**RICHLAND SPECIAL UTILITY DISTRICT**
**P.O. Box 217**
**Richland Springs, Texas 76871**

# RESEARCH GRANT
# FINAL REPORT

Texas Water Development Board
Contract No. 2004-483-520

July, 2004

**Richland Special Utility District**

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## Executive Summary

Water Remediation Technology, LLC, Arvada, Colorado, claims to have a Radium Removal System that will lower the Radium levels in drinking water to below the Environmental Protection Agency Maximum Contaminant Levels without altering the chemical content of the water. The Board of Directors of the Richland Special Utility District is searching for a reliable and affordable method to bring the water to within EPA standards. The Board contracted with WRT to perform a Pilot Test of their System at the RSUD well-site in McCulloch County, Texas. That Pilot Test began on December 3, 2003 and was concluded on April 27, 2004.

There was need to perform some tests of the water to assure that the system would perform satisfactorily and do so without creating additional water service problems. The RSUD applied to the Texas Water Development Board for a Research Grant to perform some of the necessary testing. The results of this Research should be of interest to the many Water Service Systems that must meet the EPA standards.

The results of the entire series of tests show that the WRT Radium Removal System will successfully treat the drinking water to EPA standards. The water quality tests showed that the treatment system does not alter the quality of the water for potable use. Tests designed to assure the stability of the System showed that there is no danger of Radium breakthrough caused by water flow interruptions. Tests showed that there is no radioactive material, such as Radon, created during the treatment process that would pass through into the finish water. It was concluded that the Radium Removal System does perform the task as proposed by WRT.

There are a few unanswered questions of concern to any Water Service System that might be interested in such a treatment system. One has to do with the ability of the media to retain stability under chemical interactions. The media is a proprietary material mined and formulated by WRT. There was a contractual agreement that the RSUD would not reveal any details of the media and could not perform tests to determine the chemical stability of the media material. So this concern for the chemical stability of the media is unanswered.

Also, the cost of an actual treatment facility is not yet known. Certainly there will be capital costs to prepare for and set up the treatment equipment. There are operational costs yet to be determined. Systems, such as RSUD, already have high costs of operations and the customers are economically disadvantaged. Increased cost of water will cause many of the RSUD customers to return to their shallow wells and stock tanks for water that is far more dangerous to their health.

Finally, the proposal is that WRT will maintain ownership of the equipment and be responsible for handling and transporting the radioactive media to safe disposal sites. Interested Water Service Systems need to be aware that there is an on-site responsibility for radiation safety. The media will become radioactive and the Water Service System must be responsible for and assure the security of the System while the media is on-site to protect the employees and the public.

## Introduction

The Richland Special Utility District (RSUD) entered into a Research Grant Contract (no. 2004-483-520) with the Texas Water Development Board (TWDB) on April 13, 2004. The final report deadline for this contract is January 31, 2005.

In December 2000, the Environmental Protection Agency (EPA) issued Maximum Contaminant Levels (MCLs) for radionuclides in drinking water. The Texas Commission on Environmental Quality (TCEQ) is the Agency of Primacy for the EPA in Texas. The TCEQ is presently establishing rules designed to enforce the MCLs to bring drinking water to within the requirements set by the EPA. The rules will require that Water Service Systems must somehow ensure that the Maximum Contaminant Levels for total Radium in drinking water be less than 5 pCi/L and that Gross Alpha measurements not exceed 15 pCi/L. TCEQ estimates that 94 Community Water Service Systems now exceed these MCLs in Texas. These affected water systems are searching for affordable techniques to meet these standards.

The RSUD serves water from the Hickory Underground Aquifer that presently exceeds the MCLs set by the EPA to 320 customers in rural McCulloch County. The Directors of the RSUD have been searching for affordable methods to lower the Radium content of potable water to acceptable levels so that the system may meet the rules being adopted by TCEQ.

Water Remediation Technology, LLC, Arvada, Colorado, claims to have a system designed to effectively remove Radium from drinking water without altering the chemical content of the water. The WRT system uses a proprietary Z-88™ material that they mine in Colorado. The water to be treated is forced through the media to form a fluidized bed for maximum particulate contact between the particles of the media and the atoms in the water. The media adsorbs the radionuclides that exist in the water through a cation exchange process. The radioactive media is then removed and replaced with new media and the radioactive media is safely transported for disposal.

RSUD, state agencies and other water service systems are interested in knowing details of the WRT system. RSUD agreed to host a pilot study at the McCulloch County well site so that WRT could demonstrate the technique and interested agencies could participate to determine the capabilities of the radionuclide removal system. To that end, RSUD entered into a agreement with WRT in August, 2003 for a Pilot Study to be conducted at the RSUD well site. The WRT/RSUD Agreement was reviewed and approved by the various state agencies of interest led by TCEQ. WRT brought in their equipment and began preparations for the Pilot Study in November, 2003.

Funds from this Research Grant were used to help analyze the WRT designed Radium removal system.

## WRT Radium Removal System

The WRT Radium Removal System utilizes Z-88™ adsorptive[1] media to remove Radium from water. Z-88™ is a proprietary material mined by WRT in Colorado. The material is a form of zeolite

[1] A**d**sorb means to hold molecules to the surface. A**b**sorb means to take in or soak.

that, through an ion exchange process, adsorbs the valence 2 atoms including Radium that exist in the water. The media is ANSI/NSF Standard 61 certified for use in drinking water.

WRT maintains that their System will remove Radium-226 and Radium-228 from water that is fluidized with the media in proper proportions. The only material in contact with the water during radium removal is the media. No other chemicals are added that might affect the quality or potability of the water. The media does not serve as a filter in that most dissolved solids are not removed during the adsorptive process.

The proposal for a full treatment plant is that WRT would retain ownership of the equipment and media. When the media becomes loaded[2] with Radium, WRT would remove the radioactive media and replace it with new media. They would then transport the radioactive media in keeping with Department of Transportation rules to an approved radioactive waste disposal site. There would be no on-site radioactive waste or sludge that would require special handling and there would be no need for especially trained crews to be employed by the Water System since WRT personnel would handle the radioactive media. WRT proposes that the treated water would meet the MCLs set by the EPA and would satisfy the TCEQ rules for potable water. WRT would charge on a per thousand gallon basis for the Radium removal service.

The purpose of the Pilot Study was to demonstrate that the Radium removal system does perform the task as described by WRT.

## Pilot Study

### RSUD Well Site

The RSUD well site is located west of Highway 377 about six miles north of Brady, Texas. The system pumps about 54 million gallons of Hickory water per year. The well is drilled into the Hickory Aquifer at 2600 feet. The pump is located at 750 feet depth and pumps 310 gallons per minute. The water flows through the pump control station where chlorine is added at 5 pounds per day and phosphate is added at 0.3 pounds per day to stabilize the iron. The water enters the 110 foot tall standpipe at the 105 foot level. The maximum water pressure leaving the standpipe is 46 psi. Water from the 110 foot standpipe gravity flows to a second 51,000 gallon standpipe (Placid) about 6 miles distant. The system serves about 180 meters prior to the Placid Standpipe and about 130 meters from the Placid Standpipe. The entire system consists of 120 miles of pipeline and serves water to rural customers in McCulloch County. Only a small percentage of the water is used for potable purposes.

The RSUD well site is high fenced for security and was an ideal location for the WRT Pilot Study.

[2] As the zeolite material takes in Radium those molecules become loaded and can no longer attract Radium.

**WRT Pilot Trailer**

The Pilot Study equipment was contained in a WRT System Trailer that was located within the high fenced area at the RSUD well site. Water from a flush valve on the standpipe was connected to the trailer. The flow was regulated at about 1.2 gallons per minute and was discharged outside the high fence and absorbed into the soil surface. This arrangement was for test purposes only so not to risk contamination of the customer water service.

The Pilot Trailer contained eight vertical columns of the Z-88™ media and each column contained approximately 6,540 grams (14 pounds) of media. The amount of media in each column was sufficient to give about 2 minutes Empty Bed Contact Time as the water flowed within the media.

As seen in the picture, water entered on the left side and was plumbed so to flow upward through each column. The pressure entering each column was recorded and the water could be sampled between columns. The columns were labeled 1 though 8. The water sampled before entry into column 1 was labeled "raw", water sampled leaving column 1 was C1, leaving column 2 was C2, and so on for C3, C4, C5, C6, C7and the final water leaving column 8 was labeled "treated". In this manner, water could be sampled for radiochem and inorganic analysis as the water flowed through the various stages of treatment. A sample taken of the outflow from column 2 (C2), for example, would be water that had passed through the media in columns 1 and 2. Similarly, a C4 sample would be of water that had passed through the media in columns 1, 2, 3 and 4. A sample labeled "treated" would be of water that had passed through the media in all 8 columns.

**RSUD Pilot Study Responsibilities**

RSUD personnel monitored the Test to ensure security and proper operation. A daily operations Log was kept showing the date, name of the operator, time inside the Test Trailer, the water flow rate (to be adjusted if necessary) and the total water flow at the time of the inspection. The operator also recorded the feed water pressure, the pressure at each column and the discharge pressure. The operator took readings of the chlorine levels of the raw water and the treated water to ascertain any affect on chlorine levels because of treatment.

The RSUD Project Officer took radiation readings at each column periodically throughout the Test using the radiation monitor supplied by WRT. These readings included radiation readings taken in the center of the Trailer.

The RSUD well pump malfunctioned on two occasions and the water flow to the Test Trailer was stopped. During these periods, water was brought into the system from Brady Water Utility. The

RSUD Project Officer made certain that the Brady water was flushed from the system before the WRT Test was re-started.

RSUD personnel were responsible for taking, handling and shipping all water samples scheduled for the Test. Containers were obtained from the appropriate test labs and the samples were handled in accordance with test lab instructions. The TCEQ desired duplicate samples on two sample dates and the RSUD coordinated the State samples sent to the Texas Department of Health for analysis.

The RSUD Project Officer added certain additional sampling, as part of the research project, that were not originally planned. These extra tests involved Radon sampling and several stop-start tests wherein the water flow was stopped for a period of time and samples taken upon re-start. The objective of these stop-start tests was to determine whether sudden flow re-start might cause radiation breakthrough from the media.

The RSUD furnished the water and the electricity for the Test and was responsible for all freight costs for shipping of the water samples.

**Test Laboratories**

Testing for radionuclide content is a complicated laboratory process. The EPA outlines the methods to be used and prescribes the laboratory procedure. Care and preparation of the water samples is very important and can affect the quantitative analysis of radionuclide content. Within the laboratory, the test for Radium-226 for example, involves proper preparation of a sample and subsequent collection of Radon gas from that sample. The eventual measurement of the alpha radiation from the Radon gives the measure of Radium-226 present in the sample. The process takes several days to collect and measure the radiations emitted by the Radon. The percent error can be quite large and the results from tests of the same water sample may give very different results of Radium-226 content.

The ACZ Laboratories, Inc., Steamboat Springs, Colorado, was chosen as the primary test laboratory for the WRT Pilot Study. The Jordan Laboratory, Corpus Christi, Texas was chosen as a second test lab to perform certain tests and to provide a second analysis for comparison purposes. The TCEQ desired that certain samples be analyzed by the Laboratories of the Texas Department of Health (TDH), Austin, Texas. These Laboratories are certified as National Environmental Laboratory Accreditation Program laboratories.

**Schedule of Samples**

In order to analyze the WRT Radium Removal System, it was necessary to take several samples of water from different sampling outlets. The samples were then sent to the appropriate laboratory. The Lab then analyzed the samples for radiochemistry and inorganic chemistry depending upon the data request. The intent of the data analysis for this Pilot Test using Hickory Aquifer water being pumped by RSUD was to:

1. Determine the capability of the Z-88™ Radium Treatment Process to consistently and effectively reduce the Total Radium content to below the MCL for the Hickory Aquifer water being pumped by RSUD.

2. Determine the affect of treatment on the inorganic structure of the dissolved solids in the water.

3. Assure that the treatment would not affect the chemical structure of chemicals that are added for purification.

4. Determine the affect on Radon content of the water being treated.

5. Determine the stability of the media following adsorption of the Radium to ensure that the adsorbed Radium will not breakthrough and contaminate the service water.

6. Determine the radiation safety aspects so to predict the radiation safety demands of a full service system.

7. Determine the radiation loading rate as design criteria for a full-scale facility.

8. Determine the affect of disrupted water flow on the stability of the media.

9. Determine the effectiveness of using gross alpha as a screen for system reliability.

10. Determine the projected cost per thousand cubic feet of water to be treated using the WRT Radium Removal System, to include the estimated capital cost to create an operational facility.

The WRT Test Trailer was installed on the RSUD property on December 3, 2003. Water began flowing through the test media at the rate of 1.2 gallons per minute. The raw water was taken from a flush valve outlet from the standpipe and the treated water was discharged on the surface to be absorbed into the soil.

Sample data are reported in the tables of Appendix A.

## Radium

### Nuclear Chemistry and Physics

All matter has an atomic structure consisting of electrons (unit negative charge) encircling a nucleus. The nucleus contains protons (unit positive charge) and neutrons (no charge). The number of protons and neutrons determines the element represented. The nucleus of hydrogen, for example, has one proton and one neutron, helium has two protons and two neutrons, etc. Electrons encircle the nuclei in some manner such that, in a stable atom, the negative charge surrounding the nucleus balances the positive charge in the nucleus. The orbiting electrons need not always be so arranged that the charges are precisely balanced. Atoms in an excited state are somewhat unstable and sometime share electrons with other atoms to form chemical compounds. An atom that has too many electrons in orbit will have a negative charge and is called an ion. If the atom has too few electrons in orbit it will have a positive charge and is called a cation. The chemical reaction of atoms usually involves the outermost electrons and sometimes is facilitated by the presence of ions.

This study concerned the Radium-226 and Radium-228 in drinking water. Radium-226 has 88 protons and 138 neutrons in the nucleus with 88 encircling electrons. Radium-228 has 88 protons and 140 neutrons in the nucleus with 88 encircling electrons. These atoms are naturally radioactive because the nuclei are unstable. The atoms strongly desire to be stable and will react to gain stability by emitting the unwanted energy. The emitted energy may be in the form of alpha particles (rays), beta rays and gamma rays.

