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NATURAL RADIOACTIVITY IN GROUND WATER NEAR THE SAVANNAH RIVER SITE (U)

August 1990

Westinghouse Savannah River Company
Savannah River Laboratory
Aiken, South Carolina 29808

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by

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ABSTRACT

A study of natural radioactivity in groundwater on and adjacent to the Savannah River Site (SRS) in Aiken (S.C.) was conducted to determine the spatial and temporal variations in the concentration of specific radionuclides. All available measurements for gross alpha particle activity, gross beta activity, uranium, Ra-226, Ra-228, and radon were collated. Relatively few radionuclide-specific results were found. Twenty samples from drinking water supplies in the area were collected in October 1987 and analyzed for U-238, U-234, Ra-226, Ra-228, and Rn-222. The aquifer type for each public water supply system was determined, and statistical analyses were conducted to detect differences among aquifer types and geographic areas defined at the county level.

For samples from the public water wells and distribution systems on and adjacent to the site, most of the gross alpha particle activity could be attributed to Ra-226. All measurements of uranium were below the 0.1 pCi/L detection level. Thus, there was no need to analyze for additional alpha-emitting radionuclides. However, there was some evidence of a negative bias in the gross alpha particle measurements, possibly due to self-absorption in the high-iron groundwaters on the plant. For 5 out of 12 samples, the Ra-226 measurement for the October 1987 samples was higher than all available gross alpha particle activities, with some data going back to 1978. But significant temporal differences could also be a function of changes in the relative contribution of multiple wells. Temporal variations of 100 percent around the average value for both gross alpha particle activity and radium in multiple well systems were not uncommon. Levels of radium and radon among wells in a multiple-well system can vary by an order to magnitude. However, within an individual well, other research has shown that radium levels are relatively stable.

Aquifer type was an important factor in determining the level of radioactivity in groundwater. The igneous and metamorphic rock aquifers of the Piedmont had the highest levels of radon found in the study area. For all other measures of radioactivity, Piedmont crystalline rock aquifers produced groundwater with average concentrations. In contrast, the Tertiary sand aquifers had the highest gross alpha particle activities in the study area, with a distribution significantly different than the other aquifer types. For other radionuclide and aquifer type rankings, no statistically significant differences were detected. The distribution and geochemical factors affecting the distribution of each radionuclide for the different aquifer types are discussed in detail.

Statistical analyses were also run to test for aerial differences, among counties and the site. For all types of measurements, there were no differences in the distribution of radioactivity among the ten counties in the vicinity of the site or the site itself. The mean value for the plant was the lowest of all geographic areas for gross alpha particle activity and radon, intermediate for gross beta activity, and in the upper ranks for Ra-226 and Ra-228. It is concluded that the drinking water quality on-site is comparable with that in the vicinity.

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NATURAL RADIOACTIVITY IN GROUND WATER IN THE VICINITY OF THE SAVANNAH RIVER SITE

INTRODUCTION

As part of the routine monitoring of environmental quality at and around the Savannah River Site (SRS) in Aiken, South Carolina, public drinking water supplies onplant and offplant are analyzed for natural radionuclides. Following the analytical protocol specified by the U.S. Environmental Protection Agency (USEPA) in the interim regulations of 1976, the public drinking water supplies are sampled at the point of use and screened by determination of the gross alpha particle and gross beta activities. If the gross alpha particle activity exceeds 5 picocuries per liter (pCi/L), then the sample is tested for radium-226 (Ra-226). If the Ra-226 exceeds 3 pCi/L, then the sample is tested for Ra-228. If the gross beta activity exceeds 50 pCi/L, then the sample must be analyzed to determine which particular man-made radionuclides are present.

Current federal drinking water standards have set Maximum Contaminant Levels (MCLs) for gross alpha particle activity at 15 pCi/L (corrected for radon and uranium) and total radium at 5 pCi/L. The MCL for man-made radionuclides is a dose equivalent of 4 millirem per year. No violations nationwide have been reported for gross beta activity. Uranium and radon were excluded from the interim regulations because of uncertainties about their occurrence, toxicity, and routes of exposure. The gross alpha and beta particle activity standards were intended as screening devices only. A separate standard was set for radium because USEPA believed it to be the most radiotoxic of the radionuclides in drinking water (Cothern, 1987). New standards being developed for radon, uranium, and each isotope of radium are to be proposed in early 1988.

During review of the SRS monitoring data, the issue of how the radiological water quality in the vicinity of the plant compares with the regional water quality was raised. This issue is particularly important because the area around the plant has been shown to have high natural radioactivity. The Fall Line aquifers of the Atlantic Coastal Plain province have been identified as having elevated levels of natural radionuclides in ground water, particularly Ra-226 and Ra-228 (Michel and Cothern, 1986; Michel and Jordana, 1987). In Georgia, there are public water supplies in the inner Piedmont that have extremely elevated levels of gross alpha particle activity, uranium, and radium, with some values of uranium over 100 pCi/L (Cline et al., 1983).

The data from the SRS drinking water monitoring program consist only of gross alpha and beta particle activity because none of the values were high enough to trigger additional analyses. Although the gross alpha particle activities were all below drinking water standards, values up to 3.5 pCi/L were detected. It is important to identify which specific radionuclides are contributing to the gross alpha particle activity and if there are any patterns in their distribution. Therefore, this study was initiated to address the following radiological water-quality issues:

1. Definition of the regional radiological water quality in terms of the levels of natural radionuclides in ground water from major aquifers.
2. Analysis of the spatial and temporal trends in radiological water quality expected in the region.
3. Review of the existing radiological drinking water quality at SRS within the regional context.
4. Analysis of selected groundwater samples from public water supplies at SRS and the surrounding area to identify specific radionuclides contributing to the gross alpha particle activity.

This report is a summary of the study results. All the analytical data used are included in the appendix and also have been submitted in digital form for additional analysis as needed.

SOURCES OF WATER-QUALITY DATA

This study involved analysis of spatial and temporal variations in water quality at SRS, South Carolina, and Georgia, and therefore, numerous data sources were used. Each of these sources is described below.

State of South Carolina Monitoring Data

The S.C. Department of Health and Environmental Control (DHEC) has been monitoring radiological water quality in public drinking water supplies since 1976, following the USEPA screening protocols. Most of their results are for gross alpha and beta particle activity, with very few Ra-226, only a single measurement reported for Ra-228, and no radon or uranium measurements, as of mid-1987. Quarterly samples were collected from most supplies during 1978 or 1979 so that an annual average could be calculated, as required by USEPA, to determine compliance with the interim regulations set in 1976. Since 1979, DHEC has continued sampling and analysis every year or two for most supplies, but more frequently for supplies that showed elevated levels. DHEC data were collected for 63 systems located in the S.C. counties of Aiken, Allendale, Barnwell, and Bamberg (Fig. 1). This database provides a good basis for characterization of the temporal and spatial distribution of gross alpha and beta activities north and east of the Savannah River. These data are indicated by the abbreviation DHEC in the data appendix under Source of Data.

State of Georgia Monitoring Data

The Georgia Department of Natural Resources (GDNR) has the responsibility to monitor water quality in public drinking water supplies in Georgia. Sampling for radiological water quality was initiated in 1977, with the first round of compliance monitoring completed in 1978-1980. GDNR used the same sampling and analytical protocol as DHEC, except that instead of analyzing each quarterly sample separately, GDNR combined the samples into a single composite for analysis. Single analyses are conducted on selected samples. The only results available during this study were those compiled through June 1984. All available GDNR data for the counties of Burke, Columbia, McDuffie, Richmond, and Warren (Fig. 1) were used and consisted of 50 drinking water suppliers. In the study area, measurements of Ra-226 were available for 7 supplies, Ra-228 for 4 supplies, and uranium for 2 supplies. There were no available data on radon. These data are indicated by the abbreviation GDNR in the data appendix under Source of Data.

University of South Carolina Studies

During 1980, a detailed study of the distribution of Ra-226, Ra-228, and radon in public drinking water supplies in South Carolina utilizing ground water was conducted by the University of South Carolina (USC) Department of Geology (Michel et al., 1981; King et al., 1982). Ten of these samples were collected in the counties of interest around SRS. These results represent single, grab samples collected at the wellhead, not at the tap as in the state survey grab samples.

