35.50 | 10.02 | 2/10/96 13:35 | 182.86 | 150.84 | 50.00 | 2/12/96 9:57 | 2/12/96 9:32 | 1.83 | 2117.69 |
| 9-2 | 25.34 | 36.04 | 10.70 | 2/10/96 13:35 | 192.76 | 160.74 | 50.00 | 2/12/96 10:48 | 2/12/96 10:23 | 1.87 | 2126.89 |
| 9-3 | 25.39 | 36.67 | 11.28 | 2/10/96 13:36 | 191.32 | 159.30 | 50.00 | 2/12/96 11:39 | 2/12/96 11:14 | 1.90 | 2012.09 |
| 9-4 | 25.45 | 36.49 | 11.04 | 2/10/96 13:36 | 191.06 | 159.04 | 50.00 | 2/12/96 12:31 | 2/12/96 12:06 | 1.94 | 2065.97 |
| 9-5 | 25.51 | 36.66 | 11.15 | 2/10/96 13:37 | 190.70 | 158.68 | 50.00 | 2/12/96 13:22 | 2/12/96 12:57 | 1.97 | 2053.85 |
| 10-1 | 25.49 | 37.63 | 12.14 | 2/9/96 14:50 | 248.45 | 216.43 | 40.25 | 2/11/96 19:03 | 2/11/96 18:42 | 2.16 | 2662.90 |
| 10-2 | 25.31 | 36.82 | 11.51 | 2/9/96 14:50 | 239.54 | 207.52 | 41.75 | 2/11/96 19:46 | 2/11/96 19:25 | 2.19 | 2707.39 |
| 10-3 | 25.47 | 39.18 | 13.71 | 2/9/96 14:50 | 282.25 | 250.23 | 35.44 | 2/11/96 20:22 | 2/11/96 20:04 | 2.22 | 2754.31 |
| 10-4 | 25.38 | 37.69 | 12.31 | 2/9/96 14:51 | 252.36 | 220.34 | 39.63 | 2/11/96 21:03 | 2/11/96 20:43 | 2.24 | 2714.06 |
| 10-5 | 25.27 | 36.84 | 11.57 | 2/9/96 14:51 | 237.76 | 205.74 | 42.06 | 2/11/96 21:47 | 2/11/96 21:25 | 2.27 | 2710.87 |
| 11A-1 | 25.41 | 36.43 | 11.02 | 2/10/96 16:10 | 61.02 | 29.00 | 50.00 | 2/12/96 22:47 | 2/12/96 22:22 | 2.26 | 399.96 |
| 11A-2 | 25.44 | 36.24 | 10.80 | 2/10/96 16:10 | 60.74 | 28.72 | 50.00 | 2/12/96 23:38 | 2/12/96 23:13 | 2.29 | 406.77 |
| 11A-3 | 25.40 | 37.42 | 12.02 | 2/10/96 16:11 | 64.46 | 32.44 | 50.00 | 2/13/96 0:30 | 2/13/96 0:05 | 2.33 | 415.50 |
| 11A-4 | 25.36 | 37.94 | 12.58 | 2/10/96 16:11 | 64.46 | 32.44 | 50.00 | 2/13/96 1:21 | 2/13/96 0:56 | 2.36 | 400.20 |
| 11A-5 | 25.33 | 38.13 | 12.80 | 2/10/96 16:12 | 64.30 | 32.28 | 50.00 | 2/13/96 2:12 | 2/13/96 1:47 | 2.40 | 393.22 |
| 11B-1 | 25.37 | 35.65 | 10.28 | 2/10/96 16:12 | 47.18 | 15.16 | 50.00 | 2/13/96 3:04 | 2/13/96 2:39 | 2.44 | 231.42 |
| 11B-2 | 25.38 | 36.03 | 10.65 | 2/10/96 16:13 | 47.40 | 15.38 | 50.00 | 2/13/96 3:55 | 2/13/96 3:30 | 2.47 | 228.05 |
| 11B-3 | 25.25 | 37.01 | 11.76 | 2/10/96 16:13 | 51.76 | 19.74 | 50.00 | 2/13/96 4:47 | 2/13/96 4:22 | 2.51 | 266.83 |
| 11B-4 | 25.51 | 36.52 | 11.01 | 2/10/96 16:14 | 47.52 | 15.50 | 50.00 | 2/13/96 5:38 | 2/13/96 5:13 | 2.54 | 225.19 |
| 11B-5 | 25.42 | 36.72 | 11.30 | 2/10/96 16:14 | 48.94 | 16.92 | 50.00 | 2/13/96 6:29 | 2/13/96 6:04 | 2.58 | 241.06 |
| 12-1 | 25.52 | 36.89 | 11.37 | 2/9/96 15:15 | 121.46 | 89.44 | 50.00 | 2/11/96 22:38 | 2/11/96 22:13 | 2.29 | 1202.66 |
| 12-2 | 25.43 | 36.74 | 11.31 | 2/9/96 15:15 | 120.62 | 88.60 | 50.00 | 2/11/96 23:29 | 2/11/96 23:04 | 2.33 | 1205.40 |
| 12-3 | 25.42 | 37.44 | 12.02 | 2/9/96 15:15 | 126.98 | 94.96 | 50.00 | 2/12/96 0:21 | 2/11/96 23:56 | 2.36 | 1223.61 |
| 12-4 | 25.47 | 37.05 | 11.58 | 2/9/96 15:16 | 118.68 | 86.66 | 50.00 | 2/12/96 1:12 | 2/12/96 0:47 | 2.40 | 1166.41 |
| 12-5 | 25.30 | 37.15 | 11.65 | 2/9/96 15:16 | 118.28 | 86.26 | 50.00 | 2/12/96 2:03 | 2/12/96 1:38 | 2.43 | 1141.86 |
| 13-1 | 25.29 | 37.52 | 12.23 | 2/10/96 16:53 | 63.20 | 31.18 | 50.00 | 2/13/96 7:21 | 2/13/96 6:56 | 2.59 | 411.18 |
| 13-2 | 25.32 | 36.12 | 10.80 | 2/10/96 16:53 | 59.70 | 27.68 | 50.00 | 2/13/96 8:12 | 2/13/96 7:47 | 2.62 | 416.01 |
| 13-3 | 25.36 | 36.34 | 10.98 | 2/10/96 16:53 | 59.24 | 27.22 | 50.00 | 2/13/96 9:03 | 2/13/96 8:38 | 2.66 | 404.98 |
| 13-4 | 25.36 | 36.20 | 10.84 | 2/10/96 16:54 | 58.00 | 25.98 | 50.00 | 2/13/96 9:55 | 2/13/96 9:30 | 2.69 | 394.04 |
| 13-5 | 25.36 | 36.25 | 10.89 | 2/10/96 16:54 | 57.84 | 25.82 | 50.00 | 2/13/96 10:46 | 2/13/96 10:21 | 2.73 | 392.33 |