Alpha and beta rays are particulate radiation while gamma rays are electromagnetic radiation. Alpha rays are the same as moving nuclei of helium containing 2 protons and 2 neutrons bound together and moving at high speed. Beta rays are unit charges, either negative or positive, moving at high speed. Beta rays are some times called negatrons or positrons depending upon the charge. A negatron is the same as an electron moving at high speed.

Electromagnetic radiation are quantities of energy called photons moving at the speed of light. Photons have no mass and exist only when moving at the speed of light. Photons have wavelengths that determine their identity. Ordinary light consists of photons of various wavelength from ultraviolet to infrared. Radio waves and microwaves are photons with still shorter wavelengths. X-rays and gamma rays are photons of very short wavelengths. Gamma rays are emitted from the radioactive nuclei while x-rays originate within the electronic structure of an excited atom.

Unstable nuclei gain stability by emitting radiation. When either an alpha or beta ray are emitted, the nucleus changes its identity to that of a different element called a "daughter". The process is referred to as radioactive decay. The decay series will continue until the atomic structure becomes stable. For example, Radium-226 is a daughter of Uranium-238 and the decay series will eventually become stable Lead-206.

When an atom changes by the emission of radiation, the unstable daughter nucleus does not immediately decay. The actual lifetime of the unstable nucleus is not predictable. However, if there are a number of unstable nuclei of the same daughter, the time it takes for one-half of them to change can be measured statistically and this time is referred to as the "half-life". Radium-226 is part of the Uranium decay series and has a half-life of 1620 years. Radium-228 is a daughter in the Thorium decay series with a half-life of 6.7 years..

During each disintegration event as these radioactive atoms strive for stability, radiation in the form of alpha rays, beta rays and/or gamma rays will be emitted. If these radiations encounter human tissue, there can be a health concern because of the absorption of the radiated energy. The radioactive particles moving at high speed within human tissue can ionize or destabilize the atoms of the tissue. If the damage results in unnatural reproduction of human cells the result can be carcinogenic.

The Curie is defined as the quantity of any radioactive material that gives $3.700 \times 10^{10}$ disintegrations per second; the number of disintegrations occurring in one gram of Radium. The unit most often used is the picoCurie (Curie times $10^{-12}$) or 0.037 disintegrations per second (2.22 disintegrations per minute). Thus 1 pCi/L is one picoCurie per liter and would yield 2.22 disintegrations per minute within one liter.

## Radiation Safety

In this Pilot Test, the media adsorbs the Radium and holds it on the particles of the media. Since Radium is radioactive, the media becomes more and more radioactive as Radium is adsorbed. The radioactive media must be monitored and there is concern for radiation safety.

The primary responsibility for radiation safety was with the WRT. The WRT Radiation Safety Officer prepared a radiation safety plan of the Pilot Test. The amount of radiation that members of the public can be exposed to is 2 mrem per hour and 100 mrem over the course of one year. The safety plan includes radiation-exposure monitoring, logging of elapsed time each time an operator works in the vicinity of the test columns, dose-rate monitoring using dosimetry badges adjacent to the test columns and at a "background" location, and emergency procedures and equipment. WRT furnished radiation monitoring equipment to be used for data purposes during the Test.

The US Department of Transportation (USDOT) limit of specific activity is 2,000 pCi/gram for purposes of transporting radioactive material. WRT estimated that the specific activity in the most radioactive column, column 1, would not approach this limit. However, if a column approached the limit that column would be taken off-line to avoid further Radium accumulation.

The RSUD was responsible for the security of the system while on-site. The local Emergency Management System personnel and the Sheriff were briefed on radiation safety in case of an emergency spill of the radioactive media. The Texas Department of Health was made aware of the presence of the small amount of radioactive material on-site during this Pilot Study.

Duane Bollig, Environmental Manager for WRT, briefed the RSUD crews on radiation safety and briefed local Emergency Management Service personnel on specific hazards of radiation should there be an accidental spill of the radioactive media. Radiation Safety information was properly posted in the Test Trailer giving the appropriate Texas contacts in case of a radioactive emergency.

# Test Results

## Radium Removal

The purpose for treating the water is to remove Radium so that the water Radium content is within the Maximum Contaminant Level. Water began to flow through the WRT Test Trailer on December 3, 2003. The first sample was taken on December 8 and that data for Total Radium is shown in Figure 1. When this sample was taken, 8,645 gallons of water had passed through and the 14 pounds of media in Column 1 was sufficient to adsorb most of the Radium. The Total Radium content in the raw water was 27.5 pCi/L and the media in Column 1 adsorbed 89% of the Radium to a level of 3.07 pCi/L, well below the MCL of 5 pCi/L.

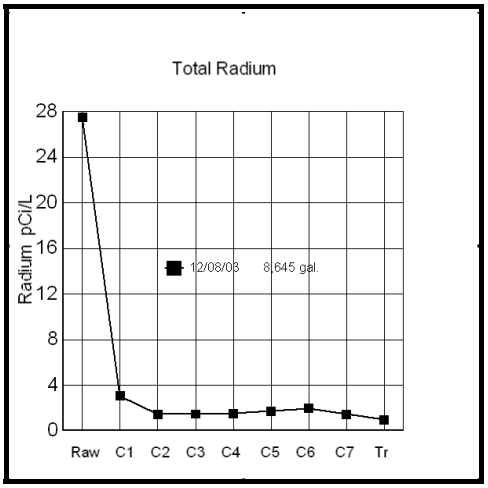


Figure 1

There were three sample days when samples were taken from raw and all eight of the columns. These data are shown in Figure 2 for comparison. The Radium atoms in the fluidized bed of media are adsorbed onto the particles of media. Obviously there is a limit to the amount of Radium that can be removed by a limited amount of media. In this test, each column contained 14 pounds of media. As the particles of media become loaded with Radium, there is less particle surface area to adsorb additional Radium. The loading of the media in Column 1 can be seen in the plots of Figure 2.

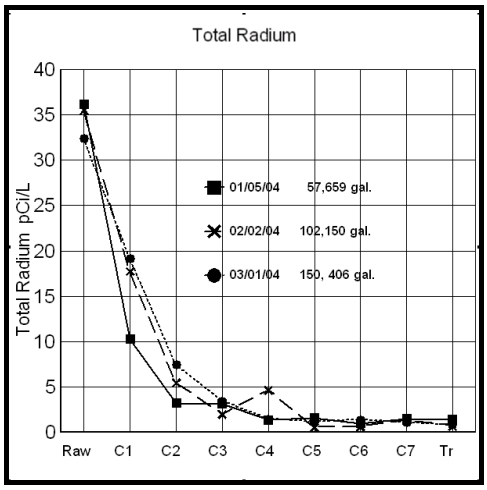

Figure 2

When the sample was taken on January 5th, 49,014 gallons of water had passed through the media in Column 1 since the sample on December 8th as shown in Figure 1. The loading of the Column 1 media can be seen in the data. It took the additional media of Column 2 to bring the Radium level below 5 pCi/l.

That trend can be seen in the samples from February 2nd and March 1st. The amount of water flowing between those dates was about the same. The flow from January 5th to February 2nd was 44,491 gallons and from February 2nd to March 1st was 48,256 gallons. By the total flow of 150,406 gallons it was taking some of the media in Column 3 to bring the Radium level below 5 pCi/L.

**Radium-226 and Radium-228**

The Radium in the Hickory water is part Radium-226 and part Radium-228. When interpreting the radiochem analysis of samples for each of these, one must consider the method of measurement. The test for Radium-226 collects the Radon gas escaping from the prepared sample and measures the Radon emission as a measure of the Radium-226 in the sample. Radon emits an alpha ray and the rate of emission of the alpha rays provides the measurement. The test for Radium-228 involves the beta activity of Actinium-228 which is the first daughter in the decay scheme of Radium-228. The Beta activity is measured to determine the Radium-228 content. The capability to measure these emissions affects the accuracy of the data.

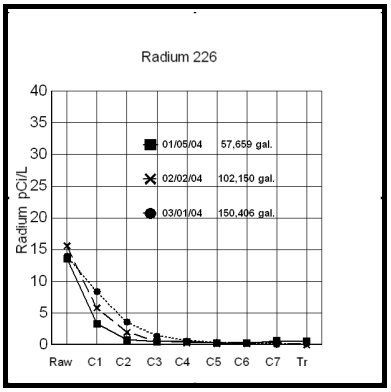

Figure 3

The data in Figures 3 and 4 give the Radium-226 and Radium-228 data plots for the same samples that are shown in Figure 2 for the Total Radium. In fact, the plots in Figure 2 for Total Radium are merely the sum of the plots in Figures 3 and 4. It can be seen that the hump in the February 2nd curve at C4 comes from the Radium-228 data.

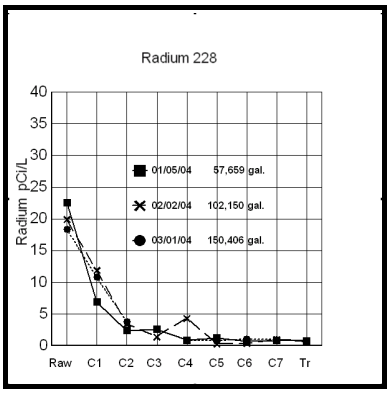

Figure 4

It is often assumed that the Radium content in water has a one-to-one ratio for Radium-226 to Radium-228. The Hickory water at the RSUD well site has more Radium-228 than Radium-226 and that has a definite influence on the adsorption of the Total Radium in the media.

**Gross Alpha**

The acceptable use of Gross Alpha measurements as a screening measure of Total Radium content is demonstrated in Figure 5. Figure 5 shows the Gross Alpha, Total Radium, Radium-226 and Radium-228 data for the sample taken on March 1, 2004. The data shows that the plot for Gross Alpha closely resembles the plot for Total Radium. The measurement of Gross Alpha is considerably less expensive than measuring separately for Radium-226 and Radium-228 to arrive at the Total Radium. This comparison shows that it would be reasonable to use Gross Alpha as a screen for the satisfactory operation of a full-scale treatment plant using the WRT media.

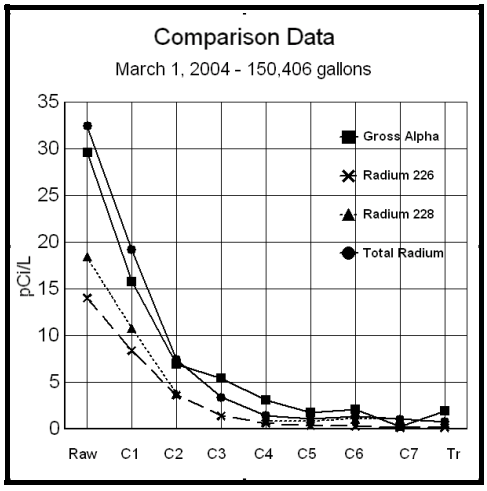


Figure 5

**Lab Comparison Data**

Since the lab analysis of water samples for Radium is complicated and the acceptable error is large, there was need to have the same water samples tested by different labs. On two occasions as can be seen in the data in Appendix A, samples taken on a specific day were sent to the ACZ Lab and to the TDH Lab for radiochem analysis.

The data for the March 1, 2004 samples are presented in Figure 6. The top two plots are of the TDH Lab data as compared to the ACZ Lab data in the bottom plots.

The greatest difference is in the Gross Alpha data where the TDH shows considerably higher number for the raw water sample. The trend of the data compare well again showing that the media contained in the first three columns was sufficient to bring the Total Radium level to within the MCL. The comparison also shows that the Gross Alpha can be safely used as a screening measure for Total Radium.

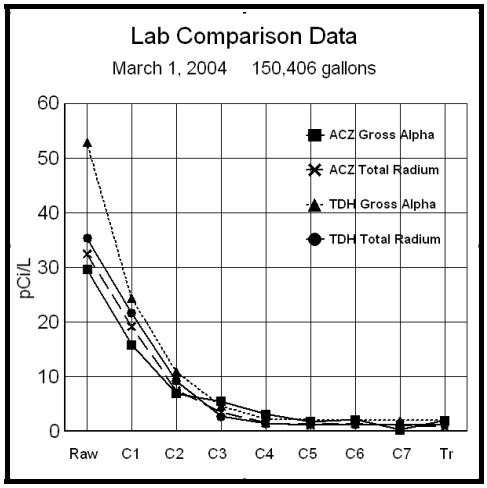


Figure 6

Samples were also sent to Jordan Labs on two dates for radiochem analysis. The samples were not sent to the ACZ Lab on the same day so the comparison is more questionable than the above comparison where the same samples were sent to ACZ Labs and TDH Lab.

Table 1. Comparison of data from ACZ Labs and Jordan Labs.

| Radiochem Data | Raw mg/L | | C1 mg/L | | C2 mg/L | | Treated mg/L | |
|---|---|---|---|---|---|---|---|---|
| Laboratory | ACZ 1.05.04 | Jordan 1.12.04 | ACZ 1.05.04 | Jordan 1.12.04 | ACZ 1.05.04 | Jordan 1.12.04 | ACZ 1.05.04 | Jordan 1.12.04 |
| Gross Alpha | 41.4 | 199.0 | 13.6 | 40.0 | 1.56 | | 2.08 | 2.8 |
| Gross Beta | | 92.0 | | 38.0 | | | | 18.0 |
| Radium 226 | 13.6 | 13.0 | 3.33 | 5.4 | 0.82 | | 0.58 | 0 |
| Radium 228 | 22.6 | 38.0 | 6.92 | 16.0 | 2.41 | | 0.82 | 0 |
| Total Radium | 36.2 | 51 | 10.25 | 21.4 | 3.23 | | 1.4 | 0 |

The primary difference in the ACZ and Jordan comparison is in the Gross Alpha data for the raw samples. The data for the Radium 226 and Radium 228 do compare reasonably well. Again, both sets of data show that the Radium was removed by the media during treatment. Even though there is a large difference in the Gross Alpha data for the raw water, the use of the Gross Alpha for screening the Radium is acceptable for determining Total Radium.