The different collection technique of the USC survey has two important impacts on the results. First, the results are representative only of the well sampled, not of the water quality of the distribution system which is usually a mixture of several wells. Second, by sampling at the well head, loss of radon by outgassing during transportation through the distribution system is

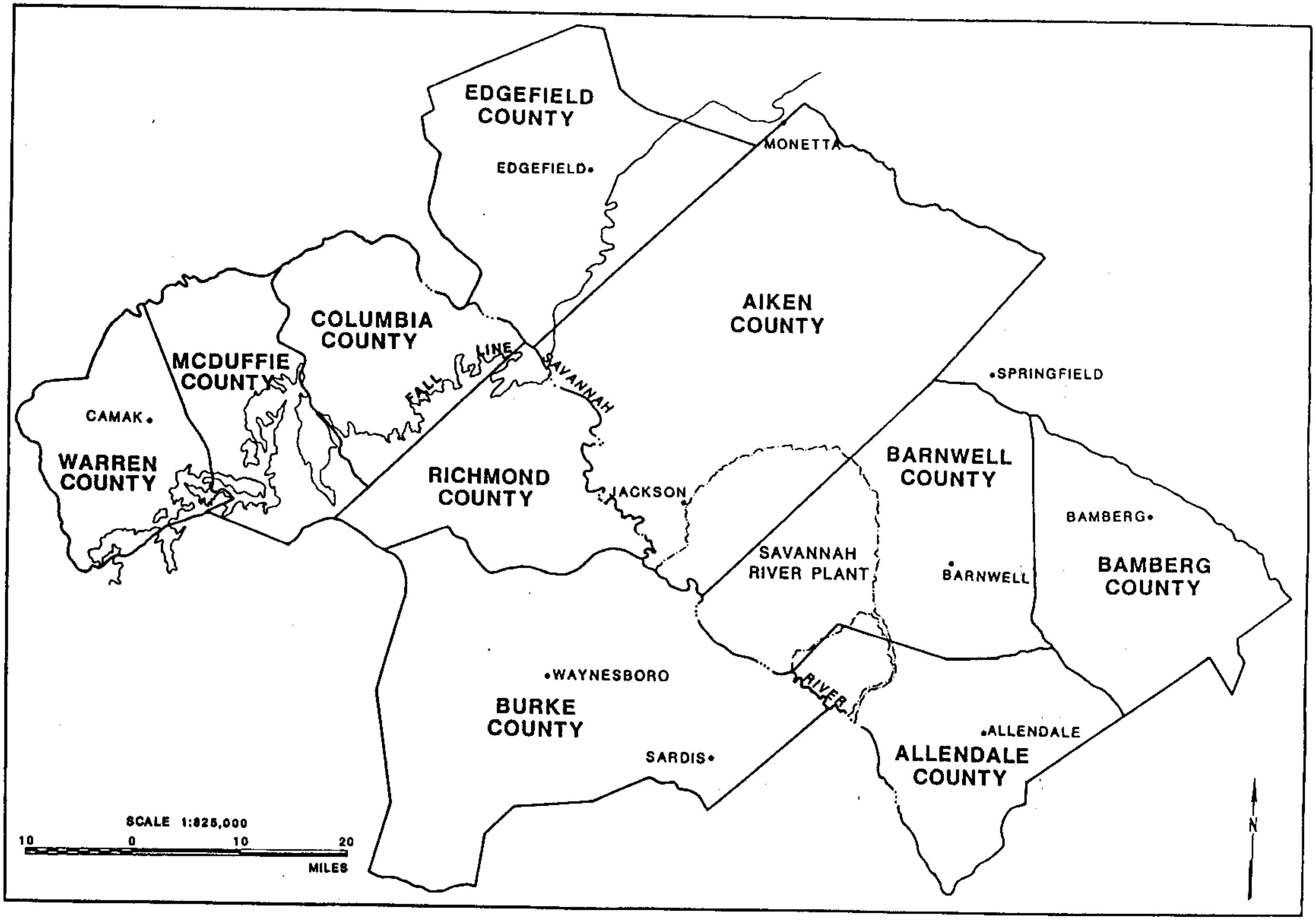

Figure 1. Location Map Showing the Counties in Georgia and South Carolina Included in This Study. Note the Position of the Fall Line, the Contact, the Piedmont and Coastal Plain Provinces.

prevented. Thus, the measurement is more representative of the radon content of the ground water and is likely to be higher than the radon levels at the user tap. These differences should be noted when comparing data sets. These data are indicated by the abbreviation USC in the data appendix under Source of Data.

USEPA Nationwide Study of Radon and Other Radioactivity

In 1980 and 1981, USEPA conducted a systematic study of the nationwide distribution of radon in drinking water supplies which utilize groundwater sources and serve more than 1,000 people (Horton, 1985). Single samples were collected from the distribution system with samples near the source of water preferred to minimize loss of radon. Samples were also collected for analysis of gross alpha particle and beta activity. If the gross alpha particle activity exceeded 3 pCi/L (instead of 5 pCi/L), Ra-226 and uranium analyses were performed. During the second half of the study, samples with gross beta activity greater than 15 pCi/L were analyzed also for Ra-228. This data set provided results for 17 supplies in South Carolina and 2 supplies in Georgia and is indicated by the abbreviation EPA under Source of Data.

USEPA National Inorganic and Radionuclide Survey (NIRS)

The NIRS database consists of 990 samples collected nationwide with every sample analyzed for gross alpha particle activity, gross beta activity, Ra-226, Ra-228, radon, and uranium. Samples were collected from the distribution system during 1985 and 1986. The NIRS database provided only one result for South Carolina, which is indicated by the abbreviation NIRS under Source of Data in the data appendix.

SRS Environmental Report for 1986

Natural radioactivity in drinking water at locations onplant and offplant is determined quarterly as part of the environmental monitoring program at SRS. Samples are collected at the tap and analyzed according to USEPA protocol. In 1986, 36 locations onplant and 14 towns around the plant were sampled, with 1-5 samples per location. The mean value was used, as indicated by SRS under Source of Data in the data appendix.

Current Study Samples for 1987

On 23 October, 1987, 20 samples were collected for analysis for Ra-226, Ra-228, and radon. Six samples were selected for uranium isotopic analysis. These samples were from 6 towns around the plant, sampled at the tap, and 14 locations onplant, sampled at both the tap and the well head. All analyses were conducted at the Department of Geological Sciences, USC. The radon samples were collected with evacuated flasks and analyzed using the emanation/Lucas cell scintillation method. Radium isotopes were concentrated from a large volume of water (15-20 L) on manganese-impregnated fibers, which were leached and the radium coprecipitated with barium sulfate. After storing the samples for about 30 days to allow progeny ingrowth, they were counted by gamma-ray spectroscopy. Both radium isotopes were determined simultaneously. With this method, it is possible to detect the presence of any Th-228 as well. Uranium was coprecipitated with iron, separated by cation exchange, and measured by alpha spectroscopy. The results are indicated by the abbreviation RPI under Source of Data in the data appendix.

DISCUSSION OF RESULTS

ANALYTICAL RESULTS

The analytical results for samples collected in October 1987 are shown in Table 1, along with the range in gross alpha particle activity during 1987 as reported by SRS. The first 14 samples are from various locations on-plant, collected from the distribution system as named or at the wellhead when the well identification is listed. It should be noted that each location has its own wells and distribution system. Six samples were collected from selected towns around the plant, all in South Carolina. Analytical and counting uncertainties for all radionuclides are less than 10 percent.

The highest Ra-226 activities on-plant were at F Area, Firing Range, and Forestry Building, all above 2.0 pCi/L. The only town greater than 2.0 pCi/L was Jackson, with 2.6 pCi/L. H Area had the highest Ra-228 with 4.4 pCi/L, followed by Firing Range and F Area. Jackson again had the highest Ra-228 among the towns sampled. Four on-plant supplies and 3 towns had below detection levels (<1.0 pCi/L) for both radium isotopes: Gate 7, Gate 8, K Area, and Par Pond lab; Springfield, Wagener, and Barnwell.

All three wells and the distribution system in H Area were sampled, and the results for Ra-226 are nearly identical. Ra-228 values range more widely, but the system measurement is within analytical uncertainty of the highest well and the Ra-228/Ra-226 activity ratio for the system matches the highest well. Comparison of the Ra-228 results for the distribution system and two wells in F Area suggests that the distribution system value is low. Both wells have Ra-228/Ra-226 activity ratios greater than unity (1.0 and 2.1), yet the distribution system ratio is 0.5. Ra-228/Ra-226 activity ratios at the other locations ranged from 0.5 to 1.2.

Rn-222 concentrations varied widely, from 2-133 pCi/L, with Par Pond lab having the highest value. The town with the highest radon was Jackson, with 73 pCi/L. The uranium content of all samples was below the detection level of 0.1 pCi/L.

The gamma-ray spectra of all 20 samples were scanned for the presence of other radionuclides, particularly Th-228. The sample for well 905-80-H had a small number of counts in the Th-228 peak range, but the activity was well below detection levels. No other unusual peaks were observed.

Variations in Gross Alpha Particle Activity

The gross alpha and beta activities onplant are very low, well below levels of regulatory concern for individual samples as well as annual averages. However, one of the problems with the gross alpha particle activity screen is that no information is provided as to what specific radionuclides are present and contributing to the alpha activity. Table 1 shows the range in gross alpha particle activity as measured by SRS in 1987 for the same locations analyzed for specific radionuclides. In most cases, the gross alpha particle activity is accounted for by Ra-226; the exceptions are very close and always within the range. Therefore, further analysis for other alpha-emitting radionuclides in the drinking water at SRS was not conducted.

For most samples measured, the Ra-226 was larger than the highest 1987 gross alpha particle activity measured, which is not surprising because the gross alpha method has a high counting uncertainty and can have a negative bias due to self-absorption in samples with high dissolved solids. The high iron content of SRS drinking water could cause some self-adsorption problems with this measurement technique.