Table A5: Sample Run #5 - Raw Data

| SAMPLE DESIGNATION | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 31.78 | | 50.00 | 6/5/96 19:35 | | | |
| BACK | | | | | 31.68 | | 50.00 | 6/5/96 20:26 | | | |
| BACK | | | | | 31.68 | | 50.00 | 6/5/96 21:17 | | | |
| BACK | | | | | 30.10 | | 50.00 | 6/5/96 22:09 | | | |
| RADONSTD | | | | | 7255.07 | | 1.38 | 6/6/96 1:36 | | | |
| 5-1 | 25.23 | 35.08 | 9.85 | 6/5/96 16:22 | 208.53 | 177.22 | 47.96 | 6/6/96 2:25 | 6/6/96 2:01 | 0.40 | 1904.64 |
| 5-2 | 25.48 | 35.62 | 10.14 | 6/5/96 16:22 | 205.89 | 174.58 | 48.58 | 6/6/96 3:15 | 6/6/96 2:50 | 0.44 | 1834.05 |
| 5-3 | 25.38 | 35.70 | 10.32 | 6/5/96 16:22 | 157.94 | 126.63 | 50.00 | 6/6/96 4:06 | 6/6/96 3:41 | 0.47 | 1315.42 |
| 5-4 | 25.35 | 35.10 | 9.75 | 6/5/96 16:23 | 140.50 | 109.19 | 50.00 | 6/6/96 4:58 | 6/6/96 4:33 | 0.51 | 1208.30 |
| 5-5 | 25.33 | 35.29 | 9.96 | 6/5/96 16:23 | 127.32 | 96.01 | 50.00 | 6/6/96 5:49 | 6/6/96 5:24 | 0.54 | 1048.75 |
| 6-1 | 25.52 | 36.46 | 10.94 | 6/5/96 17:55 | 46.72 | 15.41 | 50.00 | 6/6/96 19:29 | 6/6/96 19:04 | 1.05 | 167.65 |
| 6-2 | 25.55 | 35.84 | 10.29 | 6/5/96 18:01 | 45.60 | 14.29 | 50.00 | 6/6/96 20:20 | 6/6/96 19:55 | 1.08 | 166.23 |
| 6-3 | 25.40 | 34.69 | 9.29 | 6/5/96 18:01 | 42.72 | 11.41 | 50.00 | 6/6/96 21:12 | 6/6/96 20:47 | 1.12 | 147.98 |
| 6-4 | 25.43 | 35.37 | 9.94 | 6/5/96 18:01 | 44.36 | 13.05 | 50.00 | 6/6/96 22:03 | 6/6/96 21:38 | 1.15 | 159.20 |
| 6-5 | 25.30 | 35.84 | 10.54 | 6/5/96 18:02 | 46.52 | 15.21 | 50.00 | 6/6/96 22:54 | 6/6/96 22:29 | 1.19 | 176.09 |
| 7-1 | 25.42 | 34.98 | 9.56 | 6/5/96 18:31 | 72.78 | 41.47 | 50.00 | 6/6/96 23:46 | 6/6/96 23:21 | 1.20 | 530.87 |
| 7-2 | 25.43 | 35.60 | 10.17 | 6/5/96 18:31 | 80.28 | 48.97 | 50.00 | 6/7/96 0:37 | 6/7/96 0:12 | 1.24 | 593.08 |
| 7-3 | 25.52 | 35.94 | 10.42 | 6/5/96 18:31 | 75.42 | 44.11 | 50.00 | 6/7/96 1:28 | 6/7/96 1:03 | 1.27 | 524.76 |
| 7-4 | 25.37 | 36.90 | 11.53 | 6/5/96 18:32 | 82.50 | 51.19 | 50.00 | 6/7/96 2:19 | 6/7/96 1:54 | 1.31 | 553.84 |
| 7-5 | 25.34 | 37.11 | 11.77 | 6/5/96 18:32 | 82.38 | 51.07 | 50.00 | 6/7/96 3:11 | 6/7/96 2:46 | 1.34 | 544.83 |
| 8A-1 | 25.43 | 35.63 | 10.20 | 6/6/96 17:30 | 316.65 | 285.34 | 31.59 | 6/7/96 3:43 | 6/7/96 3:27 | 0.41 | 2968.21 |
| 8A-2 | 25.27 | 34.31 | 9.04 | 6/6/96 17:30 | 291.24 | 259.93 | 34.35 | 6/7/96 4:19 | 6/7/96 4:01 | 0.44 | 3064.18 |
| 8A-3 | 25.24 | 34.74 | 9.50 | 6/6/96 17:31 | 303.80 | 272.49 | 32.93 | 6/7/96 4:53 | 6/7/96 4:36 | 0.46 | 3069.71 |
| 8A-4 | 25.38 | 34.91 | 9.53 | 6/6/96 17:31 | 309.98 | 278.67 | 32.28 | 6/7/96 5:26 | 6/7/96 5:09 | 0.49 | 3142.62 |
| 8A-5 | 25.37 | 34.45 | 9.08 | 6/6/96 17:31 | 296.30 | 264.99 | 33.75 | 6/7/96 6:01 | 6/7/96 5:44 | 0.51 | 3150.01 |
| 8B-1 | 25.25 | 35.01 | 9.76 | 6/6/96 17:34 | 153.52 | 122.21 | 50.00 | 6/7/96 6:53 | 6/7/96 6:28 | 0.54 | 1356.51 |
| 8B-2 | 25.39 | 34.53 | 9.14 | 6/6/96 17:34 | 136.22 | 104.91 | 50.00 | 6/7/96 7:44 | 6/7/96 7:19 | 0.57 | 1253.33 |
| 8B-3 | 25.47 | 35.68 | 10.21 | 6/6/96 17:35 | 152.64 | 121.33 | 50.00 | 6/7/96 8:35 | 6/7/96 8:10 | 0.61 | 1305.79 |
| 8B-4 | 25.49 | 35.14 | 9.65 | 6/6/96 17:35 | 152.86 | 121.55 | 50.00 | 6/7/96 9:26 | 6/7/96 9:01 | 0.64 | 1392.99 |
| 8B-5 | 25.27 | 34.86 | 9.59 | 6/6/96 17:35 | 147.98 | 116.67 | 50.00 | 6/7/96 10:18 | 6/7/96 9:53 | 0.68 | 1354.27 |
| 9-1 | 25.35 | 35.13 | 9.78 | 6/6/96 17:55 | 206.91 | 175.60 | 48.33 | 6/7/96 11:08 | 6/7/96 10:43 | 0.70 | 2006.50 |
| 9-2 | 25.33 | 34.30 | 8.97 | 6/6/96 17:55 | 195.96 | 164.65 | 50.00 | 6/7/96 11:59 | 6/7/96 11:34 | 0.74 | 2064.27 |
| 9-3 | 25.64 | 35.67 | 10.03 | 6/6/96 17:56 | 207.25 | 175.94 | 48.25 | 6/7/96 12:48 | 6/7/96 12:23 | 0.77 | 1964.89 |
| 9-4 | 25.36 | 35.04 | 9.68 | 6/6/96 17:56 | 196.86 | 165.55 | 50.00 | 6/7/96 13:40 | 6/7/96 13:15 | 0.80 | 1947.70 |
| 9-5 | 25.44 | 34.54 | 9.10 | 6/6/96 17:56 | 184.06 | 152.75 | 50.00 | 6/7/96 14:31 | 6/7/96 14:06 | 0.84 | 1923.97 |
| 10-1 | 25.42 | 34.97 | 9.55 | 6/6/96 18:37 | 246.39 | 215.08 | 40.59 | 6/7/96 19:30 | 6/7/96 19:09 | 1.02 | 2688.27 |
| 10-2 | 25.45 | 36.10 | 10.65 | 6/6/96 18:37 | 268.65 | 237.34 | 37.23 | 6/7/96 20:08 | 6/7/96 19:49 | 1.05 | 2853.64 |
| 10-3 | 25.38 | 35.08 | 9.70 | 6/6/96 18:37 | 244.02 | 212.71 | 40.98 | 6/7/96 20:50 | 6/7/96 20:29 | 1.08 | 2824.31 |
| 10-4 | 25.40 | 34.91 | 9.51 | 6/6/96 18:38 | 242.00 | 210.69 | 41.33 | 6/7/96 21:33 | 6/7/96 21:12 | 1.11 | 2685.33 |
| 10-5 | 25.40 | 35.94 | 10.54 | 6/6/96 18:38 | 271.89 | 240.58 | 36.78 | 6/7/96 22:11 | 6/7/96 21:52 | 1.14 | 2780.01 |
| 11A-1 | 25.43 | 34.39 | 8.96 | 6/5/96 17:25 | 59.94 | 28.63 | 50.00 | 6/6/96 10:57 | 6/6/96 10:32 | 0.71 | 357.90 |
| 11A-2 | 25.32 | 35.10 | 9.78 | 6/5/96 17:25 | 57.92 | 26.61 | 50.00 | 6/6/96 11:48 | 6/6/96 11:23 | 0.75 | 306.72 |
| 11A-3 | 25.40 | 35.93 | 10.53 | 6/5/96 17:25 | 59.30 | 27.99 | 50.00 | 6/6/96 12:39 | 6/6/96 12:14 | 0.78 | 301.58 |
| 11A-4 | 25.32 | 35.82 | 10.50 | 6/5/96 17:26 | 67.38 | 36.07 | 50.00 | 6/6/96 13:30 | 6/6/96 13:05 | 0.82 | 392.21 |
| 11A-5 | 25.28 | 35.43 | 10.15 | 6/5/96 17:26 | 59.02 | 27.71 | 50.00 | 6/6/96 14:22 | 6/6/96 13:57 | 0.85 | 313.75 |
| 11B-1 | 25.36 | 36.13 | 10.77 | 6/5/96 17:26 | 51.26 | 19.95 | 50.00 | 6/6/96 15:13 | 6/6/96 14:48 | 0.89 | 214.25 |
| 11B-2 | 25.44 | 36.19 | 10.75 | 6/5/96 17:26 | 52.12 | 20.81 | 50.00 | 6/6/96 16:04 | 6/6/96 15:39 | 0.93 | 225.36 |
| 11B-3 | 25.34 | 35.80 | 10.46 | 6/5/96 17:27 | 51.76 | 20.45 | 50.00 | 6/6/96 16:55 | 6/6/96 16:30 | 0.96 | 229.03 |
| 11B-4 | 25.21 | 35.19 | 9.98 | 6/5/96 17:27 | 50.34 | 19.03 | 50.00 | 6/6/96 17:47 | 6/6/96 17:22 | 1.00 | 224.84 |
| 11B-5 | 25.22 | 36.66 | 11.44 | 6/5/96 17:27 | 53.24 | 21.93 | 50.00 | 6/6/96 18:38 | 6/6/96 18:13 | 1.03 | 227.50 |
| 12-1 | 25.42 | 35.88 | 10.46 | 6/6/96 18:19 | 133.68 | 102.37 | 50.00 | 6/7/96 15:22 | 6/7/96 14:57 | 0.86 | 1125.73 |
| 12-2 | 25.44 | 35.12 | 9.68 | 6/6/96 18:19 | 118.86 | 87.55 | 50.00 | 6/7/96 16:13 | 6/7/96 15:48 | 0.90 | 1047.04 |
| 12-3 | 25.52 | 36.41 | 10.89 | 6/6/96 18:19 | 129.86 | 98.55 | 50.00 | 6/7/96 17:05 | 6/7/96 16:40 | 0.93 | 1054.52 |
| 12-4 | 25.37 | 35.45 | 10.08 | 6/6/96 18:20 | 122.26 | 90.95 | 50.00 | 6/7/96 17:56 | 6/7/96 17:31 | 0.97 | 1058.06 |
| 12-5 | 25.32 | 36.28 | 10.96 | 6/6/96 18:20 | 130.58 | 99.27 | 50.00 | 6/7/96 18:47 | 6/7/96 18:22 | 1.00 | 1068.96 |
| 13-1 | 25.36 | 36.06 | 10.70 | 6/5/96 16:55 | 64.28 | 32.97 | 50.00 | 6/6/96 6:40 | 6/6/96 6:15 | 0.56 | 335.40 |
| 13-2 | 25.40 | 36.26 | 10.86 | 6/5/96 16:55 | 65.40 | 34.09 | 50.00 | 6/6/96 7:32 | 6/6/96 7:07 | 0.59 | 343.93 |
| 13-3 | 25.44 | 37.25 | 11.81 | 6/5/96 16:55 | 70.92 | 39.61 | 50.00 | 6/6/96 8:23 | 6/6/96 7:58 | 0.63 | 369.84 |
| 13-4 | 25.29 | 35.96 | 10.67 | 6/5/96 16:56 | 63.72 | 32.41 | 50.00 | 6/6/96 9:14 | 6/6/96 8:49 | 0.66 | 337.06 |
| 13-5 | 25.39 | 35.47 | 10.08 | 6/5/96 16:22 | 62.32 | 31.01 | 50.00 | 6/6/96 10:05 | 6/6/96 9:40 | 0.72 | 348.06 |