**Radiation Data**

Data used in Figure 7 were taken with a Ludlum Model 2401-P Survey Meter. This meter is designed to provide moderately sensitive scans of gamma and high energy beta radiation. For these data, the sensitive window of the meter was placed against the column containing the media. The alpha and most beta radiation were shielded from the meter by self absorption in the media and by the wall of the media tube. These data are basically in response to the gamma radiation being emitted from the columns. Some of the variations in the trend lines may be a result of meter insensitivity and reader error. The high point in the C1 data at day 56 was taken while the flow was stopped and the media was more concentrated so there were more radioactive particles in the solid angle of the meter.

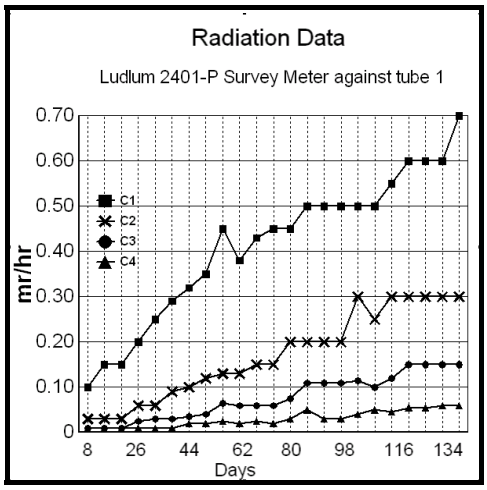

Figure 7

The data for this figure are given in a table in Appendix B. For convenience in plotting, the data were interpreted for days of treatment.

As the Radium atoms were adsorbed onto the particles of media in the columns, the media became more and more radioactive. The growth of the gamma radiation from column1 can be seen in the uppermost curve in the Figure (C1). After about 26 days, column 2 shows increased radioactivity.

The data in Figure 7 agrees with the analysis presented on page 9 for Figure 2. The January 5 data

in Figure 2 showed that the media in column 2 was needed to reduce the Total Radium level below the MCL. On January 5 there had been over 57,000 gallons of water flow through the columns and the increased radioactivity in column 2 can be seen in Figure 7. By March 1, day 99, 150,406 gallons had passed through the columns and the radiation data shows that column 3 was beginning to be slightly radioactive.

As stated above, these data are the gamma radiation at the surface of the column. The radiation level reduces in accordance with the inverse square law so that a person in the center of the Trailer would receive very little radiation. In case of an accident where a person might come in contact with or breath in dust from the radioactive media, there could be a danger to health.

**Water Quality**

It is important to know whether treatment of the water by passing it through the media alters the chemistry of the water. To this end, several samples of the water were analyzed to determine the affect of treatment. Table 2 shows the inorganic analysis of the water taken on December 8, after only 8,645 gallons of water had been treated.

Table 2. ACZ Lab Inorganic Data.

| ACZ L43991 12/08/03 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | | | | | | | | | 0.17 |
| Barium | 0.0711 | 0.0128 | 0.0142 | | 0.0036 | | 0.0043 | | 0.0044 |
| Calcium | 54.2 | 52 | 48.4 | | 53.8 | | 55.9 | | 52.5 |
| Iron | 0.31 | 0.31 | 0.29 | | 0.29 | | 0.32 | | 0.4 |
| Magnesium | 47.1 | 45.9 | 45.4 | | 46.7 | | 46.5 | | 43.4 |
| Potassium | 14.7 | 14.6 | 15.1 | | 13.8 | | 9.2 | | 3.9 |
| Sodium | 40 | 39.3 | 40.7 | | 40.8 | | 41 | | 40.2 |
| Strontium | 1.26 | 1.11 | 0.85 | | 0.48 | | 0.33 | | 0.25 |
| Uranium | | | | | | | 0.0001 | | 0.00008 |

The Calcium, Iron, Magnesium and Sodium content of the water were essentially unchanged by the treatment process. The Barium, Potassium and Strontium content were reduced so apparently atoms of these elements are attracted to the particles of media. The amount of Aluminum and Uranium are essentially unmeasurable in the water. The content of Barium in the raw water was reduced by about 94 % by treatment. The content of Potassium in the raw water was reduced by about 73% and the content of Strontium in the raw water was reduced by 80% by treatment.

Inorganic analysis data for water samples taken December 23 (57,654 gallons), January 5 (82,162 gallons), January 19 (102,150 gallons) and February 2 (138,814 gallons) are given in Appendix A. The inorganic data for the samples taken on March 1, after 150,406 gallons had passed through the media is given in Table 3.

These data show that the rate of removal of Barium dropped only slightly with treatment during this Pilot Test from about 93% to slightly less than 90%. By the time 57,654 gallons had been treated on December 23, the adsorption of Strontium had decreased from about 80% to less than 10% and by 82,162 gallons the adsorption of Strontium had ceased. Similarly, the reduction of the content of Potassium dropped sharply with additional treatment.

Table 3. ACZ Lab Inorganic Data

| ACZ L44809 03/01/04 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | | | | | | | | | |
| Barium | 0.0532 | 0.0461 | 0.0375 | 0.0342 | 0.0171 | 0.0122 | 0.0088 | 0.0062 | 0.0055 |
| Calcium | 49.8 | 48.8 | 48.5 | 48.7 | 40.5 | 40.3 | 39.1 | 37.2 | 41.2 |
| Iron | 0.34 | 0.34 | 0.36 | 0.33 | 0.33 | 0.32 | 0.31 | 0.29 | 0.3 |
| Magnesium | 45.9 | 44.6 | 44.6 | 44.6 | 38 | 38 | 36.8 | 35.1 | 38.2 |
| Potassium | 13.1 | 13 | 13 | 13.1 | 10.4 | 10.4 | 10.1 | 10.8 | 10.6 |
| Silica | 16 | 15.7 | 15.5 | 15.6 | 16 | 16.2 | 16.3 | 15.8 | 16.2 |
| Sodium | 35.9 | 34.9 | 35.1 | 34.9 | 30.1 | 30.2 | 29.3 | 29.9 | 30.3 |
| Strontium | 1.26 | 1.26 | 1.28 | 1.23 | 1.29 | 1.27 | 1.27 | 1.27 | 1.29 |
| Uranium | | | 5E-05 | | | | | | 6E-05 |
| Hardness as CaCO3 | 313 | 305 | 305 | 305 | 257 | 257 | 249 | 237 | 260 |

The data in Table 3 for March 1 after 150,406 gallons had been treated supports these observations. However, by the time this amount of water had passed through the media and some of the media had become loaded with Radium and Barium, the amount of Calcium in the raw water was being reduced by about 17% and that effect is also seen in the numbers for Hardness as Calcium Carbonate.

RSUD adds chlorine to the water as it enters the standpipe from the well. Chlorine samples were taken daily during the Pilot Test to compare the raw water chlorine content with the treated water chlorine content. The data consistently showed that the media did not affect the chlorine content of the water.

These data show that the media does not alter the chemical content of the water as it passes though the treatment process. The adsorption of Barium could act in competition with the adsorption of Radium if the Barium content was significant. The Barium content in the RSUD water does not present a problem.

Some inorganic data and a comparison of the water quality data taken of the RSUD well water before the WRT Pilot Test was begun with the February 2, 2004 data from the WRT System are given in Appendix C.

**Restart Tests**

The WRT Pilot Trailer was set up at the RSUD site to take water out of the standpipe through a flush valve. The water was the same as being served to the customers in the system. The RSUD system, at the time of the Test, was serving about 100,000 gallons of water per day to the customers or about one standpipe full each day. The water pressure at the Trailer was about 46 psi and was reasonably constant except for small change during the pump cycles. This arrangement was ideal for the Test because the flow rate through the media columns could be set and maintained without constant monitoring. The water in the standpipe had been treated with chlorine and a phosphate to stabilize the iron.

WRT proposes that the use of their Radium Removal System in an actual treatment facility would require that the water be pumped through the media on the way to the standpipe storage tank. The well pump cycles as necessary to keep the standpipe water at service level. This means that a treatment system installed in the pump line would experience start-stop cycles as the well pump operated normally. These start-stop cycles would depend upon the water usage by the customers

and the pump frequency would vary with the time of day and year. In addition, there are times when the pump needs maintenance or fails to function and the system might be off line for several days.

The media collects radium and becomes radioactive over time so the question arose as to the stability of the Radium retention in the media during these start-stop cycles. If some of the Radium being held in the media were to be released into the system water, the purpose of treatment would be violated. Breakthrough of the Radium would appear as an increase of Radium in the column 1 data. Late in the test program, several stop-start cycles were intentionally created so that the stability of the media for Radium retention could be tested.

The first of these water flow interruptions occurred unintentionally on January 27, 2004 when the pump failed. At the time of this interruption, 97,199 gallons had passed through the treatment system. The water to the Trailer was turned off and, after the pump was repaired and the standpipe was refilled with well water, the flow of water through the Trailer was restarted on January 30, 2004. Samples of raw, C1 and treated were sent to Jordan Labs for Radium analysis.

Table 4. Comparison of Jordan analysis of restart data with ACZ Lab data taken prior to the interruption. Data are in pCi/L.

| Radiochem Data ACZ and Jordan Labs | Raw | | Column 1 | | Treated | |
|---|---|---|---|---|---|---|
| | ACZ 1.19.04 | Jordan 1.30.04 | ACZ 1.19.04 | Jordan 1.30.04 | ACZ 1.19.04 | Jordan 1.30.04 |
| Radium 226 | 15.7 | 13.0 | 5.14 | 6.6 | 0.1 | 0.6 |
| Radium 228 | 23.0 | 36.0 | 14.7 | 17.0 | 1.05 | 2.0 |
| Total Radium | 38.7 | 49 | 19.84 | 23.6 | 1.16 | 2.6 |

The data in Table 4 shows the Jordan data for raw, C1 and treated upon restart of the water flow through the media columns. Also shown for comparison are the ACZ data taken on January 19, 2004 after 82,162 gallons had been treated. These data do show an increase in the column 1 Jordan Radium numbers as compared to ACZ. However, the Radium removal trend is similar taking into account that the data were from separate labs using different EPA approved methods of analysis. Also, the Jordan numbers for raw were higher than ACZ but the restart would have no affect upon the Radium in the water prior to treatment.

On March 3, 2004, after 153,801 gallons of water had passed through the media columns, samples were taken at column 1 and treated and then the water flow was intentionally stopped at 8:00 am. Table 5 shows the ACZ Lab radiochem data for those samples. These data were taken for comparison with the data to be taken after restart of flow.

Table 5. Radiochem data prior to stoppage of water flow. Data are in pCi/L.

| ACZ Radiochem Data L44838 03/03/04 | Column 1 (RB1) | | | Treated (RBF) |
|---|---|---|---|---|
| Gross Alpha (EPA M900.0) | | 18.1 | | 3.66 |
| Gross Beta (EPA M900.0) | | 42.3 | | 16.5 |
| Radium 226 (EPA M9315) | | 7.67 | | 0.22 |
| Radium 228 (EPA M9320) | | 15.9 | | 1.45 |
| Total Radium | | 23.57 | | 1.67 |

The water flow was restarted through the media columns at 11:00 am and adjusted for 1.2 gallons per minute. The raw water tap was open so that the initial water did not enter the media columns. The raw water tap was then closed and samples were immediately taken at column 1 so to sample the water that had been standing in column 1 during the off-flow time. A second sample followed at column 1 in two minutes after flow start and then a third sample was taken at column 1 at four minutes. A sample was taken at treated after twenty minutes of water flow through all columns of media. These samples were sent to ACZ Labs and the results are shown in Table 6.

Table 6. ACZ Lab data for March 3, 2004 restart of water flow. Data are in pCi/L.

| ACZ Radiochem Data L44838 03/03/04 | Column 1 | | | Treated |
|---|---|---|---|---|
| | Start RA0 | 2 min. RA2 | 4 min. RA4 | 20 min. RAF |
| Gross Alpha (EPA M900.0) | 3.53 | 11.3 | 18.7 | 1.56 |
| Gross Beta (EPA M900.0) | 10.3 | 32.0 | 38.4 | 13.0 |
| Radium 226 (EPA M9315) | 8.63 | 6.86 | 6.51 | 0.14 |
| Radium 228 (EPA M9320) | 20.9 | 15.1 | 15.7 | 0.54 |
| Total Radium | 29.53 | 21.96 | 22.21 | 0.68 |

This short three hour stop period was designed to represent a normal pump stop time that might be encountered in normal operation.

Comparing data from Table 6 with Table 5 shows that there was no breakthrough of Radium caused by the interruption of water flow. The water that was standing in column 1 (RA0) during the three hour shut down is slightly higher than the pre-shut down data in Table 5. Once flow was started, the data for column 1 (RA2 and RA4) are comparable to the RB1 data in Table 5.

In cases of pump failure, there might be periods of several days while the pump was being repaired and re-installed in the well. After the samples were taken as shown above, the water was intentionally turned off for a longer down time.

On March 8, 2004, the water to the Test Trailer was restarted and set for a flow rate of 1.2 gallons per minute. Again, as was done on March 4, the raw water tap was open during restart and samples were taken immediately, two minutes of flow and four minutes of flow at column 1. After twenty minutes of flow through all columns, a sample was taken at treated. The ACZ Lab data are shown in Table 7.

Table 7. ACZ Lab data for March 8, 2004 restart of water flow. Data are in pCi/L.

| ACZ Radiochem Data L44891 03/08/04 | Column 1 | | | Treated |
|---|---|---|---|---|
| | Start RD0 | 2 min. RD2 | 4 min. RD4 | 20 min. RDF |
| Gross Alpha (EPA M900.0) | 14.4 | 9.89 | 10.0 | 3.87 |
| Gross Beta (EPA M900.0) | 32.3 | 35.0 | 25.0 | 16.8 |
| Radium 226 (EPA M9315) | 5.66 | 5.73 | 5.35 | 0.17 |
| Radium 228 (EPA M9320) | 14.9 | 15.2 | 9.47 | 0.13 |
| Total Radium | 20.56 | 20.93 | 14.82 | 0.3 |

Comparing the data from Table 7 with the data from Table 6 shows that there was no breakthrough of the radium in the media in column 1 caused by the longer shut down period.