Table 1. Results for October 1987 Sampling of SRS and Vicinity Systems with Gross Alpha for 1987 (all in pCi/L)

System	Ra-226	Ra-228	Rn-222	Uranium	Gross Alpha Range
F Area	2.8	1.3	15	-	0.2-3.4
Well 101-F	1.1	2.3	15	-	
Well 79-F	2.9	3.0	15	-	
Forestry Building	2.2	1.1	5	<0.1	0.2-1.3
Gate 7	<1.0	<1.0	69	-	0.0-0.1
Gate 8	<1.0	<1.0	51	-	
H Area	1.9	4.4	19	<0.1	0.1-1.1
Well 905-66-H	1.6	2.6	13	-	
Well 905-80-H	1.7	3.6	12	-	
Well 905-88-H	1.8	2.9	12	-	
K Area	<1.0	<1.0	2	-	0.1-0.4
Par Pond Lab	<1.0	<1.0	133	<0.1	0.0-0.0
Firing Range	2.7	1.9	24	-	0.0-2.2
TC	1.0	<1.0	39	-	0.7-1.6
Springfield	<1.0	<1.0	50	-	
Barnwell	<1.0	<1.0	14	-	0.2-0.3
Williston	1.5	1.2	26	<0.1	0.1-0.9
Jackson	2.6	3.1	73	<0.1	0.3-2.3
Wagener	<1.0	<1.0	21	-	
New Ellenton	<1.0	1.1	23	-	0.3-2.1

Comparison of samples taken at different times can be further complicated by the variation in the relative contribution of multiple wells. Figure 2 is a plot of the gross alpha particle activity as measured at the towns of Aiken and Monetta since 1977, using all sources of data. For both towns, there is about a 100 percent variation around the mean value, which is not unusual at these low activities. Figure 3 is a plot of Ra-228 and Rn-222 versus Ra-226 for the 8 individual wells in the Monetta system. The concentrations of all 3 radionuclides varies by an order of magnitude among the wells, with 2 wells producing relatively high concentrations. Within an individual well, Michel and Moore (1980) showed that the Ra-226 and Ra-228 content was stable over time, for periods up to several years. Variations in monitoring results over time are mostly due to variations in the relative contributions of multiple wells or to analytical problems.

Care should be taken when evaluating samples taken over time from a distribution system fed by multiple wells. The analytical results may range widely because of different well pumping schedules between sampling or restricted distribution of water from individual wells to part of the system. USEPA requires the collection of four quarterly samples to determine compliance because of these temporal and spatial variations in a system's water quality.

There also can be significant analytical differences among laboratories which contribute to the measured variation in gross alpha particle activity shown on Figure 2. A single laboratory is usually consistent in its analysis, but comparison of results among laboratories analyzing the same samples shows wide differences. All laboratories should participate in the USEPA Radioactivity in Water Cross-Check Program and track their performance to detect systematic errors in precision. There is surprisingly good correlation among the many sources of gross alpha data in the appendix. All laboratories reported data in similar ranges.

The analytical precision of the technique usually improves at higher concentrations, and the wide variations observed over time are more likely due to variations in the source contribution. Figure 4 is a plot of gross alpha particle activity over time for the town of Perry (open circles). The wide range is probably due to the multiple well system rather than lack of analytical accuracy. Since Ra-226 data are available also, this conclusion can be tested by correlation of the fluctuations in Ra-226. Most of the time, Ra-226 fluctuations match the gross alpha fluctuations, so the variation over time at Perry is due to variations in the source contribution. Each well should be sampled in this case because the levels are so high. For most systems, however, the expected range of activities should be determined over time, and unusual values can then be considered due to analytical problems.

Data for the town of Jackson provide a good example of how complicated this analysis can be. Figure 5 shows all the available gross alpha data for Jackson since 1978. The long-term average is about 1.5 pCi/L, with a usual high of about 3 pCi/L. The single, very high measurement of 16 pCi/L in 1982 was not corroborated by later analysis and probably was discarded as an analytical problem. There are 4 available Ra-226 analyses as follows: 1.6 pCi/L for the distribution system sample that had the high gross alpha reading; wellhead samples collected in 1980 which contained 17.1 and 2.2 pCi/L; and a distribution system sample with 2.6 pCi/L in 1987.

What do these data mean? It is possible that samples are usually taken from the same general location or part of the distribution system, except for one time in August 1981. Did the sample change between the high gross alpha measurement and the subsequent Ra-226 analysis, causing the Ra-226 to be removed from solution? There is obviously a well in Jackson with very high Ra-226 and Ra-228. Is it still in service? Is it used only occasionally when water demand is very high (perhaps in August 1981)? The sample collected in October 1987 for this study was above the total radium MCL of 5 pCi/L, yet no previous monitoring data indicated noncompliance. The wide spatial variability in concentration requires detailed review of all possible sources in multiple well systems.

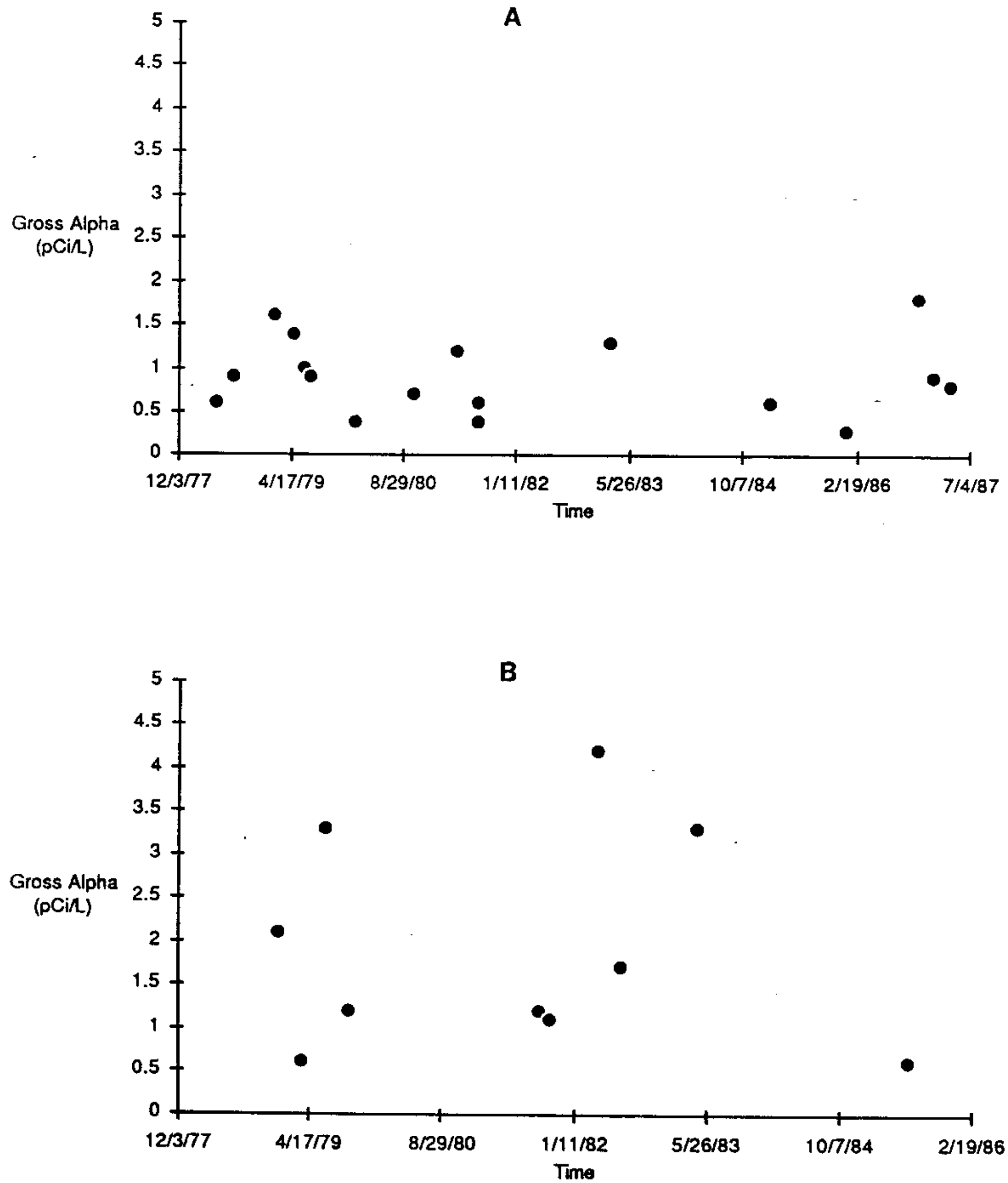

Figure 2. Plots of Gross Alpha Particle Activity Over Time in the Aiken (A) and Monetta (B) Water Supplies.