Table A6: Special Test #1 - Raw Data

| SAMPLE DESIGNATION | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 32.08 | | 50.00 | 6/26/96 14:37 | | | |
| BACK | | | | | 32.58 | | 50.00 | 6/26/96 15:28 | | | |
| BACK | | | | | 31.56 | | 50.00 | 6/26/96 16:20 | | | |
| BACK | | | | | 31.78 | | 50.00 | 6/26/96 17:11 | | | |
| RADONSTD | | | | | 7215.11 | | 1.39 | 6/26/96 17:13 | | | |
| 1 | 25.35 | 35.85 | 10.50 | 6/26/96 10:15 | 222.59 | 190.59 | 44.93 | 6/26/96 17:59 | 6/26/96 17:36 | 0.31 | 1699.00 |
| 2 | 25.38 | 35.71 | 10.33 | 6/26/96 10:15 | 219.61 | 187.61 | 45.54 | 6/26/96 18:46 | 6/26/96 18:23 | 0.34 | 1911.28 |
| 3 | 25.35 | 35.9 | 10.55 | 6/26/96 10:16 | 224.67 | 192.67 | 44.47 | 6/26/96 19:32 | 6/26/96 19:09 | 0.37 | 1934.96 |
| 4 | 25.27 | 36.45 | 11.18 | 6/26/96 10:16 | 221.39 | 189.39 | 45.17 | 6/26/96 20:19 | 6/26/96 19:56 | 0.40 | 1803.54 |
| 5 | 25.36 | 37.38 | 12.02 | 6/26/96 10:17 | 246.69 | 214.69 | 40.54 | 6/26/96 21:00 | 6/26/96 20:39 | 0.43 | 1911.76 |
| 6 | 25.38 | 35.81 | 10.43 | 6/26/96 10:30 | 192.86 | 160.86 | 50 | 6/26/96 21:52 | 6/26/96 21:27 | 0.46 | 1657.93 |
| 7 | 25.44 | 35.48 | 10.04 | 6/26/96 10:30 | 201.33 | 169.33 | 49.68 | 6/26/96 22:43 | 6/26/96 22:18 | 0.49 | 1824.74 |
| 8 | 25.36 | 35.81 | 10.45 | 6/26/96 10:31 | 205.72 | 173.72 | 48.62 | 6/26/96 23:33 | 6/26/96 23:08 | 0.53 | 1809.86 |
| 9 | 25.53 | 35.81 | 10.28 | 6/26/96 10:31 | 195.36 | 163.36 | 50 | 6/27/96 0:24 | 6/26/96 23:59 | 0.56 | 1741.07 |
| 10 | 25.52 | 36.59 | 11.07 | 6/26/96 10:32 | 198.42 | 166.42 | 50 | 6/27/96 1:16 | 6/27/96 0:51 | 0.60 | 1657.72 |
| 11 | 25.39 | 36.31 | 10.92 | 6/26/96 10:45 | 204.39 | 172.39 | 48.93 | 6/27/96 2:06 | 6/27/96 1:41 | 0.62 | 1749.01 |
| 12 | 25.45 | 36.28 | 10.83 | 6/26/96 10:45 | 206.4 | 174.40 | 48.46 | 6/27/96 2:56 | 6/27/96 2:31 | 0.66 | 1795.45 |
| 13 | 25.52 | 36.07 | 10.55 | 6/26/96 10:46 | 201.49 | 169.49 | 49.64 | 6/27/96 3:47 | 6/27/96 3:22 | 0.69 | 1802.40 |
| 14 | 25.45 | 35.76 | 10.31 | 6/26/96 10:46 | 191.7 | 159.70 | 50 | 6/27/96 4:39 | 6/27/96 4:14 | 0.73 | 1749.21 |
| 15 | 25.3 | 35.35 | 10.05 | 6/26/96 10:47 | 179.64 | 147.64 | 50 | 6/27/96 5:30 | 6/27/96 5:05 | 0.76 | 1671.69 |
| 16 | 25.34 | 35.47 | 10.13 | 6/26/96 11:00 | 185.46 | 153.46 | 50 | 6/27/96 6:22 | 6/27/96 5:57 | 0.79 | 1730.01 |
| 17 | 25.3 | 35.52 | 10.22 | 6/26/96 11:00 | 185.5 | 153.50 | 50 | 6/27/96 7:13 | 6/27/96 6:48 | 0.82 | 1726.28 |
| 18 | 25.4 | 35.31 | 9.91 | 6/26/96 11:01 | 172.84 | 140.84 | 50 | 6/27/96 8:04 | 6/27/96 7:39 | 0.86 | 1643.75 |
| 19 | 25.5 | 35.41 | 9.91 | 6/26/96 11:01 | 171.94 | 139.94 | 50 | 6/27/96 8:56 | 6/27/96 8:31 | 0.90 | 1644.01 |
| 20 | 25.55 | 35.59 | 10.04 | 6/26/96 11:02 | 165.7 | 133.70 | 50 | 6/27/96 9:47 | 6/27/96 9:22 | 0.93 | 1560.16 |
| 21 | 25.28 | 35.2 | 9.92 | 6/26/96 11:30 | 172.48 | 140.48 | 50 | 6/27/96 10:39 | 6/27/96 10:14 | 0.95 | 1664.13 |
| 22 | 25.29 | 35.7 | 10.41 | 6/26/96 11:30 | 193.18 | 161.18 | 50 | 6/27/96 11:30 | 6/27/96 11:05 | 0.98 | 1831.20 |
| 23 | 25.37 | 35.12 | 9.75 | 6/26/96 11:31 | 175.14 | 143.14 | 50 | 6/27/96 12:21 | 6/27/96 11:56 | 1.02 | 1747.30 |
| 24 | 25.43 | 35.58 | 10.15 | 6/26/96 11:31 | 176.18 | 144.18 | 50 | 6/27/96 13:13 | 6/27/96 12:48 | 1.05 | 1701.74 |
| 25 | 25.23 | 35.76 | 10.53 | 6/26/96 11:32 | 181.66 | 149.66 | 50 | 6/27/96 14:04 | 6/27/96 13:39 | 1.09 | 1713.44 |
| 26 | 25.36 | 36.44 | 11.08 | 6/26/96 12:00 | 194.48 | 162.48 | 50 | 6/27/96 14:56 | 6/27/96 14:31 | 1.10 | 1773.23 |
| 27 | 25.31 | 35.88 | 10.57 | 6/26/96 12:00 | 187.24 | 155.24 | 50 | 6/27/96 15:47 | 6/27/96 15:22 | 1.14 | 1787.40 |
| 28 | 25.35 | 35.11 | 9.76 | 6/26/96 12:01 | 180.54 | 148.54 | 50 | 6/27/96 16:38 | 6/27/96 16:13 | 1.18 | 1863.90 |
| 29 | 25.39 | 36.04 | 10.65 | 6/26/96 12:01 | 189.16 | 157.16 | 50 | 6/27/96 17:30 | 6/27/96 17:05 | 1.21 | 1819.15 |
| 30 | 25.32 | 36.33 | 11.01 | 6/26/96 12:02 | 189.78 | 157.78 | 50 | 6/27/96 18:21 | 6/27/96 17:56 | 1.25 | 1777.77 |
| 31 | 25.36 | 35.87 | 10.51 | 6/26/96 14:02 | 189.34 | 157.34 | 50 | 6/27/96 19:13 | 6/27/96 18:48 | 1.20 | 1841.31 |
| 32 | 25.34 | 36.21 | 10.87 | 6/26/96 14:04 | 188.42 | 156.42 | 50 | 6/27/96 20:04 | 6/27/96 19:39 | 1.23 | 1780.88 |
| 33 | 25.42 | 36.96 | 11.54 | 6/26/96 14:06 | 205.25 | 173.25 | 48.72 | 6/27/96 20:54 | 6/27/96 20:29 | 1.27 | 1869.39 |
| 34 | 25.33 | 35.39 | 10.06 | 6/26/96 14:08 | 152.2 | 120.20 | 50 | 6/27/96 21:46 | 6/27/96 21:21 | 1.30 | 1497.06 |
| 35 | 25.39 | 36.79 | 11.40 | 6/26/96 14:10 | 217.46 | 185.46 | 45.99 | 6/27/96 22:33 | 6/27/96 22:10 | 1.33 | 2050.45 |
| 36 | 25.4 | 35.1 | 9.70 | 6/26/96 14:12 | 175.12 | 143.12 | 50 | 6/27/96 23:25 | 6/27/96 23:00 | 1.37 | 1870.94 |
| 37 | 25.45 | 35.97 | 10.52 | 6/26/96 14:14 | 168.94 | 136.94 | 50 | 6/28/96 0:16 | 6/27/96 23:51 | 1.40 | 1660.63 |
| 38 | 25.37 | 35.82 | 10.45 | 6/26/96 14:16 | 167.94 | 135.94 | 50 | 6/28/96 1:07 | 6/28/96 0:42 | 1.43 | 1670.03 |
| 39 | 25.31 | 35.89 | 10.58 | 6/26/96 14:18 | 116.7 | 84.70 | 50 | 6/28/96 1:59 | 6/28/96 1:34 | 1.47 | 1034.25 |
| 40 | 25.24 | 35.6 | 10.36 | 6/26/96 14:20 | 110.34 | 78.34 | 50 | 6/28/96 2:50 | 6/28/96 2:25 | 1.50 | 982.95 |
| 41 | 25.36 | 35.87 | 10.51 | 6/26/96 16:02 | 203.52 | 171.52 | 49.14 | 6/28/96 3:41 | 6/28/96 3:16 | 1.47 | 2107.92 |
| 42 | 25.29 | 36.01 | 10.72 | 6/26/96 16:04 | 199.98 | 167.98 | 50 | 6/28/96 4:32 | 6/28/96 4:07 | 1.50 | 2036.40 |
| 43 | 25.43 | 35.84 | 10.41 | 6/26/96 16:06 | 174.2 | 142.20 | 50 | 6/28/96 5:24 | 6/28/96 4:59 | 1.54 | 1786.42 |
| 44 | 25.47 | 35.3 | 9.83 | 6/26/96 16:08 | 154.34 | 122.34 | 50 | 6/28/96 6:15 | 6/28/96 5:50 | 1.57 | 1637.69 |
| 45 | 25.41 | 34.73 | 9.32 | 6/26/96 16:10 | 128.8 | 96.80 | 50 | 6/28/96 7:07 | 6/28/96 6:42 | 1.61 | 1375.34 |
| 46 | 25.3 | 34.62 | 9.32 | 6/26/96 16:12 | 173.76 | 141.76 | 50 | 6/28/96 7:58 | 6/28/96 7:33 | 1.64 | 2026.01 |
| 47 | 25.42 | 35.9 | 10.48 | 6/26/96 16:14 | 194.42 | 162.42 | 50 | 6/28/96 8:49 | 6/28/96 8:24 | 1.67 | 2077.74 |
| 48 | 25.37 | 35.4 | 10.03 | 6/26/96 16:16 | 162 | 130.00 | 50 | 6/28/96 9:41 | 6/28/96 9:16 | 1.71 | 1748.61 |
| 49 | 25.49 | 35.48 | 9.99 | 6/26/96 16:18 | 178.46 | 146.46 | 50 | 6/28/96 10:32 | 6/28/96 10:07 | 1.74 | 1990.14 |
| 50 | 25.29 | 35.07 | 9.78 | 6/26/96 16:20 | 153.9 | 121.90 | 50 | 6/28/96 11:24 | 6/28/96 10:59 | 1.78 | 1702.67 |
| 51 | 25.42 | 36.47 | 11.05 | 6/26/96 18:02 | 177.02 | 145.02 | 50 | 6/28/96 12:15 | 6/28/96 11:50 | 1.74 | 1781.32 |
| 52 | 25.24 | 34.83 | 9.59 | 6/26/96 18:04 | 147 | 115.00 | 50 | 6/28/96 13:06 | 6/28/96 12:41 | 1.78 | 1637.71 |
| 53 | 25.23 | 35.5 | 10.27 | 6/26/96 18:06 | 184.9 | 152.90 | 50 | 6/28/96 14:15 | 6/28/96 13:50 | 1.82 | 2050.50 |
| 54 | 25.28 | 35.82 | 10.54 | 6/26/96 18:08 | 183.96 | 151.96 | 50 | 6/28/96 15:07 | 6/28/96 14:42 | 1.86 | 1998.24 |
| 55 | 25.34 | 35.5 | 10.16 | 6/26/96 18:10 | 170.12 | 138.12 | 50 | 6/28/96 15:58 | 6/28/96 15:33 | 1.89 | 1895.84 |
| 56 | 25.35 | 35.62 | 10.27 | 6/26/96 18:12 | 156.56 | 124.56 | 50 | 6/28/96 16:50 | 6/28/96 16:25 | 1.93 | 1702.09 |
| 57 | 25.38 | 34.87 | 9.49 | 6/26/96 18:14 | 137.18 | 105.18 | 50 | 6/28/96 17:41 | 6/28/96 17:16 | 1.96 | 1565.03 |
| 58 | 25.34 | 35.21 | 9.87 | 6/26/96 18:16 | 123.86 | 91.86 | 50 | 6/28/96 18:33 | 6/28/96 18:08 | 1.99 | 1322.52 |
| 59 | 25.3 | 35.15 | 9.85 | 6/26/96 18:18 | 112.08 | 80.08 | 50 | 6/28/96 19:24 | 6/28/96 18:59 | 2.03 | 1162.41 |
| 60 | 25.45 | 35.22 | 9.77 | 6/26/96 18:20 | 98.56 | 66.56 | 50 | 6/28/96 20:16 | 6/28/96 19:51 | 2.06 | 980.23 |