The WRT Test Trailer was left in place in case there was need for additional testing. The water was left flowing on March 8, 2004. On April 7, 2004, the pump failed and the water to the Test Trailer was turned off at 10:00 a.m.. The total flow through the system was 203,680 gallons.

On April 27, 2004, the water was turned on to the Test Trailer with the raw tap open. After adjusting the flow to 1.2 gallons per minute, a sample was taken of the raw water and then the flow was started through column 1 and a sample was taken immediately. After 60 minutes of water flow through all media columns, samples were taken at column 1, column 4 and treated. These samples were analyzed by ACZ Lab and the data are given in Table 8.

Table 8. ACZ Lab data for April 27, 2004 for the last restart test.

| ACZ Radiochem April 27, 2004 | Raw | Column 1 | | Column 4 | Treated |
|---|---|---|---|---|---|
| pCi/L | First Flow 1:30 pm | First Flow 1:30 pm | 60 min Flow 2:30 pm | 60 min Flow 2:30 pm | 60 min Flow 2:30 pm |
| Gross Alpha | 35.2 | 38.1 | 21.6 | 0.98 | 2.85 |
| Gross Beta | 52.6 | 49.5 | 40.7 | 14.3 | 9.33 |
| Radium 226 | 13.4 | 9.39 | 7.26 | 0.83 | 0.22 |
| Radium 228 | 28.7 | 15.2 | 20.0 | 1.32 | 0.0 |
| Total Radium | 42.1 | 24.59 | 27.26 | 2.15 | 0.22 |

There had been no water flow through the media columns for 20 days when these data were taken. The data compare closely with the data taken on March 8 as shown in Table 7, and the March 3 data as shown in Table 6.

All of the restart data show no radium breakthrough caused by interruption of water flow through the media. It is concluded that the treatment system could be used reliably in the main pump line and would function without radium breakthrough concern for water flow interruptions.

**Radon Tests**

Radon 222 is the first daughter in the decay scheme of Radium 226. Radon is an inert gas and even though its half-life is just 3.82 days, there is considerable Radon found in water and the surface of the earth. As can be seen in Table 9, the water being pumped from the Hickory contains over 300 pCi/L of Radon 222.

The media in this Test becomes loaded with Radium 226 and some of the radiation in the media column is emitted in secular equilibrium with Radon 226. This means that each time an atom of Radium 226 decays it creates an atom of Radon 222. The Radium 226 has a long half-life (1620 years) and the activity is controlled by its decay.

There was concern that the Radium 226 being accumulated in the media would create additional Radon and the quantity of Radon would increase as the water was being treated. Thus several samples of water were analyzed for Radon 222 and the results of those tests are given in Table 9.

Table 9. Comparison of Radon Test Data

| | Jordan 1.13.04 pCi/L Method 903.1 | Jordan 2.23.04 pCi/L Method 903.1 | ACZ 2.23.04 pCi/L Method 913.0 | ACZ 4.27.04 pCi/L Method 913.0 |
|---|---|---|---|---|
| Well | 330 +/- 10 | 195 +/- 8 | 200 +/- 28 | 356 +/- 35 |
| Raw | 156 +/- 7 | 181 +/- 7 | 145 +/- 24 | 156 +/- 23 |
| Treated | 181 +/- 7 | 210 +/- 7 | 107 +/- 21 | 152 +/- 22 |

The water from the well is pumped into a 100,000 gallon standpipe. The water is served to the customers from the standpipe. The water enters the standpipe at an elevation of 105 feet and is somewhat aerated during the pumping process. At the time of this Test the system was using about one standpipe of water per day. The loss of Radon shown in the data during storage was as expected. Radon, being a gas, is lost to the atmosphere as it is aerated and stored in the standpipe. The Jordan data does show an increase in Radon as the water goes through the treatment process. The ACZ data do not confirm this analysis.

The fact that Radon 222 has a much shorter half-life than Radium 226 and is decaying in secular equilibrium with Radon 226, the Radon that is created decays to Polonium 218 and does not build up in the media columns. Radon 220 is part of the Radium 228 decay scheme and it has an even shorter half-life (52 seconds) and, therefore, will not be a problem.

It is safe to conclude that the quantity of Radon being created in the media does not create an additional concern for Radon in the water. In an actual treatment plant where the media is located

prior to the standpipe, if there were to be any creation of Radon in the media that Radon will be subject to the aeration loss in storage.

**Blend Data**

Several Water Systems are considering blending the Radium-Rich water with Radium-Free or Low-Radium water to bring the water supply within EPA standards. Theoretically, if one blends 1 part Radium-Rich with 1 Radium-Free part, the Radium level should be reduced by 1/2. If the blend is 1 part Radium-Rich to 6 parts Radium-Free, then the Radium level should be reduced by 1/7. Similarly, a blend of a 8 to1 will reduce the Radium level by 1/9. If there is Radium in both parts of the blend then, for the half and half blend, the final Radium level will merely be ½ of the sum of the Radium in the two parts.

Samples of the three blends were prepared and sent to ACZ Lab for analysis. The anticipated levels of total Radium were calculated and those calculations appear in the Table for comparison with the measured data.

For example, the Richland Blend 6 to 1 was a sample with 6 parts of Richland water that has no Radium with 1 part of the raw water. The calculated values are the raw values divided by 7. The measured amount of Total Radium came out about half of the amount the calculation anticipated.

Table 10. Radiochem data for some sample blends. These samples were analyzed by ACZ Lab. Data are in pCi/L.

| | Raw Data | Richland Blend 6 to 1 | | Richland Blend 8 to 1 | | WRT Blend half raw-half treated | | Treated Data |
|---|---|---|---|---|---|---|---|---|
| | | Data | Calc. | Data | Calc. | Data | Calc. | |
| Gross Alpha | 35.2 | 7.09 | 5.02 | 4.85 | 3.91 | 11.1 | 19.03 | 2.85 |
| Gross Beta | 52.6 | 6.55 | 7.50 | 4.82 | 5.84 | 32.8 | 30.97 | 9.33 |
| Radium 226 | 13.4 | 1.67 | 1.91 | 1.46 | 1.49 | 5.6 | 6.81 | 0.22 |
| Radium 228 | 28.7 | 1.25 | 4.10 | 0.29 | 3.18 | 10.6 | 14.35 | 0 |
| Total Radium | 42.1 | 2.92 | 6.01 | 1.75 | 4.67 | 16.2 | 21.16 | 0.22 |

The analysis shows that nearly all of the data points were less than the calculated values. One must consider the error in the measurements and the fact that throughout this Pilot Test, there have been variance in the values for the raw water samples. The anomaly may be related to sampling, rather than to theory.

## Conclusion

The Z-88™ media mined and formulated by Water Remediation Technology, LLC, does remove the Radium from the Hickory water. The media adsorbs and holds the Radium within the media. This Pilot Test proved that the Radium Removal System is capable of lowering the Radium content of the Hickory water to within the Maximum Contaminant Levels set by the Environmental Protection Agency without altering the chemical content.

The samples tested during the Test confirmed that Radium 226 was lowered from 14 pCi/L to nearly zero and the Radium 228 was lowered from 30 pCi/L to less than 1 pCi/L, well below the EPA MCL of 5 pCi/L for the Total Radium.

The tests also proved that the Radium Removal System is stable and the interruption of water flow through pump cycling and down times for pump failure will not cause Radium breakthrough. The tests also showed that there is no additional Radon buildup during the media treatment process.

The Pilot Study provides the data needed to design a full treatment system that will contain sufficient media to treat the Hickory water for a long period of time before the media becomes loaded with Radium and must be removed and safely transported for disposal.

There are a few unknowns of concern that were not resolved with this pilot test. Most zeolites will release Radium if the proper chemical is liquidized into the media. Since the Z-88™ media is proprietary, the RSUD entered into a contractual agreement that there would be no testing of the material that would reveal its chemistry nor would the RSUD release any information concerning the media material. Therefore, whether there is a chemical that would reverse the adsorptive process for this material remains an unknown and a serious concern.

The media does do its job but now those water systems that might be interested in using this technology for a Radium Removal System need to know the costs. There will be a capital cost to prepare and install the equipment and an operational cost to treat the water. The fact that WRT maintains ownership of the equipment and provides the handling of the radioactive media and its transport to disposal is a major advantage. Whether the Radium Removal System can be affordable for disadvantaged communities is an unknown.

Water Service Systems that may be interested in this System must also be aware that there is a radiation safety concern. Even though WRT will be responsible for the handling and shipment of the radioactive media, the responsibility for the security of the radioactive media while on-site lies with the Water Service System. Any accidental spill of the radioactive media could create a health hazard for those operating the System and those Emergency Medical Personnel that would respond to the accident. There would certainly be a need for special training for the Water System personnel and for the local EMS crews. It is yet to be determined whether the TCEQ will require special licensing for such operational water treatment systems.

The WRT Radium Removal System uses a mined media material that cannot be regenerated and reused. The future of a treatment system depends upon the availability of media supply. If, for any reason, WRT cannot fulfill the contractual obligation, the Water Service System will be left without water treatment and would be required to seek other solutions for Radium removal.

Texas Water Development Board

RESEARCH GRANT

FINAL REPORT

Contract No. 2004-483-520

# APPENDIX A

## DATA FROM SAMPLE ANALYSIS

## APPENDIX A

The WRT Test Trailer was installed on RSUD property on December 3, 2003. Water began flowing through the test media at the rate of 1.2 gallons per minute. The raw water was taken from a flush valve outlet from the standpipe and was discharged on the surface to be absorbed into the soil. Samples of water were taken at different outlets of the test flow and were sent to the chosen labs for analysis. The laboratory results of these samples are recorded in the following tables.

December 8, 2003 First test samples were taken and sent to ACZ Labs for inorganic and radiochem analysis. Data were received on December 29, 2003. Flow 8,645 gallons.

| ACZ L43991 12/08/03 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Alumuinum | | | | | | | | | 0.17 |
| Barium | 0.0711 | 0.0128 | 0.0142 | | 0.0036 | | 0.0043 | | 0.0044 |
| Calcium | 54.2 | 52 | 48.4 | | 53.8 | | 55.9 | | 52.5 |
| Iron | 0.31 | 0.31 | 0.29 | | 0.29 | | 0.32 | | 0.4 |
| Magnesium | 47.1 | 45.9 | 45.4 | | 46.7 | | 46.5 | | 43.4 |
| Potassium | 14.7 | 14.6 | 15.1 | | 13.8 | | 9.2 | | 3.9 |
| Sodium | 40 | 39.3 | 40.7 | | 40.8 | | 41 | | 40.2 |
| Strontium | 1.26 | 1.11 | 0.85 | | 0.48 | | 0.33 | | 0.25 |
| Uranium | | | | | | | 0.00006 | | 0.00008 |
| | | | | | | | | | |

| ACZ Radiochem Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| L43991 12/08/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
| Gross Alpha (EPA M900.0) | 46.2 +/- 8.9 | 44.7 +/- 8.6 | 5.2 +/- 3.7 | | 0 +/- 2.4 | | 1.45 +/- 2.9 | | 0.57 +/- 2.9 |
| Radium 226 (EPA M9315) | 14.4 +/- 1.2 | 1.26 +/- 0.4 | 0.41 +/- 0.3 | | 0.3 +/- 0.2 | | 0.18 +/- 0.2 | | 0.27 +/- 0.2 |
| Radium 228 (EPA M9320) | 13.1 +/- 1.3 | 1.81 +/- 0.8 | 1.03 +/- 0.7 | | 1.21 +/- 0.7 | | 1.77 +/- 0.8 | | 0.69 +/- 0.7 |
| Total Radium | 27.5 | 3.07 | 1.44 | | 1.51 | | 1.95 | | 0.96 |

December 23, 2003 Samples taken on this date resulted in the following data received on January 19, 2004. Flow 34,568 gallons.

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| ACZ L44170 12/23/03 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Alumuinum | | | | | | | | | |
| Barium | 0.056 | 0.0271 | 0.011 | | 0.0043 | | 0.0045 | | 0.0041 |
| Calcium | 51.4 | 44.1 | 48 | | 48.5 | | 51.3 | | 52.9 |
| Iron | 0.33 | 0.33 | 0.32 | | 0.32 | | 0.34 | | 0.36 |
| Magnesium | 46.4 | 40.3 | 43.1 | | 43.6 | | 45.6 | | 47.2 |
| Potassium | 14 | 11.4 | 12.3 | | 12.5 | | 13.4 | | 14.1 |
| Sodium | 38.3 | 33.9 | 35.8 | | 35.8 | | 37.1 | | 38.4 |
| Strontium | 1.25 | 1.26 | 1.21 | | 1.1 | | 0.9 | | 0.74 |
| Uranium | | | | | | | | | |

| ACZ Radiochem Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample L44170 12/23/03 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
| Gross Alpha (EPA M900.0) | 29.2 +/- 5 | 5.31 +/- 2.5 | 4.36 +/- 2.3 | | 3.63 +/- 2.2 | | 2.15 +/- 1.9 | | 0.48 +/- 1.5 |
| Radium 226 (EPA M9315) | 0.31 +/- 0.2 | 0.13 +/- 0.1 | 0.03 +/- 0.1 | | 0.05 +/- 0.1 | | 0.05 +/- 0.1 | | |
| Radium 228 (EPA M9320) | 21.6 +/- 1.8 | 5.59 +/- 1.3 | 2.91 +/- 1.2 | | 3.8 +/- 1.0 | | 3.6 +/- 0.9 | | |
| Total Radium | | | | | | | | | |

January 5, 2004 Samples were taken at all test outlets and sent to ACZ Lab and the following data were received on February 11, 2004. Flow 57,654 gallons.