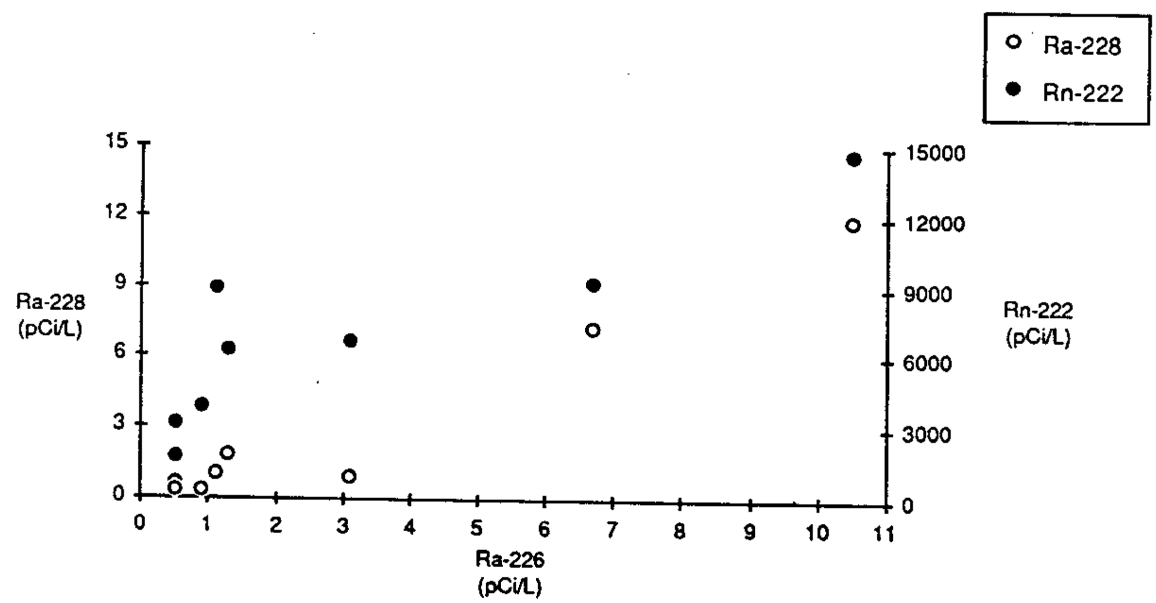

Figure 3. Comparison of the Ra-228 and Rn-222 versus Ra-226 in the 8 Individual Wells in Monetta, South Carolina, Based on Samples Collected in 1980.

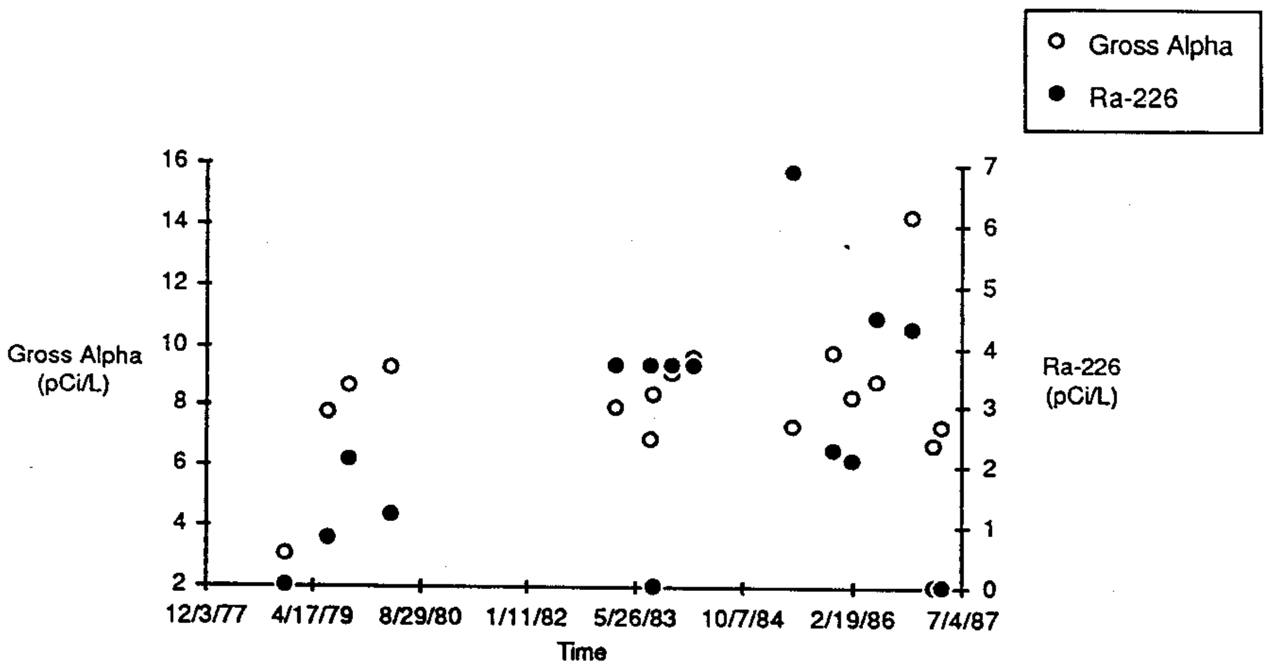

Figure 4. Plot of Gross Alpha and Ra-226 Over Time for the Perry, South Carolina, Water Supply.

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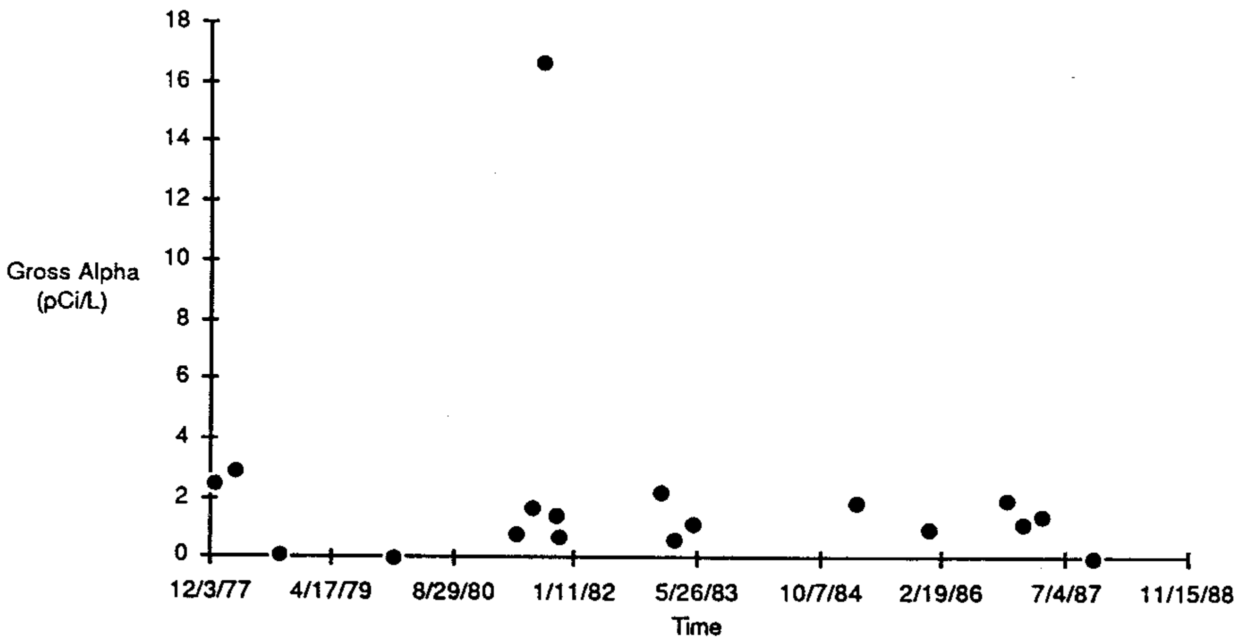

Figure 5. Plot of Gross Alpha Activity Over Time for the Jackson, South Carolina, Water Supply.

GEOCHEMISTRY OF NATURAL RADIONUCLIDES IN GROUND WATER

There are both geochemical and radiochemical properties of each radionuclide that greatly affect its occurrence and behavior in ground water. These properties are summarized below for the conditions expected to occur in southeastern aquifers.

URANIUM

Uranium has two oxidation states, +4 and +6. In the +4 oxidation state, uranium is not soluble nor does it form soluble complexes. In contrast, when oxidized to the +6 oxidation state, it forms readily soluble complexes, most importantly with carbonate anions. These complexes can be quite stable, and uranium can be transported long distances in ground water. Uranium, however, is removed rapidly from solution when reducing conditions are encountered.

In aquifers without strong reducing agents, coprecipitation and sorption onto clays can affect the groundwater solubilities of uranium. Both these processes are driven by the reactivity of iron hydroxides which are strong scavengers of uranium. Iron is such a good scavenger that, to concentrate uranium from a large water sample, a common analytical approach is to bubble an acidified sample with helium to remove the carbonate, add iron, and raise the pH to precipitate iron hydroxide and nearly 100 percent of the uranium. In the oxidized region of the Coastal Plain aquifers, iron plays an important role in mediating uranium in ground water.

Another important process affecting uranium solubility is known as alpha recoil. During alpha decay of a parent radionuclide, the alpha particle is ejected from the nucleus with so much energy that the progeny is recoiled in the opposite direction (much like the kick of a gun when a bullet is fired). This recoil energy is great enough to break chemical bonds and physically move the atom. If the atom is located near a fracture or pore, it actually can be "recoiled" into the pore space, greatly increasing its likelihood of dissolution. Because of this alpha-recoil process, progeny within the same decay series usually have higher activities in ground water, notwithstanding chemical differences. Thus, U-234/U-238 activity ratios in ground water are usually greater than unity and in the range of 1.2-2.0, although activity ratios as great as 10-15 are not uncommon for very low concentrations (Osmond and Cowart, 1976).

Uranium can occur in ground water in concentrations greater than 100 pCi/L, although normal concentrations are usually less than 1 pCi/L (1 pCi/L of uranium is about equal to 0.7 ppb). In a study of the National Uranium Resource Evaluation (NURE) data from public groundwater supplies, the U.S. population-weighted average uranium concentration was estimated to be 0.8 pCi/L; in South Carolina, it was 0.2 pCi/L; and in Georgia, it was <0.1 pCi/L (Drury et al., 1981). Uranium in drinking water is not considered to be of concern in the Southeast (Hess et al., 1985).