Table A7 Special Test #2 - Raw Data

| SAMPLE DESIGNA' | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 31.4 | | 50 | 6/29/96 16:17 | | | |
| BACK | | | | | 32.7 | | 50 | 6/29/96 17:08 | | | |
| BACK | | | | | 31.8 | | 50 | 6/29/96 17:59 | | | |
| BACK | | | | | 31.52 | | 50 | 6/29/96 18:51 | | | |
| RADONSTD | | | | | 7260.87 | | 1.38 | 6/29/96 18:53 | | | |
| 1 | 25.63 | 36.76 | 11.13 | 6/27/96 10:16 | 206.23 | 174.375 | 48.49 | 6/29/96 19:43 | 35245.8 | 2.376913 | 2371.201 |
| 2 | 25.49 | 35.3 | 9.81 | 6/27/96 10:16 | 169.18 | 137.325 | 50 | 6/29/96 20:34 | 35245.84 | 2.411806 | 2132.107 |
| 3 | 25.45 | 35.1 | 9.65 | 6/27/96 10:16 | 165.32 | 133.465 | 50 | 6/29/96 21:26 | 35245.88 | 2.447917 | 2120.379 |
| 4 | 25.5 | 35.44 | 9.94 | 6/27/96 10:17 | 161.86 | 130.005 | 50 | 6/29/96 22:17 | 35245.91 | 2.482639 | 2017.821 |
| 5 | 25.54 | 34.28 | 8.74 | 6/27/96 10:17 | 137.56 | 105.705 | 50 | 6/29/96 23:08 | 35245.95 | 2.518056 | 1877.948 |
| 6 | 25.59 | 34.88 | 9.29 | 6/27/96 10:35 | 165.22 | 133.365 | 50 | 6/30/96 0:00 | 35245.98 | 2.541667 | 2238.646 |
| 7 | 25.51 | 35.14 | 9.63 | 6/27/96 10:35 | 171.02 | 139.165 | 50 | 6/30/96 0:51 | 35246.02 | 2.577083 | 2268.056 |
| 8 | 25.61 | 34.81 | 9.2 | 6/27/96 10:35 | 152.72 | 120.865 | 50 | 6/30/96 1:43 | 35246.05 | 2.613194 | 2075.429 |
| 9 | 25.43 | 35.31 | 9.88 | 6/27/96 10:36 | 162.16 | 130.305 | 50 | 6/30/96 2:34 | 35246.09 | 2.647917 | 2096.693 |
| 10 | 25.52 | 36.31 | 10.79 | 6/27/96 10:36 | 174.84 | 142.985 | 50 | 6/30/96 3:26 | 35246.13 | 2.684028 | 2120.532 |
| 11 | 25.46 | 35.29 | 9.83 | 6/27/96 10:55 | 151.8 | 119.945 | 50 | 6/30/96 4:17 | 35246.16 | 2.70625 | 1960.448 |
| 12 | 25.55 | 35.24 | 9.69 | 6/27/96 10:55 | 141.72 | 109.865 | 50 | 6/30/96 5:08 | 35246.2 | 2.741667 | 1833.381 |
| 13 | 25.45 | 34.6 | 9.15 | 6/27/96 10:55 | 134.32 | 102.465 | 50 | 6/30/96 6:00 | 35246.23 | 2.777778 | 1822.706 |
| 14 | 25.61 | 35.89 | 10.28 | 6/27/96 10:56 | 156.88 | 125.025 | 50 | 6/30/96 6:51 | 35246.27 | 2.8125 | 1992.058 |
| 15 | 25.68 | 35.47 | 9.79 | 6/27/96 10:56 | 145.82 | 113.965 | 50 | 6/30/96 7:43 | 35246.3 | 2.848611 | 1919.251 |
| 16 | 25.59 | 35.87 | 10.28 | 6/27/96 11:15 | 159.32 | 127.465 | 50 | 6/30/96 8:34 | 35246.34 | 2.870833 | 2052.54 |
| 17 | 25.63 | 35.88 | 10.25 | 6/27/96 11:15 | 150.26 | 118.405 | 50 | 6/30/96 9:25 | 35246.38 | 2.90625 | 1924.555 |
| 18 | 25.57 | 35.55 | 9.98 | 6/27/96 11:15 | 149 | 117.145 | 50 | 6/30/96 10:17 | 35246.41 | 2.942361 | 1968.441 |
| 19 | 25.65 | 35.4 | 9.75 | 6/27/96 11:16 | 145.1 | 113.245 | 50 | 6/30/96 11:08 | 35246.45 | 2.977083 | 1960.105 |
| 20 | 25.51 | 36.06 | 10.55 | 6/27/96 11:16 | 159.98 | 128.125 | 50 | 6/30/96 11:59 | 35246.48 | 3.0125 | 2062.703 |
| 21 | 25.3 | 35.49 | 10.19 | 6/27/96 11:45 | 148.78 | 116.925 | 50 | 6/30/96 12:51 | 35246.52 | 3.028472 | 1954.55 |
| 22 | 25.35 | 35.2 | 9.85 | 6/27/96 11:45 | 145.36 | 113.505 | 50 | 6/30/96 13:42 | 35246.55 | 3.063889 | 1975.526 |
| 23 | 25.43 | 34.86 | 9.43 | 6/27/96 11:45 | 128.92 | 97.065 | 50 | 6/30/96 14:34 | 35246.59 | 3.1 | 1776.233 |
| 24 | 25.37 | 35.97 | 10.6 | 6/27/96 11:46 | 151.84 | 119.985 | 50 | 6/30/96 15:25 | 35246.63 | 3.134722 | 1965.646 |
| 25 | 25.38 | 35.71 | 10.33 | 6/27/96 11:46 | 138.46 | 106.605 | 50 | 6/30/96 16:17 | 35246.66 | 3.170833 | 1803.877 |
| 26 | 25.4 | 36.32 | 10.92 | 6/27/96 12:15 | 152.64 | 120.785 | 50 | 6/30/96 17:08 | 35246.7 | 3.186111 | 1938.759 |
| 27 | 25.27 | 35.56 | 10.29 | 6/27/96 12:15 | 147.4 | 115.545 | 50 | 6/30/96 18:00 | 35246.73 | 3.222222 | 1981.136 |
| 28 | 25.3 | 35.72 | 10.42 | 6/27/96 12:15 | 139.74 | 107.885 | 50 | 6/30/96 18:51 | 35246.77 | 3.257639 | 1838.494 |
| 29 | 25.36 | 35.31 | 9.95 | 6/27/96 12:16 | 139.22 | 107.365 | 50 | 6/30/96 19:43 | 35246.8 | 3.293056 | 1928.408 |
| 30 | 25.28 | 35.13 | 9.85 | 6/27/96 12:16 | 136.06 | 104.205 | 50 | 6/30/96 20:34 | 35246.84 | 3.328472 | 1902.839 |
| 31 | 25.35 | 36.02 | 10.67 | 6/27/96 13:15 | 143.58 | 111.725 | 50 | 6/30/96 21:26 | 35246.88 | 3.323611 | 1881.71 |
| 32 | 25.37 | 36.28 | 10.91 | 6/27/96 13:15 | 138 | 106.145 | 50 | 6/30/96 22:17 | 35246.91 | 3.359028 | 1759.672 |
| 33 | 25.4 | 35.46 | 10.06 | 6/27/96 13:15 | 132.66 | 100.805 | 50 | 6/30/96 23:09 | 35246.95 | 3.395139 | 1824.258 |
| 34 | 25.37 | 35.7 | 10.33 | 6/27/96 13:16 | 134.78 | 102.925 | 50 | 7/1/96 0:00 | 35246.98 | 3.429861 | 1825.401 |
| 35 | 25.43 | 37.03 | 11.6 | 6/27/96 13:16 | 151.46 | 119.605 | 50 | 7/1/96 0:51 | 35247.02 | 3.465278 | 1901.164 |
| 36 | 25.2 | 34.49 | 9.29 | 6/27/96 14:15 | 127.3 | 95.445 | 50 | 7/1/96 1:43 | 35247.05 | 3.460417 | 1892.704 |
| 37 | 25.4 | 36.09 | 10.69 | 6/27/96 14:15 | 133.88 | 102.025 | 50 | 7/1/96 2:34 | 35247.09 | 3.495833 | 1769.556 |
| 38 | 25.31 | 36.58 | 11.27 | 6/27/96 14:15 | 146.64 | 114.785 | 50 | 7/1/96 3:26 | 35247.13 | 3.531944 | 1900.824 |
| 39 | 25.39 | 35.48 | 10.09 | 6/27/96 14:16 | 129.8 | 97.945 | 50 | 7/1/96 4:17 | 35247.16 | 3.566667 | 1823.087 |
| 40 | 25.32 | 36.37 | 11.05 | 6/27/96 14:16 | 138.7 | 106.845 | 50 | 7/1/96 5:09 | 35247.2 | 3.602778 | 1827.904 |
| 41 | 25.26 | 34.92 | 9.66 | 6/27/96 15:15 | 121.48 | 89.625 | 50 | 7/1/96 6:00 | 35247.23 | 3.597222 | 1752.168 |
| 42 | 25.39 | 34.76 | 9.37 | 6/27/96 15:15 | 113.18 | 81.325 | 50 | 7/1/96 6:52 | 35247.27 | 3.633333 | 1649.863 |
| 43 | 25.37 | 35.19 | 9.82 | 6/27/96 15:15 | 117.86 | 86.005 | 50 | 7/1/96 7:43 | 35247.3 | 3.66875 | 1675.604 |
| 44 | 25.4 | 35.21 | 9.81 | 6/27/96 15:16 | 113.72 | 81.865 | 50 | 7/1/96 8:35 | 35247.34 | 3.704167 | 1606.863 |
| 45 | 25.31 | 36 | 10.69 | 6/27/96 15:16 | 128.84 | 96.985 | 50 | 7/1/96 9:26 | 35247.38 | 3.739583 | 1758.194 |
| 46 | 25.18 | 34.38 | 9.2 | 6/27/96 16:15 | 114.5 | 82.645 | 50 | 7/1/96 10:18 | 35247.41 | 3.734722 | 1739.345 |
| 47 | 25.34 | 34.86 | 9.52 | 6/27/96 16:15 | 116.32 | 84.465 | 50 | 7/1/96 11:10 | 35247.45 | 3.770833 | 1729.166 |
| 48 | 25.43 | 35.37 | 9.94 | 6/27/96 16:15 | 119.64 | 87.785 | 50 | 7/1/96 12:01 | 35247.48 | 3.80625 | 1732.312 |
| 49 | 25.33 | 34.99 | 9.66 | 6/27/96 16:16 | 121.82 | 89.965 | 50 | 7/1/96 12:53 | 35247.52 | 3.841667 | 1638.566 |
| 50 | 25.29 | 35.35 | 10.06 | 6/27/96 16:16 | 126.86 | 95.005 | 50 | 7/1/96 13:44 | 35247.55 | 3.877083 | 1676.363 |
| 51 | 25.4 | 35.15 | 9.75 | 6/27/96 17:15 | 115.86 | 84.005 | 50 | 7/1/96 14:36 | 35247.59 | 3.872222 | 1710.372 |
| 52 | 25.43 | 35.11 | 9.68 | 6/27/96 17:15 | 117.6 | 85.745 | 50 | 7/1/96 15:27 | 35247.63 | 3.907639 | 1769.758 |
| 53 | 25.23 | 34.58 | 9.35 | 6/27/96 17:15 | 118.92 | 87.065 | 50 | 7/1/96 16:19 | 35247.66 | 3.94375 | 1672.654 |
| 54 | 25.27 | 34.57 | 9.3 | 6/27/96 17:16 | 110.58 | 78.725 | 50 | 7/1/96 17:10 | 35247.7 | 3.978472 | 1713.132 |
| 55 | 25.33 | 35.43 | 10.1 | 6/27/96 17:16 | 118 | 86.145 | 50 | 7/1/96 18:02 | 35247.73 | 4.014583 | 1737.461 |
| 56 | 25.39 | 35.29 | 9.9 | 6/27/96 18:15 | 112.22 | 80.365 | 50 | 7/1/96 18:53 | 35247.77 | 4.009028 | 1651.963 |
| 57 | 25.38 | 35.61 | 10.23 | 6/27/96 18:15 | 116.78 | 84.925 | 50 | 7/1/96 19:45 | 35247.81 | 4.045139 | 1700.468 |
| 58 | 25.22 | 36.38 | 11.16 | 6/27/96 18:15 | 126.48 | 94.625 | 50 | 7/1/96 20:36 | 35247.84 | 4.080556 | 1748.017 |
| 59 | 25.4 | 36.55 | 11.15 | 6/27/96 18:16 | 120.2 | 88.345 | 50 | 7/1/96 21:28 | 35247.88 | 4.115972 | 1643.999 |
| 60 | 25.3 | 35.61 | 10.31 | 6/27/96 18:16 | 115.28 | 83.425 | 50 | 7/1/96 22:19 | 35247.91 | 4.151389 | 1689.749 |