| ACZ L44234 01/05/04 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Alumuinum | | | | | | | | | |
| Barium | 0.0709 | 0.0457 | 0.0232 | 0.0133 | 0.0072 | 0.0062 | 0.0055 | 0.0053 | 0.0053 |
| Calcium | 54.9 | 54.2 | 55.1 | 55 | 55.3 | 52.3 | 54.9 | 55 | 56.3 |
| Iron | 0.33 | 0.39 | 0.35 | 0.4 | 0.42 | 0.41 | 0.38 | 0.37 | 0.39 |
| Magnesium | 43.5 | 44.3 | 44.2 | 43.8 | 43.6 | 43.8 | 43.9 | 43.8 | 43.5 |
| Potassium | 13.2 | 13.3 | 13.1 | 12.7 | 12.5 | 12.4 | 12.6 | 12.7 | 12.6 |
| Sodium | 35.8 | 36.7 | 36.7 | 36.3 | 36 | 36.4 | 36.3 | 36.2 | 36 |
| Strontium | 1.31 | 1.35 | 1.3 | 1.29 | 1.28 | 1.3 | 1.24 | 1.21 | 1.18 |
| Uranium | 6E-05 | 5E-05 | 6E-05 | 5E-05 | | 6E-05 | 7E-05 | 6E-05 | 6E-05 |

| ACZ Radiochem Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| L44234 01/05/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
| Gross Alpha (EPA M900.0) | 41.4 +/- 6.8 | 13.6 +/- 4.2 | 1.56 +/- 1.4 | 2.02 +/- 2 | 0 +/- 1.6 | 2.22 +/- 2.3 | 1.29 +/- 2.1 | 0.46 +/- 1.7 | 2.08 +/- 2.1 |
| Radium 226 (EPA M9315) | 13.6 +/- 0.8 | 3.33 +/- 0.4 | 0.82 +/- 0.2 | 0.51 +/- 0.2 | 0.49 +/- 0.2 | 0.32 +/- 0.2 | 0.27 +/- 0.2 | 0.64 +/- 0.2 | 0.58 +/- 0.2 |
| Radium 228 (EPA M9320) | 22.6 +/- 1.6 | 6.92 +/- 1 | 2.41 +/- 0.8 | 2.61 +/- 0.8 | 0.89 +/- 0.9 | 1.25 +/- 0.9 | 0.69 +/- 0.8 | 0.87 +/- 0.8 | 0.82 +/- 0.8 |
| Total Radium | 36.2 | 10.25 | 3.23 | 3.12 | 1.38 | 1.57 | 0.96 | 1.51 | 1.4 |

January 12, 2004 Samples were sent to Jordan Labs for radiochem analysis and the data below were received on February 9, 2004. Flow 69,726 gallons.

| Jordan Radiochem 01/12/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/L | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
|---|---|---|---|---|---|---|---|---|---|
| Gross Alpha (EPA 900.0) | 199 +/- 14 | 40 +/- 7 | | | | | | | 2.8 +/- 3.2 |
| Gross Beta (EPA 900.0) | 92 +/- 4 | 38 +/- 3 | | | | | | | 18 +/- 2 |
| Radium 228 (EPA 901.1M) | 13 +/- 1 | 5.4 +/- 0.3 | | | | | | | -0.1 +/- 0.1 |
| Radium 228 (EPA 901.1M) | 38 +/- 1 | 16+/- 1 | | | | | | | -0.3 +/- 0.2 |
| Total Radium | 51 | 21.4 | | | | | | | -0.4 |

Samples were also taken for radon content analysis and sent to Jordan Labs. Three samples were taken, one of the water being pumped from the well (well), one from the water entering the WRT Test Trailer (raw) and one after treatment by the Test Trailer. Jordan Labs used Method 903.1 for the analysis.

Well 330 +/- 10 pCi/L
Raw 156 +/- 7 pCi/L
Treated 181 +/- 7 pCi/L.

January 19, 2004 Split Sample Day. Samples were taken for the ACZ Lab and the TDH Lab to perform inorganic and radiochem analysis. The TDH radiochem data were received on February 11, 2004. Flow 82,162 gallons.

| Sample TDH 01/19/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/L | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
|---|---|---|---|---|---|---|---|---|---|
| Combined Uranium | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | | < 2.0 ug/L | | < 2.0 ug/L | | < 2.0 ug/L |
| Uranium 234 | 0.5 +/- 0.1 | < 0.5 | < 0.5 | | 0.5 +/- 0.1 | | 0.5 +/- 0.1 | | 0.5 +/- 0.1 |
| Uranium 235 | < 0.5 | < 0.5 | < 0.5 | | < 0.5 | | < 0.5 | | < 0.5 |
| Uranium 238 | < 0.5 | < 0.5 | < 0.5 | | < 0.5 | | < 0.5 | | < 0.5 |
| Gross Alpha | 55.6 +/- 4.5 | 20.9 +/- 2.7 | 8.5 +/- 1.8 | | > 2.0 | | > 2.0 | | > 2.0 |
| Gross Beta | 71.3 +/- 4.4 | 36.3 +/- 3.2 | 19.4 +/- 2.5 | | 13.6 +/- 2.2 | | 10.7 +/- 2.0 | | 11.5 +/- 2.1 |
| Radium 226 | 10.3 +/- 0.4 | 5.2 +/- 0.3 | 1.1 +/- 0.2 | | 0.2 +/- 0.1 | | > 0.2 | | > 0.2 |
| Radium 228 | 24.4 +/- 1.3 | 10.1 +/- 0.8 | 3.0 +/- 0.5 | | > 1.0 | | > 1.0 | | > 1.0 |
| Total Radium | 34.7 | 15.3 | 4.1 | | > 1.2 | | >1.2 | | > 1.2 |

The Inorganic and radiochem data from ACZ were received on February 16, 2004.

| Sample L44373 01/19/04 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Alumuinum | | | | | | | | | |
| Barium | 0.0552 | 0.0453 | 0.0263 | | 0.0081 | | 0.0054 | | 0.0043 |
| Calcium | 50.4 | 50.8 | 50.9 | | 50.2 | | 51.1 | | 50.9 |
| Iron | 0.36 | 0.36 | 0.36 | | 0.34 | | 0.33 | | 0.37 |
| Magnesium | 45.2 | 45.5 | 45.7 | | 44.9 | | 45.8 | | 45.5 |
| Potassium | 13.5 | 13.7 | 13.5 | | 13 | | 13.2 | | 12.9 |
| Sodium | 36.6 | 37.1 | 37.1 | | 36.2 | | 37.3 | | 37.4 |
| Strontium | 1.27 | 1.26 | 1.28 | | 1.27 | | 1.27 | | 1.26 |
| Uranium | | | | | | | | | |

| ACZ L44373 01/19/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
|---|---|---|---|---|---|---|---|---|---|
| Gross Alpha (EPA M900.0) | 37.8 +/- 6.5 | 12 +/- 4 | 7.63 +/- 3.6 | | 6.22 +/- 2.7 | | 3.47 +/- 2.5 | | 4.6 +/- 2.5 |
| Radium 226 (EPA M9315) | 15.7 +/- 0.8 | 5.14 +/- 0.5 | 1.85 +/- 0.3 | | 0.32 +/- 0.1 | | 0.24 +/- 0.1 | | 0.1+/- 0.3 |
| Radium 228 (EPA M9320) | 23 +/- 1.3 | 14.7 +/- 1.1 | 5.5 +/- 0.9 | | 1.24 +/- 0.7 | | 0.4 +/- 0.7 | | 1.05 +/- 0.7 |
| Total Radium | 38.7 | 19.84 | 7.35 | | 1.56 | | 0.68 | | 1.16 |

January 27, 2004 Flow was interrupted because of pump failure. The water was turned off to the Test Trailer and was properly flushed and restarted at 3:50 pm on January 30, 2004. Total flow prior to stoppage was 97,199 gallons.

January 30, 2004 Flow to the Test Trailer was re-started at 3:50 pm and samples were sent to Jordan Labs for radiochem analysis. Test results were received on February 24, 2004. Total water flow at this time was 97,199 gallons.

| Jordan Radiochem 01/30/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/L | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
|---|---|---|---|---|---|---|---|---|---|
| Gross Alpha (EPA 900.0) | | | | | | | | | |
| Gross Beta (EPA 900.0) | | | | | | | | | |
| Radium 226 (EPA 901.1M) | 13.0 +/- 1.0 | 6.6 +/- 0.3 | | | | | | | 0.6 +/- 0.1 |
| Radium 228 (EPA 901.1M) | 36.0 +/- 1.0 | 17.0 +/- 1.0 | | | | | | | 2.0 +/- 0.2 |
| Total Radium | 49 | 23.6 | | | | | | | 2.6 |

February 2, 2004 Samples taken were sent to ACZ Lab for radiochem and inorganic analysis and the results were received February 24, 2004.Total water flow was 102,150 gallons.

| ACZ L44506 02/02/04 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | | | | | | | | | |
| Barium | 0.0623 | 0.0509 | 0.0336 | 0.0201 | 0.0112 | 0.0087 | 0.0065 | 0.006 | 0.0054 |
| Calcium | 45.1 | 49 | 47.6 | 43.3 | 46.8 | 42.8 | 45.3 | 43.3 | 43.5 |
| Iron | 0.38 | 0.38 | 0.36 | 0.37 | 0.37 | 0.38 | 0.36 | 0.35 | 0.32 |
| Magnesium | 41.7 | 45 | 43.7 | 40.2 | 43.1 | 39.8 | 41.7 | 40.2 | 39.9 |
| Potassium | 12.2 | 13.1 | 12.6 | 11.4 | 12.3 | 11.5 | 12.4 | 12 | 15.1 |
| Sodium | 34.3 | 36.8 | 35.8 | 33.5 | 35.9 | 33.5 | 34.5 | 33.6 | 32.7 |
| Strontium | 1.3 | 1.3 | 1.28 | 1.28 | 1.29 | 1.32 | 1.26 | 1.27 | 1.24 |
| Uranium | | | | 5E-05 | 5E-05 | 5E-05 | 5E-05 | 7E-05 | 8E-05 |

| ACZ Radiochem Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| L44506 02/02/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
| Gross Alpha (EPA M 900.0) | 27.9 +/- 5.8 | 15.9 +/- 4.1 | 5.56 +/- 2.9 | 8.49 +/- 3.2 | 6.09 +/- 3.2 | 6.11 +/- 2.6 | 8.7 +/- 3.4 | 0 +/- 2.2 | 1.05 +/- 2 |
| Gross Beta (EPA M900.0) | 55.5 +/- 4.5 | 34 +/- 3.7 | 18.1 +/- 3.1 | 18.3 +/- 2.8 | 17.4 +/- 2.7 | 17.4 +/- 2.8 | 15.4 +/- 3 | 12.7 +/- 2.7 | 11.5 +/- 2.6 |
| Radium 226 (EPA M9315) | 15.6 +/- 0.8 | 5.83 +/- 0.5 | 1.98 +/- 0.3 | 0.58 +/- 0.2 | 0.32 +/- 0.2 | 0.23 +/- 0.1 | 0.22 +/- 0.1 | 0.3 +/- 0.2 | 0.01 +/- 0.1 |
| Radium 228 (EPA M9320) | 19.9 +/- 1.4 | 11.9 +/- 1.1 | 3.45 +/- 0.8 | 1.38 +/- 0.7 | 4.3 +/- 1.9 | 0.27 +/- 0.8 | 0.37 +/- 0.8 | 0.98 +/- 0.6 | 0.65 +/- 1.6 |
| Total Radium | 35.5 | 17.73 | 5.43 | 1.96 | 4.62 | 0.5 | 0.59 | 1.28 | 0.66 |

Samples were also taken for radon content analysis and sent to ACZ Lab. Three samples were taken, one of the water being pumped from the well (well), one from the water entering the WRT Test Trailer (raw) and one after treatment by the Test Trailer. ACZ Lab used Method 913.0 for the analysis that was received March 9, 2004..

Well 200 +/- 28 pCi/L
Raw 145 +/- 24 pCi/L
Treated 107 +/- 21 pCi/L.

Samples were also taken for radon content analysis and sent to Jordan Labs. Three samples were taken, one of the water being pumped from the well (well), one from the water entering the WRT Test Trailer (raw) and one after treatment by the Test Trailer. Jordan Labs used Method 903.1 for the analysis that was received March 17, 2004.

Well 195 +/- 8 pCi/L
Raw 181 +/- 7 pCi/L
Treated 210 +/- 7 pCi/L.