Because of its very long half-life, the chemical toxicity of uranium is about equal to its radioactive toxicity. USEPA is considering regulating uranium around the 10 pCi/L level, which represents an estimated lifetime risk level of about 10^{-5} (Cothern, 1987).

RADIUM

Radium itself is not soluble, and it does not form any soluble complexes that enhance its dissolution into ground water. Even though radium has such limited solubility, it is the radionuclide of greatest human-health concern because it is a bone seeker. The estimated lifetime risk of developing cancer from exposure to total radium of 5 pCi/L is about 10^{-5} (Cothern, 1987).

At the drinking water limit of 5 pCi/L, the mass equivalents are quite low; Ra-226 is on the order of 10^{-6} ppm, and Ra-228 is about 10^{-8} ppm.

The most important factor affecting radium levels in ground water is the distribution of the parent isotope. And because each radium isotope comes from separate decay series headed by very different elements, there are very important differences.

Ra-226 is part of the U-238 decay series. Because uranium can be transported by ground water over long distances, its occurrence can be influenced significantly by secondary processes. As a result, Ra-226 can be found over a wide range of aquifer types. Ra-226 is more likely to occur at very elevated levels because its parent uranium can be concentrated into secondary deposits by ground water. Ra-226 is also the third alpha-recoiled progeny in the decay series, making it more susceptible to dissolution.

In contrast, Ra-228 is part of the Th-232 decay series, and it is the direct progeny of Th-232. Thorium is extremely insoluble and is not subject to mobilization by ground water. As a result, Ra-228 is directly controlled by the distribution of thorium in the aquifer solids. Where there has been no secondary enrichment of uranium, Ra-228 is generally the dominant radium isotope in solution, primarily due to the higher natural abundance of thorium over uranium. In a study of S.C. ground water by King et al. (1980), the average Ra-228/Ra-226 activity ratio was 1.3. Ground waters with Ra-226 higher than Ra-228 are usually indicative of areas where uranium has been enriched. Ra-228 is subject to only one alpha-recoil event, further limiting its solubility.

Another important difference affecting the groundwater levels of Ra-226 versus Ra-228 is a function of their half-lives (5.7 years for Ra-228 versus 10,000 years for Ra-226). For example, under conditions where groundwater flow averaged 0.3 meters (m) per day, Ra-228 would decay to half its original concentration within a distance of about 500 m. It would decay to essentially zero in about 20 years (5 half-lives), which represents a distance less than a few kilometers. Thus, Ra-228 transport is extremely limited in normal groundwater settings, and it does not accumulate in ground water over long distances. The Ra-228 measured in a well-water sample was dissolved from the aquifer solids a relatively short distance from the well.

One important consequence of the significant difference in the solubility of the parent isotopes of Ra-226 versus Ra-228 is that uranium could be preferentially leached from an aquifer, leaving thorium behind. Consequently, the gross alpha and Ra-226 would be low, and analysis for Ra-228 would never be triggered. King et al. (1982) attempted to predict the percentage of groundwater supplies which contain total radium in excess of 5 pCi/L in the Atlantic and Gulf Coastal Plain and Appalachian Provinces aquifers yet had Ra-226 values less than 3 pCi/L. Using the S.C. database, they calculated that roughly 40-50 percent of the groundwater wells with total radium in excess of 5 pCi/L may be overlooked in these 2 geologic provinces with the current screening methods. This estimate may be somewhat high because of the limited database, but their results pointed out the need to decouple Ra-228 from Ra-226 in certain geological provinces. In fact, in the revised drinking-water regulations, USEPA is considering separate analysis of Ra-228.

RADON

Because radon is a noble gas with no chemical reactivity, its concentration in ground water is a function of the concentration and distribution of its parent in the aquifer solids, the nature of the aquifer solids, and its half-life (3.8 days). Alpha recoil is a very important mechanism for radon transfer from solids into ground water. It is subject to direct recoil from the grain surface, as are all progeny, such as Ra-226. However, Rn-222/Ra-226 activity ratios are frequently 100 to 1,000, indicating that there are other, more important mechanisms.

As a noble gas, radon can migrate by diffusion. Numerous studies have been conducted to determine diffusion coefficients under various conditions of moisture, grain size, and rock type. These studies support the conclusion that a major part of the radon in ground water comes by alpha recoil from within the grains, not only from the outer surface. Most solids actually are riddled with tiny fractures, and radon can diffuse out of the solid, be it a sand grain or piece of granite, along these fractures into the intergranular pore space where it can move by advection. It is because these fractures greatly increase the surface area which generates direct-recoil atoms that there is so much unsupported Rn-222 in ground water. Crystalline rocks, such as granites, which have relatively high uranium content and a very large rock-to-water ratio, have consistently very high Rn-222 levels. In contrast, clean, unconsolidated sand aquifers, with up to 30 percent porosity, generally have very low Rn-222.

Once in solution, groundwater flow is the dominant mechanism by which radon is transported in aquifers. The limiting factor in the transport length of radon in ground water is its half-life. In 30 days, the radon content of ground water will be less than 1 percent of its original activity. Thus, radon in ground water is a very near field phenomenon and can be highly variable.

Radon is of health concern primarily because of inhalation of its short-lived progeny. There are three progeny with half-lives on the order of minutes or less. They sort onto particles and are inhaled, resulting in increased risk of lung cancer. The estimated lifetime risk from exposure to 1,000 pCi/L Rn-222 is about 10^{-4} (Cothern, 1987).

DISCUSSION OF RESULTS BY MAJOR AQUIFER TYPE

INTRODUCTION

The distribution of natural radioactivity in ground water is directly controlled by aquifer type. In fact, in many cases the relative concentrations of different radionuclides in a sample can be used to determine the source aquifer being utilized. In this study, four major aquifers were sampled and studied: the rock aquifers of the Piedmont Province, the unconsolidated Cretaceous sand aquifer, the unconsolidated Tertiary sand aquifer, and the Tertiary limestone aquifer. Although there is some overlap in the geographical usage of these aquifers, particularly in the middle Coastal Plain, there was usually enough information from geological logs of the public water-supply wells to determine the source aquifer for each supply. The cross-sections published in Colquhoun et al. (1983) were used to determine the source aquifer in the Coastal Plain when only the depths of screened intervals were identified. Aquifer selections were verified by comparisons with data published by federal and state water resource agencies and discussion with state hydrogeologists. Where possible, attempts were made to differentiate among the various bedrock types for wells in the Piedmont in the discussion of results but not in the statistical analysis because of the limited number of samples for each rock type. Whenever there was any uncertainty as to the source aquifer, the public water supply was not used in the aquifer-type analysis. Usually, it was the very small systems, serving trailer parks and small subdivisions, for which the aquifer type could not be determined.

Several analytical techniques were used to compare the distribution of radionuclides in the different aquifer types. In addition to analysis of the means and ranges of natural radioactivity, its distribution in each aquifer was compared using the General Linear Model Analysis and the Bonferroni T test. In this statistical analysis technique, the distribution patterns for each measure of radioactivity are classified into groups of similarity and ranked by their means. Table 2 is a summary of these groupings and rankings for the entire database in the appendix, consisting of 113 public water-supply systems offsite and the 14 samples collected onsite.

Table 2. Results of the General Linear Model Analysis Showing the Rank and Groupings of Radioactivity in Various Aquifers in the Vicinity of SRS

Grouping		Mean	Aquifer
Gross Alpha Particle Activity (pCi/L)			
	A	2.9	Tertiary Sand
	B	2.0	Piedmont
C	B	1.4	Cretaceous Sand
C		0.9	Tertiary Limestone
Gross Beta Activity (pCi/L)			
	A	4.8	Tertiary Limestone
	A	4.8	Piedmont
B	A	3.6	Tertiary Sand
B		2.7	Cretaceous Sand
Ra-226 (pCi/L)			
	A	2.2	Tertiary Sand
	A	1.9	Piedmont
	A	1.7	Cretaceous Sand
Ra-228 (pCi/L)			
	A	1.7	Cretaceous Sand
	A	1.3	Piedmont
	A	0.9	Tertiary Sand
Rn-222 (pCi/L)			
	A	3,165	Piedmont
	B	161	Tertiary Sand
	B	150	Tertiary Limestone
	B	143	Cretaceous Sand

Under the heading "Grouping" are a series of letters which are used to identify subsets of a group that are statistically indistinguishable from other elements of the same group. So, when all aquifers are identified with the same letter, there is no statistically significant difference in the distribution of that radionuclide among the aquifers. A different letter is used to identify different groups. However, groupings that overlap, such as for gross beta activity, indicate that the particular individual groups are not unique. Fully separated groups, such as shown for Rn-222, indicate the class of aquifers in group B has significantly lower Rn-222 than the Piedmont aquifer in group A. The rankings, though not always statistically significant, are helpful in discerning trends.

In the following sections, the distribution of natural radioactivity in the four major aquifers around SRS (Piedmont, Cretaceous sand, Tertiary sand, and limestone) is discussed.