Table A8: Special Test #3 - Raw Data

| SAMPLE DESIGNA | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 33.04 | | 50 | 7/12/96 23:29 | | | |
| BACK | | | | | 31.74 | | 50 | 7/13/96 0:21 | | | |
| BACK | | | | | 32.24 | | 50 | 7/13/96 1:12 | | | |
| BACK | | | | | 33.26 | | 50 | 7/13/96 2:03 | | | |
| RADONSTD | | | | | 7338.69 | | 1.37 | 7/13/96 2:05 | | | |
| 1 | 25.47 | 35.6 | 10.13 | 7/12/96 10:15 | 167.24 | 134.67 | 50 | 7/14/96 16:54 | 35260.69 | 2.259722 | 1948.847 |
| 2 | 25.47 | 35.57 | 10.1 | 7/12/96 10:15 | 158.88 | 126.31 | 50 | 7/14/96 17:46 | 35260.72 | 2.295833 | 1845.346 |
| 3 | 25.64 | 37.26 | 11.62 | 7/12/96 10:16 | 178.58 | 146.01 | 50 | 7/14/96 18:37 | 35260.76 | 2.330556 | 1865.836 |
| 4 | 25.59 | 35.76 | 10.17 | 7/12/96 10:16 | 160.28 | 127.71 | 50 | 7/14/96 19:28 | 35260.79 | 2.365972 | 1876.685 |
| 5 | 25.55 | 35.73 | 10.18 | 7/12/96 10:17 | 158.52 | 125.95 | 50 | 7/14/96 20:20 | 35260.83 | 2.401389 | 1860.922 |
| 6 | 25.42 | 35.63 | 10.21 | 7/12/96 10:19 | 151.54 | 118.97 | 50 | 7/14/96 21:11 | 35260.87 | 2.435417 | 1763.479 |
| 7 | 25.6 | 35.77 | 10.17 | 7/12/96 10:21 | 155.98 | 123.41 | 50 | 7/14/96 22:03 | 35260.9 | 2.470139 | 1848.093 |
| 8 | 25.46 | 35.96 | 10.5 | 7/12/96 10:23 | 159.36 | 126.79 | 50 | 7/14/96 22:54 | 35260.94 | 2.504167 | 1850.423 |
| 9 | 25.56 | 35.3 | 9.74 | 7/12/96 10:25 | 149.12 | 116.55 | 50 | 7/14/96 23:46 | 35260.97 | 2.538889 | 1845.288 |
| 10 | 25.54 | 35.7 | 10.16 | 7/12/96 10:27 | 145.68 | 113.11 | 50 | 7/15/96 0:37 | 35261.01 | 2.572917 | 1727.425 |
| 11 | 25.68 | 35.5 | 9.82 | 7/12/96 10:29 | 139.66 | 107.09 | 50 | 7/15/96 1:29 | 35261.04 | 2.607639 | 1702.806 |
| 12 | 25.76 | 35.88 | 10.12 | 7/12/96 10:31 | 144.02 | 111.45 | 50 | 7/15/96 2:20 | 35261.08 | 2.641667 | 1730.247 |
| 13 | 25.31 | 35.15 | 9.84 | 7/12/96 10:33 | 135.6 | 103.03 | 50 | 7/15/96 3:12 | 35261.12 | 2.676389 | 1656.437 |
| 14 | 25.63 | 35.65 | 10.02 | 7/12/96 10:35 | 145 | 112.43 | 50 | 7/15/96 4:03 | 35261.15 | 2.710417 | 1785.006 |
| 15 | 25.62 | 35.75 | 10.13 | 7/12/96 10:37 | 151.4 | 118.83 | 50 | 7/15/96 4:54 | 35261.19 | 2.744444 | 1877.685 |
| 16 | 25.62 | 35.39 | 9.77 | 7/12/96 10:55 | 145.78 | 113.21 | 50 | 7/15/96 5:46 | 35261.22 | 2.768056 | 1862.758 |
| 17 | 25.59 | 35.52 | 9.93 | 7/12/96 10:55 | 143.18 | 110.61 | 50 | 7/15/96 6:37 | 35261.26 | 2.803472 | 1802.195 |
| 18 | 25.52 | 36.8 | 11.28 | 7/12/96 10:56 | 157.34 | 124.77 | 50 | 7/15/96 7:29 | 35261.29 | 2.838889 | 1801.143 |
| 19 | 25.58 | 36.85 | 11.27 | 7/12/96 10:56 | 155.74 | 123.17 | 50 | 7/15/96 8:20 | 35261.33 | 2.874306 | 1791.094 |
| 20 | 25.53 | 35.61 | 10.08 | 7/12/96 10:57 | 141.78 | 109.21 | 50 | 7/15/96 9:11 | 35261.37 | 2.909028 | 1788.796 |
| 21 | 25.48 | 35.21 | 9.73 | 7/12/96 10:59 | 147.68 | 115.11 | 50 | 7/15/96 10:03 | 35261.4 | 2.94375 | 1963.401 |
| 22 | 25.51 | 35.63 | 10.12 | 7/12/96 11:01 | 139.92 | 107.35 | 50 | 7/15/96 10:54 | 35261.44 | 2.977778 | 1771.378 |
| 23 | 25.34 | 34.94 | 9.6 | 7/12/96 11:03 | 132 | 99.43 | 50 | 7/15/96 11:46 | 35261.47 | 3.0125 | 1740.49 |
| 24 | 25.54 | 36.51 | 10.97 | 7/12/96 11:05 | 145.88 | 113.31 | 50 | 7/15/96 12:37 | 35261.51 | 3.046528 | 1746.497 |
| 25 | 25.51 | 35.84 | 10.33 | 7/12/96 11:07 | 138.22 | 105.65 | 50 | 7/15/96 13:29 | 35261.54 | 3.08125 | 1740.248 |
| 26 | 25.55 | 35.69 | 10.14 | 7/12/96 11:09 | 128 | 95.43 | 50 | 7/15/96 14:20 | 35261.58 | 3.115278 | 1611.278 |
| 27 | 25.62 | 34.9 | 9.28 | 7/12/96 11:11 | 121.6 | 89.03 | 50 | 7/15/96 15:12 | 35261.62 | 3.15 | 1652.901 |
| 28 | 25.4 | 35.36 | 9.96 | 7/12/96 11:13 | 129.32 | 96.75 | 50 | 7/15/96 16:03 | 35261.65 | 3.184028 | 1683.957 |
| 29 | 25.6 | 35.32 | 9.72 | 7/12/96 11:15 | 123.28 | 90.71 | 50 | 7/15/96 16:55 | 35261.69 | 3.21875 | 1628.036 |
| 30 | 25.53 | 35.11 | 9.58 | 7/12/96 11:17 | 121.86 | 89.29 | 50 | 7/15/96 17:46 | 35261.72 | 3.252778 | 1636.038 |
| 31 | 25.64 | 36.15 | 10.51 | 7/12/96 11:55 | 133.54 | 100.97 | 50 | 7/15/96 18:38 | 35261.76 | 3.2625 | 1689.319 |
| 32 | 25.52 | 35.57 | 10.05 | 7/12/96 11:55 | 131.96 | 99.39 | 50 | 7/15/96 19:29 | 35261.79 | 3.297917 | 1750.205 |
| 33 | 25.68 | 36.4 | 10.72 | 7/12/96 11:56 | 145.62 | 113.05 | 50 | 7/15/96 20:20 | 35261.83 | 3.332639 | 1878.122 |
| 34 | 25.59 | 35.02 | 9.43 | 7/12/96 11:56 | 117.6 | 85.03 | 50 | 7/15/96 21:12 | 35261.87 | 3.36875 | 1616.418 |
| 35 | 25.57 | 36.5 | 10.93 | 7/12/96 11:57 | 135.76 | 103.19 | 50 | 7/15/96 22:03 | 35261.9 | 3.403472 | 1703.124 |
| 36 | 25.47 | 34.75 | 9.28 | 7/12/96 11:59 | 120.3 | 87.73 | 50 | 7/15/96 22:55 | 35261.94 | 3.438194 | 1716.187 |
| 37 | 25.55 | 35.62 | 10.07 | 7/12/96 12:01 | 128.88 | 96.31 | 50 | 7/15/96 23:46 | 35261.97 | 3.472222 | 1746.978 |
| 38 | 25.47 | 38.11 | 12.64 | 7/12/96 12:03 | 159.6 | 127.03 | 50 | 7/16/96 0:38 | 35262.01 | 3.506944 | 1847.312 |
| 39 | 25.47 | 36 | 10.53 | 7/12/96 12:05 | 123.72 | 91.15 | 50 | 7/16/96 1:29 | 35262.04 | 3.540972 | 1600.966 |
| 40 | 25.47 | 36.41 | 10.94 | 7/12/96 12:07 | 131.7 | 99.13 | 50 | 7/16/96 2:20 | 35262.08 | 3.575 | 1686.284 |
| 41 | 25.57 | 36.32 | 10.75 | 7/12/96 12:09 | 133.9 | 101.33 | 50 | 7/16/96 3:12 | 35262.12 | 3.609722 | 1765.258 |
| 42 | 25.38 | 34.96 | 9.58 | 7/12/96 12:11 | 121.42 | 88.85 | 50 | 7/16/96 4:03 | 35262.15 | 3.64375 | 1747.638 |
| 43 | 25.41 | 35.99 | 10.58 | 7/12/96 12:13 | 127.12 | 94.55 | 50 | 7/16/96 4:55 | 35262.19 | 3.678472 | 1694.615 |
| 44 | 25.59 | 37.18 | 11.59 | 7/12/96 12:15 | 141.42 | 108.85 | 50 | 7/16/96 5:46 | 35262.22 | 3.7125 | 1791.93 |
| 45 | 25.48 | 36.12 | 10.64 | 7/12/96 12:17 | 135.74 | 103.17 | 50 | 7/16/96 6:38 | 35262.26 | 3.747222 | 1861.76 |