February 23, 2004 Samples taken for radiochem and inorganic analysis were sent to ACZ Lab and test results were received on March 22, 2004. The total flow at this sampling was 138,814 gallons.

| ACZ L44739 02/23/04 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | | | | | | | | | |
| Barium | 0.0735 | 0.0654 | 0.0486 | | 0.021 | | 0.0096 | | 0.0072 |
| Calcium | 44.9 | 52.8 | 42.9 | | 43.8 | | 47.1 | | 41.7 |
| Iron | 0.32 | 0.34 | 0.32 | | 0.31 | | 0.29 | | 0.28 |
| Magnesium | 41.4 | 47.9 | 39.5 | | 40.1 | | 43.3 | | 38.6 |
| Potassium | 12.3 | 14.7 | 11.8 | | 12.2 | | 13.4 | | 11.6 |
| Sodium | 35.1 | 39.6 | 33.4 | | 34.2 | | 36.2 | | 33.1 |
| Strontium | 1.29 | 1.3 | 1.31 | | 1.32 | | 1.33 | | 1.3 |
| Uranium | | | | | | | | | |
| Hardness as CaCO3 | 282 | 329 | 270 | | 274 | | 296 | | 263 |

| ACZ Radiochem Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| L44739 02/23/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
| Gross Alpha (EPA M900.0) | 52 +/- 7.3 | 18.1 +/- 4.9 | 5.78 +/- 2.9 | | 1.87 +/- 1.8 | | 1.6 +/- 1.7 | | 1.58 +/- 2.1 |
| Gross Beta (EPA M900.0) | 61.2 +/- 4.6 | 40.1 +/- 4 | 19.2 +/- 3.1 | | 13.6 +/- 2.8 | | 12.8 +/- 2.6 | | 11.2 +/- 2.8 |
| Radium 226 (EPA M9315) | 13.7 +/- 0.9 | 6.91 +/- 0.5 | 3.07 +/- 0.3 | | 0.48 +/- 0.3 | | 0.16 +/- 0.1 | | 0.13 +/- 0.1 |
| Radium 228 (EPA M9320) | 31 +/- 1.5 | 19.8 +/- 1.2 | 9.76 +/- 1 | | 0.95 +/- 0.8 | | 0.44 +/- 0.7 | | 0.42 +/- 0.7 |
| Total Radium | 44.7 | 26.71 | 12.83 | | 1.43 | | 0.6 | | 0.55 |

March 1, 2004 Split Sample Day. Samples were taken for the ACZ Lab to perform inorganic and radiochem analysis. The ACZ Lab data were received on March 25, 2004. The total water flow at this sampling was 150,406 gallons.

| ACZ L44809 03/01/04 | Raw mg/L | C1 mg/L | C2 mg/L | C3 mg/L | C4 mg/L | C5 mg/L | C6 mg/L | C7 mg/L | Treated mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | | | | | | | | | |
| Barium | 0.0532 | 0.0461 | 0.0375 | 0.0342 | 0.0171 | 0.0122 | 0.0088 | 0.0062 | 0.0055 |
| Calcium | 49.8 | 48.8 | 48.5 | 48.7 | 40.5 | 40.3 | 39.1 | 37.2 | 41.2 |
| Iron | 0.34 | 0.34 | 0.36 | 0.33 | 0.33 | 0.32 | 0.31 | 0.29 | 0.3 |
| Magnesium | 45.9 | 44.6 | 44.6 | 44.6 | 38 | 38 | 36.8 | 35.1 | 38.2 |
| Potassium | 13.1 | 13 | 13 | 13.1 | 10.4 | 10.4 | 10.1 | 10.8 | 10.6 |
| Silica | 16 | 15.7 | 15.5 | 15.6 | 16 | 16.2 | 16.3 | 15.8 | 16.2 |
| Sodium | 35.9 | 34.9 | 35.1 | 34.9 | 30.1 | 30.2 | 29.3 | 29.9 | 30.3 |
| Strontium | 1.26 | 1.26 | 1.28 | 1.23 | 1.29 | 1.27 | 1.27 | 1.27 | 1.29 |
| Uranium | | | 5E-05 | | | | | | 6E-05 |
| Hardness as CaCO3 | 313 | 305 | 305 | 305 | 257 | 257 | 249 | 237 | 260 |

| ACZ Radiochem Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| L44809 03/01/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/l | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
| Gross Alpha (EPA M900.0) | 29.6 +/- 5.8 | 15.8 +/- 4.6 | 6.92 +/- 3.2 | 5.44 +/- 2.8 | 3.1 +/- 2.6 | 1.75 +/- 2.1 | 2.1 +/- 2.2 | 0.25 +/- 1.8 | 1.95 +/- 2. |
| Gross Beta (EPA M900.0) | 57 +/- 4.3 | 32.5 +/- 3.5 | 25.6 +/- 3.2 | 19.4 +/- 3.2 | 13.4 +/- 2.7 | 15.1 +/- 2.9 | 16.6 +/- 3 | 12.2 +/- 2.6 | 13.3 +/- 2.8 |
| Radium 226 (EPA M9315) | 14 +/- 0.8 | 8.38 +/- 0.6 | 3.61 +/- 0.4 | 1.41 +/- 0.3 | 0.59 +/- 0.2 | 0.35 +/- 0.2 | 0.29 +/- 0.2 | 0.1 +/- 0.1 | 0.16 +/- 0.1 |
| Radium 228 (EPA M9320) | 18.4 +/- 1.7 | 10.8 +/- 1.4 | 3.82 +/- 1.1 | 2 +/- 1 | 0.86 +/- 0.9 | 0.76 +/- 0.7 | 1.06 +/- 0.7 | 0.97 +/- 0.7 | 0.63 +/- 0.8 |
| Total Radium | 32.4 | 19.18 | 7.43 | 3.41 | 1.45 | 1.11 | 1.35 | 1.07 | 0.79 |

Samples were taken by TDH for radiochem analysis and the resulting data were received April 6, 2004.

| TDH Radiochem 03/01/04 | Raw pCi/L | C1 pCi/L | C2 pCi/L | C3 pCi/L | C4 pCi/L | C5 pCi/L | C6 pCi/L | C7 pCi/L | Treated pCi/L |
|---|---|---|---|---|---|---|---|---|---|
| Combined Uranium | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L | < 2.0 ug/L |
| Uranium 234 | < 0.5 | 0.7 +/- 0.1 | < 0.5 | 0.5 +/- 0.1 | 0.5 +/- 0.1 | < 0.5 | 0.5 +/- 0.1 | 0.5 +/- 0.1 | 0.5 +/- 0.1 |
| Uranium 235 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Uranium 238 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Gross Alpha | 52.9 +/- 4.2 | 24.4 +/- 2.9 | 10.9 +/- 2.0 | 4.6 +/- 1.3 | 2.1 +/- 0.9 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| Gross Beta | 68.6 +/- 3.2 | 42.0 +/- 2.5 | 23.6 +/- 2.7 | 16.8 +/- 2.3 | 14.1 +/- 2.1 | 14.9 +/- 2.2 | 14.5 +/- 1.1 | 13.5 +/- 1.2 | 10.2 +/- 1.9 |
| Radium 226 | 9.5 +/- 0.4 | 6.0 +/- 0.4 | 2.6 +/- 0.3 | 1.0 +/- 0.2 | 0.4 +/- 0.2 | < 0.2 | 0.2 +/- 0.2 | < 0.2 | < 0.2 |
| Radium 228 | 25.8 +/- 1.2 | 15.6 +/- 1.0 | 6.6 +/- 0.7 | 1.7 +/- 0.4 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Total Radium | 35.3 | 21.6 | 9.2 | 2.7 | < 1.4 | < 1.2 | < 1.2 | < 1.2 | < 1.2 |

March 3, 2004 Samples were taken at C1 and treated and then the water was intentionally stopped at 8:00 am at which time the total flow was 153,801 gallons. The purpose of the stoppage was to check for possible Radium breakthrough upon re-start of the water flow. The following table shows the data prior to stoppage which was received on March 25, 2004.

| ACZ Radiochem Data L44838 03/03/04 | Column 1 (RB1) | | | Treated (RBF) |
|---|---|---|---|---|
| Gross Alpha (EPA M900.0) | | 18.1 +/- 5.2 | | 3.66 +/- 3.0 |
| Gross Beta (EPA M900.0) | | 42.3 +/- 4.6 | | 16.5 +/- 3.2 |
| Radium 226 (EPA M9315) | | 7.67 +/- 0.6 | | 0.22 +/- 0.1 |
| Radium 228 (EPA M9320) | | 15.9 +/- 1.3 | | 1.45 +/- 0.8 |
| Total Radium | | 23.57 | | 1.67 |

Flow was re-started at 11:00 am and adjusted to 1.2 gallons per minute. Samples were immediately taken at C1 so to sample the water that had been standing in tube 1. A second sample followed at C1 in two minutes of flow and then a third C1 sample was taken at four minutes of flow through tube 1. A sample was taken at treated after 20 minutes of flow through the entire system. These samples were sent to ACZ Lab for radiochem analysis and the data is given in this table..

| ACZ Radiochem Data L44838 03/03/04 | Column 1 | | | Treated |
|---|---|---|---|---|
| | Start RA0 | 2 min. RA2 | 4 min. RA4 | 20 min. RAF |
| Gross Alpha (EPA M900.0) | 3.53 +/- 2.7 | 11.3 +/- 4.2 | 18.7 +/- 5.4 | 1.56 +/- 2.5 |
| Gross Beta (EPA M900.0) | 10.3 +/- 2.7 | 32.0 +/- 4 | 38.4 +/- 4.5 | 13.0 +/- 3.1 |
| Radium 226 (EPA M9315) | 8.63 +/- 0.6 | 6.86 +/- 0.6 | 6.51 +/- 0.5 | 0.14 +/- 0.1 |
| Radium 228 (EPA M9320) | 20.9 +/- 1.4 | 15.1 +/- 1.3 | 15.7 +/- 1.3 | 0.54 +/- 0.7 |
| Total Radium | 29.53 | 21.96 | 22.21 | 0.68 |

March 4, 2004 The water to the Test Trailer was intentionally turned off to prepare for a long period of no-flo so to test for possible breakthrough upon re-start after a long delay.

March 8, 2004 The water to the Test Trailer was re-started and set for 1.2 gallons per minute. A sample (RD0) was taken immediately from Column 1, another sample followed from Column 1 at 2 minutes (RD2) and a third taken at Column 1 at 4 minutes (RD4); 20 minutes later a sample was taken at treated (RDF). The ACZ radiochem data were received on March 29, 2004 and is given in this table.

| ACZ Radiochem Data L44891 03/08/04 | Column 1 | | | Treated |
|---|---|---|---|---|
| | Start RD0 | 2 min. RD2 | 4 min. RD4 | 20 min. RDF |
| Gross Alpha (EPA M900.0) | 14.4 +/- 4.6 | 9.89 +/- 4.0 | 10.0 +/- 3.6 | 3.87 +/- 2.7 |
| Gross Beta (EPA M900.0) | 32.3 +/- 3.7 | 35.0 +/- 4.2 | 25.0 +/- 3.5 | 16.8 +/- 3.2 |
| Radium 226 (EPA M9315) | 5.66 +/- 0.5 | 5.73 +/- 0.5 | 5.35 +/- 0.5 | 0.17 +/- 0.1 |
| Radium 228 (EPA M9320) | 14.9 +/- 1.5 | 15.2 +/- 1.5 | 9.47 +/- 1.2 * | 0.13 +/- 0.7 * |
| Total Radium | 20.56 | 20.93 | 14.82 | 0.3 |

* In the original data these were 0.76 and 15.5 respectively. The samples were retested for the recorded values.

Water was left flowing after these samples.

April 7, 2004 Water flow was interrupted at 10:00 am because of pump failure. The total flow at this point was 203,680 gallons and the water was not re-started.

April 27, 2004 The water was re-started at 1:32 pm at 1.2 gallons per minute and a sample was taken immediately at Column 1. The water was allowed to flow until 2:30 and then samples were taken at raw, C1, C4 and treated.

| ACZ Radiochem April 27, 2004 | Raw | Column 1 | | Column 4 | Treated |
|---|---|---|---|---|---|
| pCi/L | First Flow 1:30 pm | First Flow 1:30 pm | 60 min Flow 2:30 pm | 60 min Flow 2:30 pm | 60 min Flow 2:30 pm |
| Gross Alpha (EPA M900.0) | 35.2 +/- 8.2 | 38.1 +/- 6.8 | 21.6 +/- 6 | 0.98 +/- 2.7 | 2.85 +/- 2.8 |
| Gross Beta (EPA M900.0) | 52.6 +/- 5.6 | 49.5 +/- 4.3 | 40.7 +/- 4.7 | 14.3 +/- 3.8 | 9.33 +/- 3.2 |
| Radium 226 (EPA M9315) | 13.4 +/- 0.7 | 9.39 +/- 1 | 7.26 +/- 0.6 | 0.83 +/- 0.2 | 0.22 +/- 0.1 |
| Radium 228 (EPA M9320) | 28.7 +/- 1.7 | 15.2 +/- 1.3 | 20.0 +/- 1.5 | 1.32 +/- 0.9 | 0.0 +/- 0.75 |
| Total Radium | 42.1 | 24.59 | 27.26 | 2.15 | 0.22 |

The well pump was started and allowed to run for sufficient time to flush the lines into the standpipe. Radon samples were taken of the well water (well), raw water entering the Test Trailer (raw) and of the water leaving the Test Trailer (treated). These samples were sent to ACZ Lab for analysis and the results are given below.

| | |
|---|---|
| Well | 356 +/- 35 pCi/L |
| Raw | 156 +/- 23 pCi/L |
| Treated | 152 +/- 22 pCi/L |

April 28, 2004 Water was turned off at 11.47 am with a total flow through the media of 205,288 gallons.