PIEDMONT AQUIFERS

Introduction

The Piedmont region in the vicinity of SRS is composed of a wide range of igneous and metamorphic rock types, none of which are very productive aquifers. Well yields can be sufficient for small systems which prefer ground water over the difficulty and expense of operating a surface-water treatment facility. Nearly all domestic water users in the Piedmont region rely upon private wells.

The geology of the Piedmont is very complex, consisting of metasedimentary, metavolcanic, gneissic, and granitic rocks with varying degrees of deformation. Two basic rock types are present in the eastern Piedmont near SRS: the volcaniclastic rocks metamorphosed to greenschist facies of the Belair belt, and the high-grade metamorphic gneisses of the Kiokee belt (Prowell, 1978). There are scattered granitic intrusions that have also undergone various degrees of metamorphism, including the Clouds Creek granite near Leesville, the Edgefield granite near Monetta, and the Appling pluton and Sparta complex in eastern Georgia (Snoke, 1978).

Even though the Piedmont region includes a wide range of rock types with a very complex geological history, hydrogeologists often classify the entire Piedmont as a major groundwater flow system in which flow and head are controlled largely by topography (Beddinger and Sargent, 1981). Because all of the Piedmont rocks have been metamorphosed to some degree, they are considered crystalline rocks as opposed to the original sedimentary deposits. There has been both extensive and local mineral recrystallization, such as in the Monazite Belt of the middle Piedmont and around granitic intrusions.

In crystalline rocks, water flows primarily through fractures and joints in the rock instead of through pores and around individual grains. As a result, ground water flowing through rock aquifers comes in contact with a very small percentage of the rock mass in the aquifer. However, weathering and geochemical reactions also are concentrated along these more permeable zones, and secondary mineralization frequently occurs in fractures and joints. Thus, the radiological water quality of Piedmont aquifers is a function of both the mineralogical composition of the rock and secondary mineralization processes, such as hydrothermal fluid intrusion and groundwater reduction zones.

Radiological Water Quality

Introduction—In national comparisons of the levels of natural radioactivity in ground water, the Piedmont is an area known to have very elevated Rn-222, elevated Ra-228 and Ra-226, and relatively low uranium (Hess et al., 1985). However, the actual measurements at specific locations can vary widely, even among wells within a single system. The town of Monetta, South Carolina, uses 8 wells drilled in granite to about the same depth within an area of about a square kilometer (km). The concentration varies over an order of magnitude among these wells for all three radionuclides in a relatively linear fashion (Fig. 3), reflecting a similar distribution for the parent uranium and thorium. Piedmont systems are particularly susceptible to this kind of variation because they frequently need many wells to provide the volume of water needed to meet demand.

Gross Alpha Particle Activity—The mean gross alpha particle activity for the 10 Piedmont systems used in this study was 2.0 pCi/L (Table 2), significantly different only from the Tertiary sand aquifer in the vicinity of SRS. This mean excludes data from well #1 in Camak, Georgia, which has levels of 126-149 pCi/L, mostly attributable to uranium. The primary purpose of the gross alpha measurement is as a less costly screen for detecting Ra-226 violations. Thus, to determine compliance, uranium and radon are subtracted from the gross alpha activity. No other ground water systems in the Piedmont were above the 5 pCi/L level, which triggers additional analysis to determine the specific radionuclides contributing to the activity.

Gross Beta Particle Activity—Gross beta activity in Piedmont systems averaged 4.8 pCi/L, slightly above the Tertiary and Cretaceous sand aquifers and equal to the Limestone aquifer. The gross beta activity also is a screen for identifying those water systems that may be contaminated by man-made radionuclides. With an MCL of 50 pCi/L, there have not been any violations reported throughout South Carolina or Georgia.

Ra-226—Ra-226 levels in the public water systems around SRS found in the 5 systems located in the Piedmont region averaged 1.9 pCi/L (Table 2). Metasedimentary rock aquifers (with a mean of 0.7 pCi/L) were the source of water in all systems except for Monetta which uses granite (with 3.1 pCi/L). These results are similar to the mean Ra-226 levels found in different aquifer types in the Piedmont in a study by Michel and Pollman (1982), shown in Table 3. Using a much larger database of 75 systems located throughout the Georgia, South Carolina, and North Carolina Piedmont, ground water from metamorphic rock aquifers were found to have a Ra-226 range of 0.0-7.4 pCi/L and a geometric mean of 0.4 pCi/L. Amazingly, the distribution of both Ra-226 and Ra-228 was independent of original rock type. The only difference among the metamorphic rock aquifers was for the low-grade metamorphosed rocks, which had the highest Ra-226 levels, with 1.4 pCi/L, and Ra-228 of 0.3 pCi/L. It appears that increasing metamorphism tends to redistribute uranium and thorium into resistant minerals, reducing the amount of radium that dissolves into ground water. This relationship of decreasing radium levels in ground water with increasing metamorphism excludes areas with localized uranium and thorium mineralization such as from hydrothermal fluids.

In contrast, granitic rock aquifers produce ground water with high Ra-226 levels throughout the Piedmont region, ranging from 0.0-15.9 pCi/L with a mean of 1.8 pCi/L for 42 systems (Table 3). The values for the system in Monetta, the only system known to have wells in granite in the study area, fall within the usual range.

Ra-228—The distribution of Ra-228 in Piedmont wells is similar to Ra-226, with a slightly lower geometric mean for the different aquifer types. Based on the regional study by Michel and Pollman (1982), Ra-228 in metamorphic rock aquifers ranged from 0.0 to 3.9 pCi/L, with a mean of 0.3 pCi/L, and in granitic aquifers ranged from 0.0 to 22.6 pCi/L, with a mean of 1.4 pCi/L (Table 3). Within the limited area of the current study, Ra-228 measurements were available for only four Piedmont systems: Monetta, Camak, Grovetown, and Martinez. The average Ra-228 content of these systems was 1.3 pCi/L, and there was no difference among the different aquifers (Table 2). Since these supplies were tested only after first exceeding the gross alpha and then the Ra-226 screens, these values may not be representative of the usual range of Ra-228 in ground water from the Piedmont, even though they fall within the range of values in Table 3.

Table 3. Summary of Ra-228 and Ra-226 Distribution in Ground Water by Aquifer Type for the Atlantic Coastal Plain and Piedmont Provinces. All Values in pCi/L. Modified from Hess et al. (1985). Number of Samples (No.) Represents Individual Wells or Systems.

		Ra-128		Ra-226	
Aquifer Type	Number	Geometric Mean	Range	Geometric Mean	Range
Granitic	42	1.4	0.0 - 22.6	1.8	0.0 - 15.9
Metamorphic	75	0.3	0.0 - 3.9	0.4	0.0 - 7.4
Sand	143	1.0	0.0 - 17.6	1.4	0.0 - 25.9
Arkosic	92	2.2	0.0 - 13.5	2.2	0.0 - 23.0
Quartzose	50	0.3	0.0 - 17.6	0.6	0.0 - 25.9
Limestone	16	0.1	0.0 - 0.2	0.1	0.0 - 0.3

Rn-222—The distribution of Rn-222 in Piedmont ground water showed the most striking differences of all radionuclides. It has been well documented that the highest radon in ground water occurs in the granitic aquifers of the New England and Appalachian Highlands and Piedmont provinces (King et al., 1982; Hess et al., 1985; Horton, 1985; Loomis, 1987; Michel and Jordana, 1987). Activities greater than 10,000 pCi/L are not uncommon in domestic wells, and the highest reported measurement ever reported was greater than 1,000,000 pCi/L in a private well in Maine (Hess et al., 1985).

In South Carolina and Georgia, the highest Rn-222 in ground water occurs in the granites scattered throughout the Piedmont. King et al. (1982) reported a range of 400-59,000 pCi/L and a geometric mean of 2,300 pCi/L in Piedmont public water supply wells in South Carolina. Around SRS, data were available for only 2 systems, Monetta with 6,833 pCi/L and Grovetown with 698 pCi/L.

Uranium—The only data on the levels of uranium in public water supplies in the Piedmont around SRS are for the wells of Camak, Georgia (see Appendix). Of the 3 wells, 2 are below 1 pCi/L and 1 ranges from 187 to 261 pCi/L. There is obviously a zone of uranium mineralization near Camak. The GDNR is currently conducting studies of private wells in the region and is finding instances of very high uranium in ground water, so the uranium mineralization is more than localized.

CRETACEOUS SAND AQUIFER

Introduction

The Cretaceous sand aquifer, as discussed here, consists of all deposits of Cretaceous age that are penetrated by wells. This "aquifer" includes productive sands in both the lower and upper sections, which are denoted by several geological names, such as lower and upper Tuscaloosa, Middendorf/Black Creek, and Midville/Dublin, among others. It directly overlies the Piedmont basement complex, forming a feather-edge at the Piedmont-Coastal Plain contact known as the Fall Line and thickening seaward to more than 1,000 m. It is composed of sand, clay, and gravel. In some areas, particularly near the Fall Line and in the lower part of the section, the sands can be quite arkosic, although the feldspars have been completely weathered into clays. With distance from the Piedmont and up section, the sands become very clean, composed mostly of quartz.

In the upper Coastal Plain around SRS, the most commonly used aquifer is the Cretaceous aquifer (Aucott and Speiran, 1985), although with distance from the Fall Line, there is increased use of shallower aquifers. However, nearly all the public water supplies in Aiken, Richland, and Burke counties rely on the Cretaceous sand aquifer for drinking water. Most of the wells at SRS are screened in the Cretaceous sand aquifer as well.