Table A8: Special Test #3 - Raw Data (continued)

| SAMPLE DESIGNA' | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 25.5 | 35.8 | 10.3 | 7/12/96 14:02 | 212.34 | 179.77 | 47.1 | 7/13/96 2:54 | 35259.1 | 0.519757 | 1865.992 |
| 47 | 25.37 | 34.92 | 9.55 | 7/12/96 14:04 | 200.68 | 168.11 | 49.83 | 7/13/96 3:45 | 35259.14 | 0.552837 | 1893.329 |
| 48 | 25.65 | 35.24 | 9.59 | 7/12/96 14:06 | 195.1 | 162.53 | 50 | 7/13/96 4:36 | 35259.17 | 0.586806 | 1834.118 |
| 49 | 25.19 | 35.77 | 10.58 | 7/12/96 14:08 | 222.12 | 189.55 | 45.02 | 7/13/96 5:23 | 35259.21 | 0.619785 | 1950.512 |
| 50 | 25.59 | 36.22 | 10.63 | 7/12/96 14:10 | 216.56 | 183.99 | 46.2 | 7/13/96 6:10 | 35259.24 | 0.650625 | 1894.966 |
| 51 | 25.6 | 35.39 | 9.79 | 7/12/96 14:12 | 211.72 | 179.15 | 47.25 | 7/13/96 6:59 | 35259.27 | 0.682899 | 2015.196 |
| 52 | 25.63 | 35.59 | 9.96 | 7/12/96 14:14 | 208.7 | 176.13 | 47.92 | 7/13/96 7:49 | 35259.31 | 0.716 | 1959.138 |
| 53 | 25.41 | 34.78 | 9.37 | 7/12/96 14:16 | 186.9 | 154.33 | 50 | 7/13/96 8:40 | 35259.34 | 0.749306 | 1835.802 |
| 54 | 25.45 | 36.18 | 10.73 | 7/12/96 14:18 | 210.92 | 178.35 | 47.42 | 7/13/96 9:29 | 35259.38 | 0.78264 | 1863.934 |
| 55 | 25.59 | 36.12 | 10.53 | 7/12/96 14:20 | 210.37 | 177.8 | 47.54 | 7/13/96 10:18 | 35259.41 | 0.815438 | 1904.71 |
| 56 | 25.58 | 35.11 | 9.53 | 7/12/96 14:22 | 193.26 | 160.69 | 50 | 7/13/96 11:09 | 35259.45 | 0.848611 | 1913.529 |
| 57 | 25.5 | 36.56 | 11.06 | 7/12/96 14:22 | 216.85 | 184.28 | 46.12 | 7/13/96 11:57 | 35259.48 | 0.883292 | 1902.806 |
| 58 | 25.62 | 34.99 | 9.37 | 7/12/96 14:23 | 185.16 | 152.59 | 50 | 7/13/96 12:48 | 35259.52 | 0.918667 | 1871.059 |
| 59 | 25.47 | 35.52 | 10.05 | 7/12/96 14:23 | 191.4 | 158.83 | 50 | 7/13/96 13:40 | 35259.55 | 0.952778 | 1827.732 |
| 60 | 25.53 | 35.78 | 10.25 | 7/12/96 14:24 | 204.5 | 171.93 | 48.9 | 7/13/96 14:30 | 35259.59 | 0.987188 | 1952.023 |
| 61 | 25.52 | 36.44 | 10.92 | 7/12/96 16:02 | 217.55 | 184.98 | 45.99 | 7/13/96 15:17 | 35259.62 | 0.952781 | 1959.084 |
| 62 | 25.44 | 35.42 | 9.98 | 7/12/96 16:04 | 186.96 | 154.39 | 50 | 7/13/96 16:09 | 35259.66 | 0.986111 | 1799.952 |
| 63 | 25.56 | 34.96 | 9.4 | 7/12/96 16:06 | 187.62 | 155.05 | 50 | 7/13/96 17:00 | 35259.69 | 1.020139 | 1931.066 |
| 64 | 25.44 | 35.35 | 9.91 | 7/12/96 16:08 | 200.1 | 167.53 | 49.99 | 7/13/96 17:52 | 35259.73 | 1.054865 | 1991.628 |
| 65 | 25.61 | 35.99 | 10.38 | 7/12/96 16:10 | 210.81 | 178.24 | 47.44 | 7/13/96 18:41 | 35259.76 | 1.088389 | 2035.346 |
| 66 | 25.42 | 35.42 | 10 | 7/12/96 16:12 | 196.06 | 163.49 | 50 | 7/13/96 19:32 | 35259.8 | 1.121528 | 1949.542 |
| 67 | 25.55 | 35.94 | 10.39 | 7/12/96 16:14 | 198.36 | 165.79 | 50 | 7/13/96 20:23 | 35259.83 | 1.155556 | 1914.543 |
| 68 | 25.58 | 34.96 | 9.38 | 7/12/96 16:16 | 184.88 | 152.31 | 50 | 7/13/96 21:15 | 35259.87 | 1.190278 | 1960.576 |
| 69 | 25.54 | 35.96 | 10.42 | 7/12/96 16:18 | 197.02 | 164.45 | 50 | 7/13/96 22:06 | 35259.9 | 1.224306 | 1917.366 |
| 70 | 25.61 | 34.98 | 9.37 | 7/12/96 16:20 | 182.02 | 149.45 | 50 | 7/13/96 22:58 | 35259.94 | 1.259028 | 1949.983 |
| 71 | 25.26 | 35.92 | 10.66 | 7/12/96 16:22 | 198.88 | 166.31 | 50 | 7/13/96 23:49 | 35259.98 | 1.293056 | 1919.164 |
| 72 | 25.48 | 35.48 | 10 | 7/12/96 16:22 | 185.9 | 153.33 | 50 | 7/14/96 0:41 | 35260.01 | 1.329167 | 1898.575 |
| 73 | 25.52 | 35.95 | 10.43 | 7/12/96 16:23 | 193.88 | 161.31 | 50 | 7/14/96 1:32 | 35260.05 | 1.363889 | 1927.14 |
| 74 | 25.48 | 35.05 | 9.57 | 7/12/96 16:23 | 180.9 | 148.33 | 50 | 7/14/96 2:23 | 35260.08 | 1.399306 | 1943.765 |
| 75 | 25.6 | 36.31 | 10.71 | 7/12/96 16:24 | 196.12 | 163.55 | 50 | 7/14/96 3:15 | 35260.12 | 1.434722 | 1927.428 |
| 76 | 25.56 | 35.51 | 9.95 | 7/12/96 18:02 | 191.02 | 158.45 | 50 | 7/14/96 4:06 | 35260.15 | 1.402083 | 1998.088 |
| 77 | 25.43 | 35.55 | 10.12 | 7/12/96 18:04 | 186.14 | 153.57 | 50 | 7/14/96 4:57 | 35260.19 | 1.436111 | 1915.81 |
| 78 | 25.55 | 35.39 | 9.84 | 7/12/96 18:06 | 184.24 | 151.67 | 50 | 7/14/96 5:49 | 35260.23 | 1.470833 | 1958.244 |
| 79 | 25.45 | 36.33 | 10.88 | 7/12/96 18:08 | 206.33 | 173.76 | 48.48 | 7/14/96 6:39 | 35260.26 | 1.504884 | 2041.507 |
| 80 | 25.34 | 34.28 | 8.94 | 7/12/96 18:10 | 169.72 | 137.15 | 50 | 7/14/96 7:30 | 35260.3 | 1.538194 | 1973.002 |
| 81 | 25.3 | 35.65 | 10.35 | 7/12/96 18:12 | 191.94 | 159.37 | 50 | 7/14/96 8:22 | 35260.33 | 1.572917 | 1992.834 |
| 82 | 25.2 | 36.29 | 11.09 | 7/12/96 18:14 | 208.16 | 175.59 | 48.04 | 7/14/96 9:11 | 35260.37 | 1.606236 | 2061.571 |
| 83 | 25.43 | 34.59 | 9.16 | 7/12/96 18:16 | 164.74 | 132.17 | 50 | 7/14/96 10:03 | 35260.4 | 1.640278 | 1890.362 |
| 84 | 25.37 | 34.58 | 9.21 | 7/12/96 18:18 | 167.98 | 135.41 | 50 | 7/14/96 10:54 | 35260.44 | 1.674306 | 1938.136 |
| 85 | 25.42 | 34.42 | 9 | 7/12/96 18:20 | 167.6 | 135.03 | 50 | 7/14/96 11:45 | 35260.47 | 1.708333 | 1990.04 |
| 86 | 25.46 | 35.17 | 9.71 | 7/12/96 18:22 | 173.16 | 140.59 | 50 | 7/14/96 12:37 | 35260.51 | 1.743056 | 1932.613 |
| 87 | 25.56 | 34.59 | 9.03 | 7/12/96 18:22 | 160.58 | 128.01 | 50 | 7/14/96 13:28 | 35260.54 | 1.778472 | 1904.391 |
| 88 | 25.18 | 34.71 | 9.53 | 7/12/96 18:23 | 167.76 | 135.19 | 50 | 7/14/96 14:20 | 35260.58 | 1.813889 | 1917.971 |
| 89 | 25.28 | 34.52 | 9.24 | 7/12/96 18:23 | 161.24 | 128.67 | 50 | 7/14/96 15:11 | 35260.62 | 1.849306 | 1894.899 |
| 90 | 25.27 | 35.3 | 10.03 | 7/12/96 18:24 | 170.46 | 137.89 | 50 | 7/14/96 16:02 | 35260.65 | 1.884028 | 1882.558 |