Texas Water Development Board
RESEARCH GRANT
FINAL REPORT
Contract No. 2004-483-520

# APPENDIX B

## DATA FROM RADIATION MEASUREMENTS

Radiation Data with a Ludlum Mod 2401-P Survey Meter-instrument window against column surface-mR/Hr. Low/High readings were in center of room.

| Date | Calibration | background | column 1 | column 2 | column 3 | column 4 | column 5 | column 6 | column 7 | treated | low / high | notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.11.03 | 0.4 | 0.005 | 0.1 | 0.03 | bckgnd | | | | | | | |
| 12.12.03 | 0.7 | 0.005 | 0.1 | 0.03 | bckgnd | | | | | | | 15,281 gallons |
| 12.17.03 | 0.4 | 0.01 | 0.15 | 0.03 | bckgnd | | | | | | | 24,072 gallons |
| 12.20.03 | 0.6 | 0.01 | 0.15 | 0.03 | bckgnd | | | | | | | 29,215 gallons |
| 12.23.03 | 0.6 | 0.02 | 0.15+ | 0.03 | bckgnd | | | | | | | 34,568 gallons |
| 12.26.03 | 0.4 | 0.01 | 0.15 | 0.04 | 0.02 | bckgnd | | | | | | |
| 12.28.03 | 0.35 | 0.01 | 0.2 | 0.06 | 0.025 | bckgnd | | | | | | |
| 12.31.03 | 0.6 | 0.01 | 0.25 | 0.06 | 0.02 | bckgnd | | | | | | 50,604 gallons |
| 1.04.04 | 0.8 | 0.01 | 0.25 | 0.06 | 0.03 | bckgnd+ | | | | | | 56,208 gallons |
| 1.05.04 | 0.7 | 0.01 | 0.25 | 0.065 | 0.025 | bckgnd+ | | | | | | 57,654 gallons |
| 1.09.04 | 0.7 | 0.01 | 0.28 | 0.09 | 0.03 | bckgnd+ | | | | | | 65,154 gallons |
| 1.12.04 | 0.55 | 0.01 | 0.3 | 0.08 | 0.04 | 0.015 | bckgnd | | | | | 69,726 gallons |
| 1.15.04 | 0.75 | 0.01 | 0.3 | 0.09 | 0.035 | 0.02 | bckgnd | | | | | 75,014 gallons |
| 1.19.04 | 0.6 | 0.01 | 0.35 | 0.12 | 0.035 | 0.02 | bckgnd | | | | | 82,162 gallons |
| 1.21.04 | 0.65 | 0.01 | 0.35 | 0.12 | 0.04 | 0.02 | bckgnd | | | | | 85,812 gallons |
| 1.23.04 | 0.75 | 0.01 | 0.35 | 0.12 | 0.04 | 0.02 | bckgnd | | | | | 89,060 gallons |
| 1.26.04 | 0.75 | 0.01 | 0.38 | 0.12 | 0.05 | 0.025 | 0.015 | bckgnd | | | | 94,208 gallons |
| 1.27.04 | 0.75 | 0.01 | 0.45 | 0.125 | 0.065 | 0.025 | 0.02 | bckgnd | | | | off 12pm 91,799 gal-no flow data |
| 1.30.04 | 0.85 | 0.01 | 0.45 | 0.15 | 0.06 | 0.025 | 0.02 | bckgnd | | | | data before restart |
| 1.30.04 | 0.85 | 0.01 | 0.4 | 0.14 | 0.06 | 0.02 | 0.025 | 0.02 | bckgnd | | | restart data 3:50pm |
| 2.02.04 | 0.75 | 0.01 | 0.35 | 0.11 | 0.05 | 0.02 | 0.02 | 0.02 | bckgnd | | | 102150 gal |
| 2.06.04 | 0.65 | 0.01 | 0.38 | 0.145 | 0.05 | 0.025 | 0.015 | 0.015 | bckgnd | | 0.02/0.03 | 109054 gal |
| 2.09.04 | 0.75 | 0.01 | 0.4 | 0.135 | 0.075 | 0.02 | 0.015 | 0.015 | bckgnd | | 0.02/0.03 | 111467 gal |
| 2.12.04 | 0.75 | 0.01 | 0.43 | 0.15 | 0.06 | 0.02 | 0.02 | 0.02 | bckgnd | | 0.02/0.03 | 119833 gal |
| 2.15.04 | 0.75 | 0.01 | 0.4 | 0.15 | 0.06 | 0.025 | 0.015 | 0.015 | bckgnd | | 0.02/0.03 | 124887 gal |
| 2.16.04 | 0.75 | 0.01 | 0.45 | 0.155 | 0.065 | 0.04 | 0.015 | 0.02 | 0.02 | bckgnd | 0.015/0.035 | 126987 gal |
| 2.18.04 | 0.75 | 0.01 | 0.45 | 0.2 | 0.075 | 0.025 | 0.02 | 0.015 | 0.015 | bckgnd | 0.015/0.035 | 130203 gal |
| 2.21.04 | 0.75 | 0.01 | 0.43 | 0.18 | 0.075 | 0.03 | 0.02 | 0.015 | 0.015 | bckgnd | 0.02/0.035 | 134914 gal |
| 2.23.04 | 0.75 | 0.01 | 0.45 | 0.2 | 0.075 | 0.04 | 0.03 | 0.02 | 0.015 | bckgnd | 0.02/0.035 | 138814 gal |
| 2.27.04 | 0.75 | 0.01 | 0.5 | 0.2 | 0.11 | 0.05 | 0.03 | 0.015 | 0.015 | bckgnd | 0.02/0.035 | |
| 3.01.04 | 0.75 | 0.01 | 0.5 | 0.2 | 0.11 | 0.03 | 0.02 | 0.025 | 0.015 | bckgnd | 0.02/0.04 | 150406 gal 9 am |
| 3.03.04 | 0.75 | 0.01 | 0.45 | 0.2 | 0.1 | 0.03 | 0.02 | 0.02 | 0.015 | bckgnd | | 153801 gal - water off 8 am |
| 3.03.04 | 0.75 | 0.01 | 0.6 | 0.3 | 0.09 | 0.05 | 0.025 | 0.025 | 0.02 | 0.018 | 0.025/0.035 | taken while flow stopped |
| 3.03.04 | 0.75 | 0.01 | 0.45 | 0.2 | 0.07 | 0.04 | 0.02 | 0.025 | 0.015 | 0.015 | | 153830 gal - flow start 11 am |
| 3.08.04 | 0.75 | 0.01 | 0.6 | 0.3 | 0.115 | 0.045 | 0.025 | 0.025 | 0.02 | 0.015 | 0.02/0.03 | rad data taken while flow stop |
| 3.08.04 | | | | | | | | | | | | restart 9 am |
| 3.12.04 | 0.75 | 0.01 | 0.5 | 0.25 | 0.09 | 0.05 | 0.02 | 0.025 | 0.015 | 0.015 | 0.02/0.03 | 160741 gal |
| 3.22.04 | 0.75 | 0.01 | 0.55 | 0.3 | 0.115 | 0.045 | 0.02 | 0.015 | 0.02 | 0.015 | 0.02/0.03 | 177743 gal |
| 3.30.04 | 0.75 | 0.01 | 0.6 | 0.3 | 0.15 | 0.055 | 0.02 | 0.02 | 0.015 | 0.015 | 0.02/0.03 | 190713 gal |
| 4.03.04 | 0.75 | 0.01 | 0.6 | 0.3 | 0.15 | 0.045 | 0.03 | 0.02 | 0.02 | 0.015 | 0.02/0.03 | 199435 gal |
| 4.07.04 | 0.75 | 0.01 | 0.8 | 0.35 | 0.12 | 0.06 | 0.04 | 0.03 | 0.03 | 0.02 | 0.025/0.04 | off 10 am 203680 gal-no flow data |
| 4.27.04 | 0.75 | 0.01 | 0.7 | 0.42 | 0.21 | 0.07 | 0.035 | 0.025 | 0.02 | 0.015 | 0.02/0.04 | no flow data, re-start 1:32 |
| 4.28.04 | | | | | | | | | | | | water off at 11:47 - 205,288 gal |

Texas Water Development Board
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# APPENDIX C

## DATA FROM INORGANIC ANALYSIS

The following is a comparison of the water quality data taken of the RSUD well water before the WRT Pilot Test was begun with the February 2, 2004 data from the WRT system.

| PUMPED WATER QUALITY<br>Richland Special Utility District | | ACZ Lab 02/02/04 | |
|---|---|---|---|
| Constituent | Well | Raw | Treated |
| Arsenic | <0.007 | 0.0010 | 0.0009 |
| Barium | 0.061 | 0.0625 | 0.0054 |
| Cadmium | <0.001 | | |
| Calcium | 48.8 | 54.1 | 44.9 |
| Chloride | 29 | 32 | 33 |
| Chromium | <0.01 | 0.0003 | 0.0003 |
| Copper | <0.0039 | 0.041 | 0.0105 |
| Fluoride | 0.6 | | 0.7 |
| Iron | 0.395 | 0.50 | 0.32 |
| Lead | <0.001 | 0.0052 | 0.0013 |
| Magnesium | 45 | 49.3 | 41.8 |
| Manganese | <0.0077 | 0.015 | 0.012 |
| Mercury | <0.0004 | | |
| Nitrate (as N) | 0.01 | | |
| Potassium | | 14.4 | 12.2 |
| Selenium | <0.003 | | |
| Silver | <0.01 | | |
| Sodium | 34.9 | 40.4 | 34.3 |
| Sulfate | 60 | 60 | 60 |
| Total Alkalinity (as CaCO ) | 307 | 302 | 302 |
| Total Dissolved Solids | | 432 | 408 |
| Total Hardness (as CaCO ) | 307 | 338 | 284 |
| Zinc | <0.058 | 0.03 | 0.03 |
| Gross Alpha (pCi/L) | 47.3 | 27.9 | 0.01 |
| Radium 226 (pCi/L) | 11.6 | 15.6 | 0.01 |
| Radium 228 (pCi/L) | 15.4 | 19.9 | 0.65 |
| Total Radium (pCi/L) | 27.0 | 35.5 | 0.66 |
| Combined Uranium(ug/L) | <7.0 | | 0.08 |

Units are mg/L unless otherwise indicated.
RSUD Mineral sample collected 01.15.03
RSUD Radionuclide sample collected 10.16.02

A C Z **Laboratories, Inc.**
*2773 Downhill Drive Steamboat Springs, CO 80487(800) 334-5493*

**Inorganic Analytical Results**

**Water Remediation Technology, LLC**
Project ID: TEXAS
Sample ID: TREATED

ACZ Sample ID: ***L44506-10***
Date Sampled: *02/02/04 14:56*
Date Received: *02/04/04*
Sample Matrix: *Drinking Water*

Metals Analysis

| Parameter | EPA Method | Result | Qual | XQ | Units | MDL | PQL | Date | Analyst |
|---|---|---|---|---|---|---|---|---|---|
| Antimony, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0002 | 0.001 | 02/13/04 22:00 | jb |
| Arsenic, total recoverable | M200.8 ICP-MS | 0.0009 | | | mg/L | 0.0001 | 0.0005 | 02/14/04 14:49 | jb |
| Barium, total recoverable | M200.8 ICP-MS | 0.0054 | | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:00 | jb |
| Beryllium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:00 | jb |
| Cadmium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:00 | jb |
| Calcium, dissolved | M200.7 ICP | 44.9 | | | mg/L | 0.2 | 1 | 02/11/04 23:37 | wfg |
| Chromium, total recoverable | M200.8 ICP-MS | 0.0003 | B | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:00 | jb |
| Copper, total recoverable | M200.8 ICP-MS | 0.0105 | | | mg/L | 0.0005 | 0.003 | 02/13/04 22:00 | jb |
| Iron, total recoverable | M200.7 ICP | 0.32 | | | mg/L | 0.01 | 0.05 | 02/11/04 17:57 | scp |
| Lead, total recoverable | M200.8 ICP-MS | 0.0013 | | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:00 | jb |
| Magnesium, dissolved | M200.7 ICP | 41.8 | | | mg/L | 0.2 | 1 | 02/11/04 23:37 | wfg |
| Manganese, total recoverable | M200.7 ICP | 0.012 | B | | mg/L | 0.005 | 0.03 | 02/11/04 17:57 | scp |
| Mercury, total recoverable | M245.1 CVAA | | U | | mg/L | 0.0002 | 0.001 | 02/16/04 13:08 | bnh |
| Potassium, dissolved | M200.7 ICP | 12.2 | | | mg/L | 0.3 | 1 | 02/13/04 22:25 | wfg |
| Selenium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0001 | 0.0005 | 02/14/04 14:49 | jb |
| Sodium, dissolved | M200.7 ICP | 34.3 | | | mg/L | 0.3 | 1 | 02/11/04 23:37 | wfg |
| Thallium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 5E-05 | 0.0003 | 02/14/04 14:49 | jb |
| Uranium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 5E-05 | 0.0003 | 02/13/04 22:00 | jb |
| Zinc, total recoverable | M200.7 ICP | 0.03 | B | | mg/L | 0.01 | 0.05 | 02/11/04 17:57 | scp |

Metals Prep

| Parameter | EPA Method | Result | Qual | XQ | Units | MDL | PQL | Date | Analyst |
|---|---|---|---|---|---|---|---|---|---|
| Total Recoverable Digestion | M200.2 ICP | | | | | | | 02/09/04 15:28 | scp |
| Total Recoverable Digestion | M200.2 ICP-MS | | | | | | | 02/13/04 9:22 | gjl |

A C Z **Laboratories, Inc.**
*2773 Downhill Drive Steamboat Springs, CO 80487(800) 334-5493*

**Inorganic Analytical Results**

**Water Remediation Technology, LLC**
Project ID: TEXAS
Sample ID: TREATED

ACZ Sample ID: ***L44506-10***
Date Sampled: *02/02/04 14:56*
Date Received: *02/04/04*
Sample Matrix: *Drinking Water*

Wet Chemistry

| Parameter | EPA Method | Result | Qual | XQ | Units | MDL | PQL | Date | Analyst |
|---|---|---|---|---|---|---|---|---|---|
| Alkalinity as CaCO3 | SM2320B - Titration | | | | | | | | |
| Bicarbonate as CaCO3 | | 302 | | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Carbonate as CaCO3 | | | U | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Hydroxide as CaCO3 | | | U | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Total Alkalinity | | 302 | | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Cation-Anion Balance | Calculation | | | | | | | | |
| Cation-Anion Balance | | -4.5 | | | % | | | 02/23/04 0:00 | calc |
| Sum of Anions | | 8.2 | | | meq/L | 0.1 | 0.5 | 02/23/04 0:00 | calc |
| Sum of Cations | | 7.5 | | | meq/L | 0.1 | 0.5 | 02/23/04 0:00 | calc |
| Chloride | M325.2 - Colorimetric | 33 | | | mg/L | 1 | 5 | 02/11/04 17:12 | kmc |
| Fluoride | SM4500F-C | 0.7 | | | mg/L | 0.1 | 0.5 | 02/14/04 19:35 | mah |
| Hardness as CaCO3 | SM2340B - Calculation | 284 | | | mg/L | 1 | 7 | 02/23/04 0:00 | calc |
| Lab Filtration & Acidification | SM 3030 B | | | | | | | 02/07/04 15:41 | mah |
| Residue, Filterable (TDS) @180C | SM2540C - Gravimetric | 410 | | | mg/L | 10 | 20 | 02/07/04 13:40 | mah |
| Sulfate | M375.3 - Gravimetric | 60 | | | mg/L | 10 | 50 | 02/19/04 11:45 | jjc |
| TDS (calculated) | Calculation | 408 | | | mg/L | 10 | 50 | 02/23/04 0:00 | calc |
| TDS (ratio - measured/calculated) | Calculation | 1.00 | | | | | | 02/23/04 0:00 | calc |

A C Z **Laboratories, Inc.**
*2773 Downhill Drive Steamboat Springs, CO 80487(800) 334-5493*