The Fall Line aquifers in general have been found to have elevated levels of natural radioactivity (Michel and Moore, 1980; Loomis, 1987; Michel and Jordana, 1987) because of the mineralogy of the sediments and their weathering history. Because the sediments were derived from the adjacent Piedmont rocks, they are mineralogically immature. They contain higher amounts of feldspars and rock fragments and thus higher amounts of uranium- and thorium-bearing minerals than the middle and lower Coastal Plain sediments which were deposited farther from the source rocks. The intense weathering which turned these immature minerals into quartz and clay also leached out uranium into solution permitting transport by groundwater flow. Frequently, the uranium did not migrate far, but sorbed onto the clay minerals or coprecipitated with iron hydroxide coatings. In contrast, thorium does not form soluble complexes and stayed in place. The effect of weathering was to increase the surface area of grains and thus the amount of Ra-228 in solution by alpha recoil. Therefore, the upper Coastal Plain consists of zones which are either depleted or slightly enriched with uranium and enriched in thorium, a pattern which makes for wide ranges in the radiological quality of ground water.

Distribution of Natural Radioactivity

Gross Alpha Particle Activity—The Cretaceous sand aquifer was ranked third in gross alpha, with a mean of 1.4 pCi/L (Table 2), representing 56 public water supplies in the counties surrounding SRS. Four of the systems had at least 1 sample with >5 pCi/L gross alpha: Jackson (with a
16.6 pCi/L while the other 18 measurements were <3 pCi/L), a supply called Family Community in Aiken County with up to 7.8 pCi/L, South Atlantic Mobile Home Park (MHP) in Richland County with a single measure of 6 pCi/L, and Keysville in Burke County with up to 13 pCi/L. Two systems in Aiken County that are likely using the Cretaceous sand aquifer also had high gross alpha: Ashley Grove Subdivision had 9.8-36.0 pCi/L in 1979-1980 and the Riveria MHP had 3.2-12.0 pCi/L.

Gross Beta Activity—Of all 4 aquifers studied, the Cretaceous sand aquifer had the lowest gross beta activity, with a mean of 2.7 pCi/L. In all cases, those highest systems were those that also had elevated gross alpha. The highest, by far, was the 17-50 pCi/L measured at Ashley Grove Subdivision in 1979-1980.

Ra-226—The Ra-226 levels in ground water from the Cretaceous sand aquifer on and around SRS, with a mean of 1.7 pCi/L, were not significantly different than any other aquifer (Table 2). This value is lower than the 2.2 pCi/L average for the 92 wells in arkosic sand aquifers in Georgia, South Carolina, and North Carolina (Table 3) reported by Michel and Pollman (1982).

There can be wide spatial variations in Ra-226 in ground water over short distances, as found in Leesville, South Carolina, where Ra-226 varied from 2.7 to 27.0 pCi/L in 7 wells drilled within a 2-square-kilometer Coastal Plain remnant (Michel and Moore, 1980). The highest values generally are found where granite occurs in the adjacent Piedmont, such as at Leesville and other Lexington County towns. Granites provide original sediment with high amounts of uranium and thorium.

Ra-228—Using data for 11 systems, the Cretaceous sand aquifer had the highest mean Ra-228 at 1.7 pCi/L for all aquifers, but the distributions were not statistically different (Table 2). The mean Ra-228 of the 92 public water supply wells in arkosic sand aquifers studied by Michel and Pollman (1982) was 2.2 pCi/L, with a range of 0.0-13.5 pCi/L. These aquifers produced water with the largest number of high Ra-228 measurements in the southeastern United States.

Similar to Ra-226, the upper Coastal Plain sediments derived from granitic sources have the highest Ra-228. Because thorium is so insoluble, it is not subject to secondary transport processes as is uranium. As a result, the thorium content of the sediments and thus the Ra-228 concentrations in ground water decrease with distance from the Fall Line. The only other potential source of elevated Ra-228 is heavy mineral deposits which are rich in thorium-bearing minerals. However, these heavy minerals are also highly resistant to weathering, and the thorium is so tightly bound that little Ra-228 is released to ground water from these accumulations. Furthermore, the relatively short half-life of Ra-228 ($t_{1/2} = 5.7$ years) means that it decays to very low levels before traveling more than 2-3 km. And sorption onto clays would most likely remove it much more quickly than decay.

Rn-222—Public water supplies using the Cretaceous sand aquifer both on and around SRS had the lowest Rn-222 content of all aquifer types, although the 3 sedimentary aquifers were not statistically different. Based on 30 wells, all from South Carolina systems, the mean Rn-222 content was 143 pCi/L, with the highest values reported for Jackson with 73-680 pCi/L and Aiken with 216-454 pCi/L. These data correlate with the mean of 190 pCi/L for 39 upper Coastal Plain wells in South Carolina reported by King et al. (1982). Again, highest Rn-222 occurs where granitic source material contributed heavily to the adjacent sediments.

Uranium—The only uranium in drinking water data available consisted of the 6 samples analyzed during the current study, which were all <1.0 pCi/L.(Jones, P.,1979), using the results for the large number of private wells analyzed for uranium content during the National Uranium Resource Evaluation (NURE) program, showed that the natural uranium content of the upper Coastal Plain was usually less than 0.04 parts per billion.

TERTIARY SAND AQUIFER

Introduction

The Tertiary sand aquifer, as discussed here, consists of the entire Tertiary section in the middle Coastal Plain. These deposits are composed of quartzose sand, clayey sand, and thick clay units. This aquifer includes multiple water-producing zones which are not hydraulically isolated from each other. The Tertiary sand aquifer includes several stratigraphic formations known as the Ellenton, Rhems, Williamsburg, Congaree, McBean, Orangeburg Group, Gordon, and Barnwell (Colquhoun et al., 1983).

The Tertiary sand aquifer is used in much of Barnwell County and parts of Aiken, Bamberg, and Orangeburg Counties. Wells frequently have multiple screens.

Distribution of Natural Radioactivity

Gross Alpha Particle Activity—The Tertiary sand aquifer had the highest gross alpha activity of all aquifers studied, with a mean of 2.9 pCi/L. Three systems had values over 5 pCi/L: Perry with a 16-sample mean of 8.4 pCi/L, Salley with 1 high value of 5.3 pCi/L out of 10 samples, and Blackville with 1 high value of 13.4 pCi/L out of 3 samples. It should be noted that Ra-226 activities do not account for all the gross alpha particle activities when they are this high. A good example is the town of Perry, shown in Figure 3 and listed in the data appendix. The Ra-226/gross alpha particle activity ratio varies widely, from 0.1 to 0.9, with no particular pattern and likely a function of multiple wells. Other radionuclides that could contribute to the high gross alpha particle activities are uranium and radon daughters.

Gross Beta Activity—The mean gross beta activity was 3.6 pCi/L, which was not statistically different from any other aquifer.

Ra-226—The Tertiary sand aquifer had the highest Ra-226 values, although they were not statistically different from the other aquifers. Because uranium can form soluble complexes under oxidizing conditions, it tends to be leached from the up-dip part of the aquifer and transported with groundwater flow. Uranium is removed from solution by reducing conditions and coprecipitation or scavenging by iron and manganese oxides. The process of multiple leaching and fixation by ground water formed the sandstone-type uranium ores of the western United States. This process may be active in controlling the accumulation of uranium in part of the Tertiary sand aquifer of the middle Coastal Plain. The highest Ra-226 levels throughout the Coastal Plain are consistently in the middle Coastal Plain: 20-70 pCi/L in Monroe and Tift Counties in Georgia (Cline et al., 1983); 25 pCi/L in Sumter County in South Carolina (Michel and Pollman, 1982).

Ra-228—The Tertiary sand aquifer had the lowest Ra-228, but the distributions among all aquifers were not significantly different. Because Ra-228 decays directly from Th-232 and has a very short half-life, its distribution in ground water is directly related to the distribution of thorium in the aquifer solids. In the Coastal Plain, thorium decreases with distance from the source rocks in the Piedmont, as does Ra-228 in ground water. King et al. (1982) reported the geometric mean and standard deviation in Ra-228 concentrations in the S.C. Coastal Plain as follows: 1.9 ±3.0 pCi/L upper; 0.8 ±3.2 pCi/L middle; and 0.1 ±0.5 pCi/L lower. The Tertiary sand aquifer around SRS falls within the expected range for the middle and lower Coastal Plain.

Rn-222—There was very little difference in the radon content of all the sedimentary aquifers, but the Tertiary sand aquifer had the highest value (Table 2). Those factors affecting Rn-222 would be similar to Ra-226 discussed above. King et al. (1982) reported the geometric mean Rn-222 in 26 wellhead samples from the middle Coastal Plain to be 251 ±2, a surprisingly small range and higher than detected in this study. There is a significant, but highly variable, loss of radon during transport in the distribution system; thus, the USC samples (collected at the wellhead) are consistently higher than other surveys, including this one.

TERTIARY LIMESTONE AQUIFER

Introduction

The Tertiary Limestone aquifer as discussed here consists of the permeable parts of the Santee and Ocala Limestones in South Carolina. It is also referred to as the Floridan aquifer system throughout the Southeast. It is the principal aquifer of use in Allendale and parts of Bamberg County, as well as the entire southeastern part of South Carolina (Aucott and Speiran, 1985).