Table A9: Special Test #4 - Raw Data

| SAMPLE DESIGNA | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 31.94 | | 50 | 7/18/96 18:24 | | | |
| BACK | | | | | 30.68 | | 50 | 7/18/96 19:15 | | | |
| BACK | | | | | 31.2 | | 50 | 7/18/96 20:06 | | | |
| BACK | | | | | 31.38 | | 50 | 7/18/96 20:57 | | | |
| RADONSTD | | | | | 7169.29 | | 1.4 | 7/18/96 21:00 | | | |
| 1-1EPA | 16.63 | 26.53 | 9.9 | 7/18/96 15:03 | 246.55 | 215.25 | 40.56 | 7/19/96 13:40 | 35265.56 | 0.928278 | 2562.514 |
| | 16.77 | 27.33 | 10.56 | 7/18/96 15:03 | 258.34 | 227.04 | 38.72 | 7/19/96 14:20 | 35265.58 | 0.956694 | 2547.039 |
| | 16.52 | 27.23 | 10.71 | 7/18/96 15:03 | 264.07 | 232.77 | 37.68 | 7/19/96 14:59 | 35265.61 | 0.984069 | 2587.566 |
| | 16.62 | 27.93 | 11.31 | 7/18/96 15:03 | 279.73 | 248.43 | 35.76 | 7/19/96 15:36 | 35265.64 | 1.0106 | 2627.712 |
| | 16.81 | 27.86 | 11.05 | 7/18/96 15:03 | 278.71 | 247.41 | 35.88 | 7/19/96 16:13 | 35265.66 | 1.036153 | 2690.982 |
| 2-1EPA | 16.69 | 26.86 | 9.97 | 7/18/96 15:17 | 232.06 | 200.76 | 43.1 | 7/19/96 16:57 | 35265.69 | 1.054479 | 2428.193 |
| | 16.79 | 27.01 | 10.22 | 7/18/96 15:17 | 223.69 | 192.39 | 44.71 | 7/19/96 17:43 | 35265.72 | 1.085885 | 2282.998 |
| | 16.8 | 27.18 | 10.38 | 7/18/96 15:17 | 227.09 | 195.79 | 44.04 | 7/19/96 18:28 | 35265.75 | 1.117347 | 2300.634 |
| | 16.65 | 27.21 | 10.56 | 7/18/96 15:17 | 222.02 | 190.72 | 45.04 | 7/19/96 19:15 | 35265.79 | 1.149639 | 2215.802 |
| | 16.96 | 26.92 | 9.96 | 7/18/96 15:17 | 227.87 | 196.57 | 43.89 | 7/19/96 20:00 | 35265.82 | 1.181288 | 2436.286 |
| 3-1EPA | 16.54 | 27.24 | 10.7 | 7/18/96 15:34 | 220.12 | 188.82 | 45.43 | 7/19/96 20:47 | 35265.85 | 1.201587 | 2185.524 |
| | 16.87 | 26.82 | 9.95 | 7/18/96 15:34 | 213.27 | 181.97 | 46.89 | 7/19/96 21:35 | 35265.88 | 1.234413 | 2278.528 |
| | 16.71 | 27.2 | 10.49 | 7/18/96 15:34 | 212.27 | 180.97 | 47.12 | 7/19/96 22:23 | 35265.92 | 1.267667 | 2162.364 |
| | 16.72 | 26.96 | 10.24 | 7/18/96 15:34 | 209.29 | 177.99 | 47.78 | 7/19/96 23:12 | 35265.95 | 1.301465 | 2192.079 |
| | 16.9 | 27.16 | 10.26 | 7/18/96 15:34 | 209.03 | 177.73 | 47.84 | 7/20/96 0:02 | 35265.98 | 1.336167 | 2198.406 |
| 4-1EPA | 16.56 | 26.77 | 10.21 | 7/18/96 15:47 | 215.61 | 184.31 | 46.38 | 7/20/96 0:49 | 35266.02 | 1.360285 | 2301.007 |
| | 16.68 | 26.77 | 10.09 | 7/18/96 15:47 | 211.21 | 179.91 | 47.35 | 7/20/96 1:38 | 35266.05 | 1.393976 | 2286.721 |
| | 16.57 | 27.06 | 10.49 | 7/18/96 15:47 | 212.47 | 181.17 | 47.07 | 7/20/96 2:26 | 35266.09 | 1.427406 | 2228.403 |
| | 16.64 | 26.94 | 10.3 | 7/18/96 15:47 | 211.55 | 180.25 | 47.27 | 7/20/96 3:15 | 35266.12 | 1.461385 | 2271.938 |
| | 16.64 | 27 | 10.36 | 7/18/96 15:47 | 209.99 | 178.69 | 47.65 | 7/20/96 4:04 | 35266.15 | 1.49626 | 2253.043 |
| 1-1UNC | 25.32 | 35.57 | 10.25 | 7/18/96 15:00 | 286.21 | 254.91 | 34.95 | 7/18/96 21:36 | 35264.89 | 0.262865 | 2597.738 |
| | 25.31 | 34.5 | 9.19 | 7/18/96 15:00 | 274.03 | 242.73 | 36.5 | 7/18/96 22:13 | 35264.91 | 0.288021 | 2771.547 |
| | 25.42 | 37.9 | 12.48 | 7/18/96 15:00 | 349.65 | 318.35 | 28.6 | 7/18/96 22:43 | 35264.94 | 0.311597 | 2666.203 |
| | 25.22 | 35.77 | 10.55 | 7/18/96 15:01 | 300.39 | 269.09 | 33.29 | 7/18/96 23:18 | 35264.96 | 0.33358 | 2698.665 |
| | 25.56 | 34.71 | 9.15 | 7/18/96 15:01 | 264.34 | 233.04 | 37.83 | 7/18/96 23:58 | 35264.99 | 0.359781 | 2707.556 |
| 2-1UNC | 25.3 | 35 | 9.7 | 7/18/96 15:18 | 302.79 | 271.49 | 33.03 | 7/19/96 0:33 | 35265.01 | 0.373948 | 2983.09 |
| | 25.51 | 35.21 | 9.7 | 7/18/96 15:18 | 272.58 | 241.28 | 36.69 | 7/19/96 1:11 | 35265.04 | 0.399066 | 2663.256 |
| | 25.35 | 36.41 | 11.06 | 7/18/96 15:19 | 311.72 | 280.42 | 32.08 | 7/19/96 1:45 | 35265.06 | 0.423683 | 2728.772 |
| | 25.54 | 36.85 | 11.31 | 7/18/96 15:19 | 318.67 | 287.37 | 31.38 | 7/19/96 2:18 | 35265.08 | 0.446743 | 2744.09 |
| | 25.5 | 36.29 | 10.79 | 7/18/96 15:20 | 303.12 | 271.82 | 33 | 7/19/96 2:52 | 35265.11 | 0.469097 | 2731.749 |
| 3-1UNC | 25.66 | 35.39 | 9.73 | 7/18/96 15:30 | 256.79 | 225.49 | 38.95 | 7/19/96 3:32 | 35265.13 | 0.487865 | 2521.586 |
| | 25.39 | 36.35 | 10.96 | 7/18/96 15:30 | 291.97 | 260.67 | 34.25 | 7/19/96 4:06 | 35265.16 | 0.514497 | 2600.388 |
| | 25.25 | 35.06 | 9.81 | 7/18/96 15:31 | 260.92 | 229.62 | 38.33 | 7/19/96 4:47 | 35265.19 | 0.539469 | 2570.766 |
| | 25.48 | 35.2 | 9.74 | 7/18/96 15:31 | 259.29 | 227.99 | 38.57 | 7/19/96 5:27 | 35265.21 | 0.567163 | 2583.83 |
| | 25.33 | 35.66 | 10.53 | 7/18/96 15:32 | 272.26 | 240.96 | 38.73 | 7/19/96 6:05 | 35265.24 | 0.593497 | 2538.04 |
| 4-1UNC | 25.54 | 35.19 | 9.65 | 7/18/96 15:48 | 248.34 | 217.04 | 40.28 | 7/19/96 6:47 | 35265.27 | 0.610319 | 2502.187 |
| | 25.56 | 36.38 | 10.82 | 7/18/96 15:48 | 276.32 | 245.02 | 36.19 | 7/19/96 7:24 | 35265.3 | 0.637434 | 2531.732 |
| | 25.43 | 36.26 | 10.83 | 7/18/96 15:49 | 281.19 | 249.89 | 35.57 | 7/19/96 8:01 | 35265.32 | 0.662649 | 2591.496 |
| | 25.46 | 35.94 | 10.48 | 7/18/96 15:49 | 268.56 | 237.26 | 37.24 | 7/19/96 8:39 | 35265.35 | 0.688468 | 2554.623 |
| | 25.21 | 35.51 | 10.3 | 7/18/96 15:50 | 261.27 | 229.97 | 38.29 | 7/19/96 9:19 | 35265.37 | 0.715177 | 2531.644 |