**Inorganic Analytical Results**

**Water Remediation Technology, LLC**
Project ID: TEXAS
Sample ID: RAW

ACZ Sample ID: ***L44506-11***
Date Sampled: *02/02/04 15:00*
Date Received: *02/04/04*
Sample Matrix: *Drinking Water*

Metals Analysis

| Parameter | EPA Method | Result | Qual | XQ | Units | MDL | PQL | Date | Analyst |
|---|---|---|---|---|---|---|---|---|---|
| Antimony, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0002 | 0.001 | 02/13/04 22:06 | jb |
| Arsenic, total recoverable | M200.8 ICP-MS | 0.0010 | | | mg/L | 0.0001 | 0.0005 | 02/14/04 14:56 | jb |
| Barium, total recoverable | M200.8 ICP-MS | 0.0625 | | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:06 | jb |
| Beryllium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:06 | jb |
| Cadmium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:06 | jb |
| Calcium, dissolved | M200.7 ICP | 54.1 | | * | mg/L | 0.2 | 1 | 02/11/04 23:41 | wfg |
| Chromium, total recoverable | M200.8 ICP-MS | 0.0003 | B | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:06 | jb |
| Copper, total recoverable | M200.8 ICP-MS | 0.0410 | | | mg/L | 0.0005 | 0.003 | 02/13/04 22:06 | jb |
| Iron, total recoverable | M200.7 ICP | 0.50 | | | mg/L | 0.01 | 0.05 | 02/11/04 18:00 | scp |
| Lead, total recoverable | M200.8 ICP-MS | 0.0052 | | | mg/L | 0.0001 | 0.0005 | 02/13/04 22:06 | jb |
| Magnesium, dissolved | M200.7 ICP | 49.3 | | * | mg/L | 0.2 | 1 | 02/11/04 23:41 | wfg |
| Manganese, total recoverable | M200.7 ICP | 0.015 | B | | mg/L | 0.005 | 0.03 | 02/11/04 18:00 | scp |
| Mercury, total recoverable | M245.1 CVAA | | U | | mg/L | 0.0002 | 0.001 | 02/16/04 13:12 | bnh |
| Potassium, dissolved | M200.7 ICP | 14.4 | | | mg/L | 0.3 | 1 | 02/13/04 22:30 | wfg |
| Selenium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 0.0001 | 0.0005 | 02/14/04 14:56 | jb |
| Sodium, dissolved | M200.7 ICP | 40.4 | | * | mg/L | 0.3 | 1 | 02/11/04 23:41 | wfg |
| Thallium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 5E-05 | 0.0003 | 02/14/04 14:56 | jb |
| Uranium, total recoverable | M200.8 ICP-MS | | U | | mg/L | 5E-05 | 0.0003 | 02/13/04 22:06 | jb |
| Zinc, total recoverable | M200.7 ICP | 0.03 | B | | mg/L | 0.01 | 0.05 | 02/11/04 18:00 | scp |

Metals Prep

| Parameter | EPA Method | Result | Qual | XQ | Units | MDL | PQL | Date | Analyst |
|---|---|---|---|---|---|---|---|---|---|
| Total Recoverable Digestion | M200.2 ICP | | | | | | | 02/09/04 15:31 | scp |
| Total Recoverable Digestion | M200.2 ICP-MS | | | | | | | 02/13/04 9:33 | gjl |



** Please refer to Extended Qualifier Report for detail*

A C Z **Laboratories, Inc.**
*2773 Downhill Drive Steamboat Springs, CO 80487(800) 334-5493*

**Inorganic Analytical Results**

**Water Remediation Technology, LLC**
Project ID: TEXAS
Sample ID: RAW

ACZ Sample ID: ***L44506-11***
Date Sampled: *02/02/04 15:00*
Date Received: *02/04/04*
Sample Matrix: *Drinking Water*

Wet Chemistry

| Parameter | EPA Method | Result | Qual | XQ | Units | MDL | PQL | Date | Analyst |
|---|---|---|---|---|---|---|---|---|---|
| Alkalinity as CaCO3 | SM2320B - Titration | | | | | | | | |
| Bicarbonate as CaCO3 | | 302 | | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Carbonate as CaCO3 | | | U | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Hydroxide as CaCO3 | | | U | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Total Alkalinity | | 302 | | | mg/L | 2 | 10 | 02/07/04 0:00 | jjc |
| Cation-Anion Balance | Calculation | | | | | | | | |
| Cation-Anion Balance | | 4.1 | | | % | | | 02/23/04 0:00 | calc |
| Sum of Anions | | 8.2 | | | meq/L | 0.1 | 0.5 | 02/23/04 0:00 | calc |
| Sum of Cations | | 8.9 | | | meq/L | 0.1 | 0.5 | 02/23/04 0:00 | calc |
| Chloride | M325.2 - Colorimetric | 32 | | | mg/L | 1 | 5 | 02/11/04 17:13 | kmc |
| Fluoride | SM4500F-C | 0.7 | | | mg/L | 0.1 | 0.5 | 02/14/04 19:37 | mah |
| Hardness as CaCO3 | SM2340B - Calculation | 338 | | | mg/L | 1 | 7 | 02/23/04 0:00 | calc |
| Lab Filtration & Acidification | SM 3030 B | | | | | | | 02/07/04 15:44 | mah |
| Residue, Filterable (TDS) @180C | SM2540C - Gravimetric | 410 | | | mg/L | 10 | 20 | 02/07/04 13:41 | mah |
| Sulfate | M375.3 - Gravimetric | 60 | | | mg/L | 10 | 50 | 02/19/04 11:46 | jjc |
| TDS (calculated) | Calculation | 432 | | | mg/L | 10 | 50 | 02/23/04 0:00 | calc |
| TDS (ratio - measured/calculated) | Calculation | 0.95 | | | | | | 02/23/04 0:00 | calc |



** Please refer to Extended Qualifier Report for detail*

Texas Water Development Board
RESEARCH GRANT
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Contract No. 2004-483-520

# APPENDIX D

# SCOPE OF WORK

Supplement Information for the Richland Special Utility District Research Grant
submitted by Ken Bull, RSUD Project Officer, December 16, 2003

In response to TWDB request, January 8, 2004, the following is provided.

8. *A description of the plans for implementing research results.*

The Radium Removal Pilot Study that is underway at the RSUD well site in McCulloch County is a test to determine the reliability and cost of radium removal techniques offered by Water Remediation Technology, LLC, Arvada, Colorado. The results of this Pilot Study will be available to all interested Water Service Systems that are being considered in violation of the EPA Safe Drinking Water Act. The Texas Commission on Environmental Quality (TCEQ) is requiring all such WSS to show plans to bring noncompliant systems into compliance. The treatment system proposed by WRT is one of several possible methods for removing radium from water. The results will also be available to TWDB, TCEQ and the Department of Health.

9. *A List of potential users and their possible involvement with the research.*

As stated above, the potential users are the many WSS in Texas that have the problem of radium content in the water above the Maximum Contaminant Levels (MCL) set by the EPA. This request for a Research Grant is to allow for ample testing during the Pilot Test to determine the reliabillity and cost of the treatment system. The WSS using water from the Hickory Aquifer are observers of this Pilot Study but are not financially committed to the study.

15. *A list of potential sources and amounts of funding available for implementation of research results.*

Whether or not the various WSS will use the WRT proposed system will be a decision to be made by each WSS as they access the results of this Pilot Study. It is not possible for RSUD to determine a list of potential users or their source of funds. The RSUD is not committed to permanently installing the WRT system until our Board reviews the results of this Pilot Study.

16 *Are you an individual member of the Texas Water Development Board, a Board staff member, or a member of their immediate families?*

No.

18 *A detailed scope of work describing tasks and a time schedule for each.*

The WRT Test Trailer contains eight cylinders (tubes) containing a proprietary media that they mine in Colorado. Water flows through these tubes so that samples of the water may be taken as water enters each tube. In this manner, samples taken periodically will show the quality of the water at the various points of treatment. The raw (untreated) water may be sampled prior to entrance into the treatment tubes. Samples of the water will be taken at the various treatment points and will be analyzed for radium content, gross alpha radiation, gross beta radiation, radon content and a complete inorganic analysis. The test in stages of treatment will allow interpretation of the reliability of the treatment process, loading of the media and inorganic analysis to ensure reliability of the radium removal process for potable purposes.

For purposes of testing, the water entering is RAW, exiting tube 1-C1, exiting tube 2-C2, and so forth for C3, C4,C5, C6, C7, and exiting tube 8 is TREATED.

Regarding the following schedule, RSUD and WRT reserve the right to alter this schedule as interim test results might warrant.

| | | |
|---|---|---|
| December 3, 2003 | Test Trailer in place and water flowing | |
| December 8, 2003 | Samples for radium, inorganic<br>RAW, C1,C2,C4,C6,TREATED<br>6 sets at $250 each | $1500.00 |
| December 23, 2003 | Samples for radium, inorganic<br>RAW, C1,C2,C4,C6,TREATED<br>6 sets at $250 each | $1500.00 |
| January 5, 2004 | Samples for radium, inorganic<br>RAW, C1,C2,C3,C4,C5,C6,C7,TREATED<br>9 sets at $250 each | $2250.00 |
| January 12, 2004 | Samples for radium, radon, gross alpha and beta<br>RAW, TREATED<br>2 at $250, 2 at $27.50, 2 at $35.00 | $ 625.00 |
| January 20, 2004 | Samples for radium, inorganic<br>RAW, C1,C2,C4,C6,TREATED<br>6 sets at $250 each | $1500.00 |
| February 2, 2004 | Samples for radium, inorganic<br>RAW, C1,C2,C3,C4,C5,C6,C7,TREATED<br>9 sets at $250 each | $2250.00 |
| February 9, 2004 | Samples for radium for TREATED<br>radon, gross alpha/beta for RAW, TREATED<br>1 at $250.00, 2 at $27.50, 2 at $35.00 | $ 375.00 |
| February 16, 2004 | Samples for radium, inorganic<br>RAW, C1,C2,C4,C6,TREATED<br>6 sets at $250 each | $1500.00 |
| March 1, 2004 | Samples for radium, inorganic<br>RAW, C1,C2,C3,C4,C5,C6,C7,TREATED<br>9 sets at $250 each | $2250.00 |
| March 1, 2004 | Samples for radium, radon, gross alpha and beta<br>RAW, TREATED<br>2 at $250, 2 at $27.50, 2 at $35.00 | $ 625.00 |
| | Shut down for two hours, restart<br>Samples for radium, radon, gross alpha and beta<br>RAW, TREATED<br>2 at $250, 2 at $27.50, 2 at $35.00 | $ 625.00 |
| March 5, 2004 | After shut down for three days, restart<br>Samples for radium, radon, gross alpha and beta<br>RAW, TREATED<br>2 at $250, 2 at $27.50, 2 at $35.00 | $ 625.00 |
| Estimated cost of freight for samples | | $ 500.00 |
| Estimated cost of chemicals | | $ 50.00 |
| | | $16,175.00 |

RSUD performs daily inspection and tests RAW and TREATED for chlorine
takes all samples, performs radiation measurements, escorts visitors

and reports to State Agencies
Estimated in-kind contribution $3,119.50

21 *A description* of suggested project monitoring procedures

The Pilot Test is being monitored by RSUD personnel with supervision by the Project Officer, Ken Bull. TCEQ and TWDB will be kept informed of ongoing test results including a summary of test data. Radiation safety is the responsibility of WRT but is being monitored by the RSUD Project Officer. The local Emergency Services Organization and Sheriff have been briefed on radiation safety procedures in case of accident.

The Pilot Study Test Plan has been reviewed by key personnel at TWDB, TCEQ and TDH.

III. *WRITTEN ASSURANCES*

*Proposed water research does not duplicate previously completed or on-going research:* This is the first and only scheduled Pilot Test of this radium removal technology in Texas. WRT has performed tests in other states with differing water quality and radium content.

*Implementation of research results identified through the proposed research will be diligently pursued and identification and involvement of potential users will be provided:* The removal of radium from potable water is a State of Texas water problem and the appropriate State Agencies will be kept informed of Pilot Test results. In addition, potential use of this technology by WSS in Texas will be a possibility.

*If a grant is awarded, written evidence that local matching funds and in-kind services, if applicable, are available for the proposed research must be provided when the contract is executed.*

This test is on-going and the RSUD is currently providing the in-kind effort reported in this application. There are no matching funds being proposed.

Texas Water Development Board
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APPENDIX E

TWDB EXECUTIVE ADMINISTRATOR COMMENTS

August 16, 2004

Mr. Ken Bull
Project Officer
Richland Special Utility District
151 PR 827
Rochelle, TX 76872

RE: Research Contract between the Texas Water Development Board (Board) and Richland Special Utility District (RSUD), TWDB Contract No. 2004-483-520, Draft Report Review

Dear Mr. Bull:

Staff members of the Texas Water Development Board have completed a review of the draft report under TWDB Contract No. 2004-483-520. The report submitted meets the objectives as stated in the scope of work, is informative and well written. The Board looks forward to receiving one (1) electronic copy, one (1) unbound single-sided camera-ready original, and nine (9) bound double-sided copies of the final report on this study.

If you have any questions about the Board's comments, please contact Radu Boghici, the Board's designated Contract Manager, at (512) 463-6543.

Sincerely,

William F. Mullican, III
Deputy Executive Administrator
Office of Planning

c: Radu Boghici, TWDB

Texas Water Development Board
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APPENDIX F

REPORT AUTHOR

## REPORT AUTHOR

This report was prepared by Ken Bull serving as the Richland Special Utility District Project Officer. Ken is a member of the Board of Directors of the RSUD and was appointed by Larry Cottrell, President of the Board, to serve as Project Officer for the Pilot Test of the Water Remediation Technology Radium Removal System

Ken holds a Masters Degree in Physics from Texas A&M University and a Masters Degree in Radiological Physics awarded jointly by the University of Texas at Arlington, Texas and the University of Texas Health Science Center at Dallas, Texas. He is a retired U.S. Air Force Lieutenant Colonel, having served twenty one years of active duty. A large part of his Air Force duty involved research of the physics of nuclear weapons. Ken has published several reports, some in RADIOLOGY and several classified reports for the Air Force.