Table A10: Special Test #5 - Raw Data

| SAMPLE DESIGNA | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BACK | | | | | 31.98 | | 50 | 8/6/96 16:37 | | | |
| BACK | | | | | 31.98 | | 50 | 8/6/96 17:28 | | | |
| BACK | | | | | 32.2 | | 50 | 8/6/96 18:19 | | | |
| BACK | | | | | 32 | | 50 | 8/6/96 19:11 | | | |
| RADONSTD | | | | | 7338.69 | | 1.37 | 8/6/96 19:13 | | | |
| 1-1 UNC | 25.37 | 34.67 | 9.3 | 8/6/96 14:00 | 266.11 | 234.07 | 37.59 | 8/6/96 19:52 | 35283.81 | 0.231392 | 2553.719 |
| | 25.57 | 35.36 | 9.79 | 8/6/96 14:00 | 274.73 | 242.69 | 36.4 | 8/6/96 20:29 | 35283.84 | 0.2575 | 2527.182 |
| | 25.48 | 35.73 | 10.25 | 8/6/96 14:00 | 289.94 | 257.9 | 34.49 | 8/6/96 21:05 | 35283.87 | 0.283163 | 2577.014 |
| | 25.44 | 35.27 | 9.83 | 8/6/96 14:01 | 281.54 | 249.5 | 35.53 | 8/6/96 21:42 | 35283.89 | 0.307802 | 2611.244 |
| | 25.57 | 34.59 | 9.02 | 8/6/96 14:01 | 260.77 | 228.73 | 38.36 | 8/6/96 22:22 | 35283.92 | 0.334597 | 2621.55 |
| 2-1 UNC | 25.33 | 35.93 | 10.6 | 8/6/96 14:20 | 298.15 | 266.11 | 33.54 | 8/6/96 22:57 | 35283.94 | 0.347382 | 2601.382 |
| | 25.25 | 35.81 | 10.56 | 8/6/96 14:20 | 295.39 | 263.35 | 33.86 | 8/6/96 23:32 | 35283.97 | 0.371578 | 2596.52 |
| | 25.5 | 35.86 | 10.36 | 8/6/96 14:20 | 289.27 | 257.23 | 34.57 | 8/7/96 0:08 | 35283.99 | 0.39633 | 2598.284 |
| | 25.51 | 35.03 | 9.52 | 8/6/96 14:21 | 277.17 | 245.13 | 36.09 | 8/7/96 0:45 | 35284.02 | 0.420802 | 2703.914 |
| | 25.35 | 34.52 | 9.17 | 8/6/96 14:21 | 255.46 | 223.42 | 39.16 | 8/7/96 1:25 | 35284.05 | 0.447514 | 2570.932 |
| 3-1 UNC | 25.26 | 34.61 | 9.35 | 8/6/96 14:30 | 246.94 | 214.9 | 40.5 | 8/7/96 2:07 | 35284.07 | 0.469965 | 2435.183 |
| | 25.46 | 34.37 | 8.91 | 8/6/96 14:30 | 239.06 | 207.02 | 41.83 | 8/7/96 2:50 | 35284.1 | 0.499365 | 2474.9 |
| | 25.53 | 34.83 | 9.3 | 8/6/96 14:30 | 242.04 | 210 | 41.32 | 8/7/96 3:33 | 35284.13 | 0.529403 | 2418.388 |
| | 25.16 | 34.62 | 9.46 | 8/6/96 14:31 | 255.67 | 223.63 | 39.12 | 8/7/96 4:13 | 35284.16 | 0.55725 | 2544.618 |
| | 25.34 | 35.37 | 10.03 | 8/6/96 14:31 | 261.57 | 229.53 | 38.23 | 8/7/96 4:52 | 35284.19 | 0.584642 | 2475.599 |
| 4-1 UNC | 25.43 | 35.16 | 9.73 | 8/6/96 14:50 | 247.04 | 215 | 40.48 | 8/7/96 5:34 | 35284.22 | 0.599633 | 2396.979 |
| | 25.22 | 35.13 | 9.91 | 8/6/96 14:50 | 251.76 | 219.72 | 39.74 | 8/7/96 6:15 | 35284.25 | 0.628563 | 2417.676 |
| | 25.42 | 35.13 | 9.71 | 8/6/96 14:50 | 240.17 | 208.13 | 41.65 | 8/7/96 6:58 | 35284.28 | 0.65776 | 2349.73 |
| | 25.45 | 34.97 | 9.52 | 8/6/96 14:51 | 237.57 | 205.53 | 42.11 | 8/7/96 7:41 | 35284.31 | 0.686767 | 2379.174 |
| | 25.4 | 35.12 | 9.72 | 8/6/96 14:51 | 244.08 | 212.04 | 40.97 | 8/7/96 8:24 | 35284.34 | 0.717024 | 2417.26 |
| 1-1A EPA | | | 10.5 | 8/6/96 14:05 | 281.21 | 249.17 | 35.56 | 8/7/96 9:00 | 35284.36 | 0.775847 | 2657.742 |
| | | | 10.5 | 8/6/96 14:05 | 267.72 | 235.68 | 37.36 | 8/7/96 9:39 | 35284.39 | 0.802306 | 2525.947 |
| | | | 10.5 | 8/6/96 14:05 | 278.86 | 246.82 | 35.86 | 8/7/96 10:16 | 35284.42 | 0.828521 | 2657.963 |
| | | | 10.5 | 8/6/96 14:05 | 276.32 | 244.28 | 36.19 | 8/7/96 10:53 | 35284.44 | 0.854101 | 2642.836 |
| | | | 10.5 | 8/6/96 14:05 | 281.06 | 249.02 | 35.59 | 8/7/96 11:30 | 35284.47 | 0.880003 | 2706.808 |
| 2-1A EPA | | | 10.5 | 8/6/96 14:15 | 281.14 | 249.1 | 35.57 | 8/7/96 12:07 | 35284.49 | 0.89676 | 2716.906 |
| | | | 10.5 | 8/6/96 14:15 | 271.67 | 239.63 | 36.82 | 8/7/96 12:45 | 35284.52 | 0.924715 | 2625.964 |
| | | | 10.5 | 8/6/96 14:15 | 273.01 | 240.97 | 36.64 | 8/7/96 13:23 | 35284.54 | 0.951167 | 2653.34 |
| | | | 10.5 | 8/6/96 14:15 | 275.03 | 242.99 | 36.36 | 8/7/96 14:00 | 35284.57 | 0.978958 | 2688.13 |
| | | | 10.5 | 8/6/96 14:15 | 276.76 | 244.72 | 36.14 | 8/7/96 14:38 | 35284.6 | 1.003424 | 2720.298 |
| 3-1A EPA | | | 10.5 | 8/6/96 14:35 | 254.84 | 222.8 | 39.24 | 8/7/96 15:18 | 35284.62 | 1.016236 | 2482.4 |
| | | | 10.5 | 8/6/96 14:35 | 254.93 | 222.89 | 39.23 | 8/7/96 15:58 | 35284.65 | 1.044017 | 2496.95 |
| | | | 10.5 | 8/6/96 14:35 | 255.82 | 223.78 | 39.09 | 8/7/96 16:39 | 35284.68 | 1.072538 | 2518.916 |
| | | | 10.5 | 8/6/96 14:35 | 255.13 | 223.09 | 39.2 | 8/7/96 17:19 | 35284.71 | 1.100278 | 2523.818 |
| | | | 10.5 | 8/6/96 14:35 | 251.32 | 219.28 | 39.79 | 8/7/96 18:00 | 35284.74 | 1.128545 | 2493.469 |
| 4-1A EPA | | | 10.5 | 8/6/96 14:45 | 246.69 | 214.65 | 40.54 | 8/7/96 18:42 | 35284.77 | 1.150507 | 2450.565 |
| | | | 10.5 | 8/6/96 14:45 | 240 | 207.96 | 41.67 | 8/7/96 19:25 | 35284.79 | 1.179976 | 2386.914 |
| | | | 10.5 | 8/6/96 14:45 | 238.49 | 206.45 | 41.93 | 8/7/96 20:08 | 35284.82 | 1.209747 | 2382.415 |
| | | | 10.5 | 8/6/96 14:45 | 242.48 | 210.44 | 41.24 | 8/7/96 20:50 | 35284.85 | 1.239153 | 2441.449 |
| | | | 10.5 | 8/6/96 14:46 | 232.3 | 200.26 | 43.06 | 8/7/96 21:36 | 35284.88 | 1.269771 | 2336.286 |

Table A10: Special Test #5 - Raw Data (continued)

| SAMPLE DESIGNA | PRE-WEIGHT (gm) | POST-WEIGHT (gm) | SAMPLE WEIGHT (gm) | SAMPLE TIME | CPM "B" | NET "B" | COUNT TIME (min) | FINISHED COUNT TIME | MID COUNT TIME | ELAPSED TIME (day) | RADON CONC (pCi/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-1B EPA | 16.49 | 26.83 | 10.34 | 8/6/96 14:10 | 245.64 | 213.6 | 40.73 | 8/7/96 22:17 | 35284.91 | 1.324052 | 2555.515 |
| | 16.52 | 26.93 | 10.41 | 8/6/96 14:10 | 243.84 | 211.8 | 41.01 | 8/7/96 22:59 | 35284.94 | 1.353122 | 2530.249 |
| | 16.66 | 27.18 | 10.52 | 8/6/96 14:10 | 243.29 | 211.25 | 41.12 | 8/7/96 23:41 | 35284.97 | 1.38225 | 2510.521 |
| | 16.75 | 27.23 | 10.48 | 8/6/96 14:10 | 251.45 | 219.41 | 39.77 | 8/8/96 0:22 | 35285 | 1.411191 | 2631.226 |
| | 16.5 | 27.02 | 10.52 | 8/6/96 14:10 | 248.81 | 216.77 | 40.2 | 8/8/96 1:04 | 35285.03 | 1.440208 | 2603.361 |
| 2-1B EPA | 16.47 | 26.91 | 10.44 | 8/6/96 14:17 | 245.91 | 213.87 | 40.67 | 8/8/96 1:46 | 35285.06 | 1.464351 | 2599.565 |
| | 16.69 | 27.27 | 10.58 | 8/6/96 14:17 | 255.1 | 223.06 | 39.2 | 8/8/96 2:26 | 35285.09 | 1.492639 | 2689.157 |
| | 16.81 | 27.39 | 10.58 | 8/6/96 14:17 | 259.97 | 227.93 | 38.47 | 8/8/96 3:06 | 35285.12 | 1.52067 | 2761.878 |
| | 16.43 | 26.49 | 10.06 | 8/6/96 14:17 | 243.24 | 211.2 | 41.12 | 8/8/96 3:48 | 35285.14 | 1.548917 | 2705.266 |
| | 16.67 | 27.18 | 10.51 | 8/6/96 14:17 | 253.49 | 221.45 | 39.45 | 8/8/96 4:29 | 35285.17 | 1.577969 | 2729.465 |
| 3-1B EPA | 16.49 | 27.12 | 10.63 | 8/6/96 14:35 | 230.08 | 198.04 | 43.48 | 8/8/96 5:14 | 35285.2 | 1.596319 | 2420.971 |
| | 16.7 | 27.02 | 10.32 | 8/6/96 14:35 | 225.02 | 192.98 | 44.44 | 8/8/96 5:59 | 35285.23 | 1.626236 | 2443.647 |
| | 16.72 | 27.09 | 10.37 | 8/6/96 14:35 | 227.66 | 195.62 | 43.93 | 8/8/96 6:45 | 35285.27 | 1.658358 | 2479.54 |
| | 16.82 | 27.36 | 10.54 | 8/6/96 14:35 | 230.97 | 198.93 | 43.3 | 8/8/96 7:29 | 35285.3 | 1.689132 | 2494.715 |
| | 16.65 | 27.17 | 10.52 | 8/6/96 14:35 | 230.28 | 198.24 | 43.43 | 8/8/96 8:14 | 35285.33 | 1.720337 | 2504.928 |
| 4-1B EPA | 16.72 | 27.58 | 10.86 | 8/6/96 14:47 | 230.12 | 198.08 | 43.46 | 8/8/96 8:58 | 35285.36 | 1.742549 | 2434.336 |
| | 16.63 | 27.34 | 10.71 | 8/6/96 14:47 | 229.52 | 197.48 | 43.57 | 8/8/96 9:43 | 35285.39 | 1.77376 | 2474.927 |
| | 16.47 | 27.15 | 10.68 | 8/6/96 14:47 | 222.86 | 190.82 | 44.88 | 8/8/96 10:29 | 35285.42 | 1.80525 | 2411.917 |
| | 16.45 | | 10.5 | 8/6/96 14:47 | 218.81 | 186.77 | 45.72 | 8/8/96 11:16 | 35285.45 | 1.837597 | 2415.328 |
| | 16.63 | 26.96 | 10.33 | 8/6/96 14:47 | 215.15 | 183.11 | 46.48 | 8/8/96 12:04 | 35285.49 | 1.870667 | 2421.45 |
| T1 | 16.55 | 26.95 | 10.4 | 8/6/96 15:00 | 195.36 | 163.32 | 50 | 8/8/96 12:56 | 35285.52 | 1.896528 | 2155.298 |
| | 16.4 | 26.97 | 10.57 | 8/6/96 15:00 | 190.72 | 158.68 | 50 | 8/8/96 13:47 | 35285.56 | 1.931944 | 2073.666 |
| | 16.5 | 26.76 | 10.26 | 8/6/96 15:00 | 185.16 | 153.12 | 50 | 8/8/96 14:38 | 35285.59 | 1.967361 | 2074.754 |
| | 16.55 | 26.58 | 10.03 | 8/6/96 15:00 | 175.14 | 143.1 | 50 | 8/8/96 15:29 | 35285.63 | 2.002778 | 1996.232 |
| | 16.45 | 26.59 | 10.14 | 8/6/96 15:00 | 176.34 | 144.3 | 50 | 8/8/96 16:21 | 35285.66 | 2.038889 | 2004.222 |
| | 16.48 | 26.69 | 10.21 | 8/6/96 15:03 | 170.9 | 138.86 | 50 | 8/8/96 17:12 | 35285.7 | 2.072222 | 1927.059 |
| | 16.64 | 26.94 | 10.3 | 8/6/96 15:03 | 167.86 | 135.82 | 50 | 8/8/96 18:03 | 35285.73 | 2.107639 | 1880.445 |
| | 16.39 | 26.48 | 10.09 | 8/6/96 15:03 | 156.36 | 124.32 | 50 | 8/8/96 18:54 | 35285.77 | 2.143056 | 1768.375 |
| | 16.71 | 26.96 | 10.25 | 8/6/96 15:03 | 154.54 | 122.5 | 50 | 8/8/96 19:45 | 35285.81 | 2.178472 | 1726.343 |
| T10 | 16.48 | 27.1 | 10.62 | 8/6/96 15:03 | 156.46 | 124.42 | 50 | 8/8/96 20:37 | 35285.84 | 2.214583 | 1703.435 |