Distribution of Natural Radioactivity

Only five towns in the study area were identified as using the Tertiary Limestone. Of these, the only other radioactivity measurements besides gross alpha and beta were 2 values of Rn-222. The gross alpha particle activity was the lowest of all aquifers studied, and the gross beta was the highest (Table 2). Data from Michel and Pollman (1982) show that Coastal Plain limestone aquifers are also very low in Ra-226 and Ra-228, with a mean of 0.1 pCi/L for both isotopes (Table 3).

Because limestones are chemical precipitates, they naturally contain low levels of uranium and very low levels of thorium. Under certain conditions, limestone aquifers can have very high levels of uranium and Ra-226, such as in central Florida, where influenced by the overlying phosphate deposits. Otherwise, limestones throughout the United States are characterized by Ra-226 levels less than 1.0 pCi/L and Ra-228 less than 0.5 pCi/L.

Rn-222 was determined in 2 town systems: 227 pCi/L in Allendale and 74 pCi/L in Fairfax. The only other data available for comparison are from the limestone aquifer in Beaufort County, which ranged from 5 to 112 pCi/L and averaged 35 pCi/L (Michel et al., 1981). The values near SRS are somewhat higher, but within the expected range.

COMPARISON WITH OTHER STUDIES

The database used to generate the rankings and grouping of Table 2 was limited in both number and scope, to counties in the vicinity of SRS. With this small database, it was possible to identify statistically significant differences in the distribution of radioactivity among the 4 major aquifer types only for the gross alpha activity of the Tertiary sand aquifer and Rn-222 in Piedmont. However, if other regional databases are considered, more differences can be identified.

The best regional database for radon is the USC data summarized in King et al. (1982). The Rn-222 levels in public drinking water from the Piedmont aquifers in the vicinity of SRS (with a mean of 3,165 pCi/L) were well within the usual range of 400-57,000 pCi/L found for these rock types (the mean of 68 samples from South Carolina was 2,300 pCi/L). Most systems in the current study had wells in metavolcanic and metasedimentary rocks rather than granitic rocks, which generate the very highest radon levels. Domestic wells in granite in South Carolina and Georgia are likely to have Rn-222 levels in the 10,000 to 100,000 pCi/L range (Michel, 1987).

Radon is mostly a health concern for small systems or private wells in granitic terrains. For example, the population-weighted, average concentration of radon in public groundwater supplies in Maine is estimated to be 10,000 pCi/L for systems serving less than 1,000 people per system and 2,000 pCi/L for systems serving greater than 1,000 persons per system (Cothern et al., 1986). In South Carolina, the smaller-system average was 1,100 pCi/L compared with the larger-system average of 276 pCi/L. In Georgia, the smaller-system average was the same as South Carolina (because it was based on the same S.C. data) and the larger-system average was 150 pCi/L (Cothern et al., 1986). The SRS data are very similar to these regional distributions. Domestic wells frequently have an order of magnitude higher radon levels than public systems because of the shorter residence time of the water and lower losses of radon in the distribution system, but, more importantly, because private users can get enough water from low-yielding crystalline rocks whereas public suppliers frequently cannot.

The distribution of Ra-226 and Ra-228 was not significantly different using the database for the 4 major aquifers studied. However, the rankings followed the same trend found in a more extensive study of the southeastern Coastal Plain by Michel and Pollman (1982). Table 4 is a summary of their work, using the same statistical grouping and ranking technique, but only for Ra-228. The means for Ra-226 are shown, but the groupings apply only to Ra-228 distributions. With this larger database, significant differences were identified for aquifer types similar to those studied in this report. The highest group consists of granitic and arkosic sand aquifers, which also have high Ra-226. With a higher percentage of uranium- and thorium-bearing minerals, these aquifers are much more likely to produce ground water with elevated natural radioactivity. Those arkosic sand aquifers derived from granitic sources had the highest levels.

With the larger database shown in Table 4, statistically significant differences in the Ra-228 distribution also were identified between arkosic versus quartzose sand with mixed-source aquifers (essentially, the Cretaceous aquifer near the Fall Line versus the Tertiary sand aquifer of the middle Coastal Plain). The arkoses produced water with about 4 times the Ra-228 content of the quartzoses. In contrast, there was little difference in the Ra-226 content of these aquifers. The average Ra-226 content was about the same as the average Ra-228 content of the arkosic sand aquifer, reflecting the equal distribution of their parents in the aquifer solids. However, the quartzose sand aquifers of the middle Coastal Plain have much higher average Ra-226 concentrations because of the ability of its parent uranium to migrate and be concentrated by ground water. The Tertiary sand aquifer is more likely to have elevated Ra-226 rather than Ra-228.

The lower Coastal Plain sand aquifers are represented near the bottom of Table 4 as the quartzose sands derived from low thorium sources, with a mean Ra-226 and Ra-228 of 0.1 pCi/L. These mineralogically mature sediments are the products of multiple cycles of sedimentation and thus contain very low amounts of uranium and thorium. The only potential source of radioactivity would be heavy mineral accumulations, such as placer deposits. But these minerals are highly resistant, and only a small fraction of the radium progeny is able to diffuse out of the crystals and dissolve in ground water.

Metamorphic rocks, regardless of the degree of metamorphism, were all of the same group and produced water with low Ra-228 and Ra-226. It is interesting to note that the metamorphic rock aquifers in the Monazite Belt of the inner Piedmont had the lowest Ra-228 content. Michel and

Table 4. Groupings of Similarity and Rankings for Ra-228 Distribution for Various Aquifer Types in the Piedmont and Coastal Plain Provinces. Ra-226 Means are Not Ranked

Grouping	Mean Ra-228 (pCi/L)	Numbaer	Aquifer Description	Mean Ra-226 (pCi/L)
				A
				3.0
				2
				Syenitic granite
				0.8
A				
A	2.5	46	Arkosic sands derived from granitic sources (high Th)	2.0
A				
B A	2.1	43	Arkosic sands derived from mixed sources (medium Th)	2.7
B A				
B A C	1.6	35	Granite	2.3
B A C				
B D A C	0.8	3	Dioritic granite	1.0
B D C				
B D E C	0.5	31	Quartzose sands derived from mixed sources (medium Th)	1.7
D E C				
F D E C	0.4	37	High-grade metamorphic rocks, no specific Th mineralization	0.3
F D E				
F D E	0.3	10	Low-grade metamorphic rocks, no specific Th mineralization	1.4
F D E				
F D E	0.3	3	Arkosic sands derived from low Th sources	0.3
F D E				
F D E	0.3	13	Medium-grade metamorphic, no specific Th mineralization	0.2
F D E				
F D E G	0.2	15	High-grade metamorphic rocks, monazite mineralization zone	0.2
F D E G				
F E G	0.1	2	Granite with monazite mineralization	0.1
F E G				
F G	0.1	19	Quartzose sands derived from low Th sources	0.1
F G				
G	0.1	16	Limestone	0.1

Cothern (1986) proposed that the intense metamorphism that resulted in the formation of monazite in this zone tended to recrystallize any thorium into refractory minerals such as monazite, making it less likely for Ra-228 to go into solution. Diffusion out of refractory minerals is much lower than from the surface of grains, intergranular pores, or clay minerals, sites where a significant amount of the thorium occurs in granites and sediments. Only Rn-222, as an inert gas, can diffuse out of the tiny fractures in these mineral crystals. Most of the radium remains trapped inside.

The limestone aquifers of South Carolina produced water with the lowest radium content (Table 4). This result corroborates the data in Table 2 which show that the Tertiary limestone aquifer had the lowest gross alpha particle activity, with a mean of 0.9 pCi/L (there were no radium data for the Tertiary limestone aquifer in the study area). In fact, the only areas nationwide where systems using carbonate aquifers were not in compliance with USEPA standards were in the phosphate region of central Florida and in central Iowa where water was thought to be leaking in from overlying sandstone aquifers. In general, limestone aquifers do not have high levels of natural radioactivity.

COMPARISON OF THE DISTRIBUTION OF NATURAL RADIOACTIVITY BY COUNTY

An analysis of the distribution of natural radioactivity in ground water in the 11 counties and onplant was conducted using the same statistical method as before; namely, the General Linear Models Procedure. The results are summarized in Table 5 using the same approach of showing the groupings, mean, and number of systems. The lists are ranked by means for each measure of radioactivity. A county is not listed when there were no data available; however, all data in the appendix were used.

One important factor to note when reviewing Table 5 is the number of systems in the county for each parameter. In many cases, there are results from only 1 or 2 systems in a county. Such a small sample may not be representative of the entire county, so the means should be used very cautiously. The larger the number of systems, the more reliable the mean value is as an indicator of the levels of radioactivity likely to be found. This analysis by county was conducted primarily to compare SRS levels with those in other public water supplies. All available radiological data were used in the county statistics.

There were no statistical differences in the distribution of gross alpha particle activity among SRS and the counties. Public water supplies at SRS had the lowest mean gross alpha particle activity (0.5 pCi/L), even though the adjacent counties of Aiken and Barnwell were 2.1 and 1.2 pCi/L, respectively. Of the 35 SRS samples, only 5 were above 1 pCi/L, and the maximum value measured was 3.4 pCi/L from F Area. It is possible that the low SRS mean is related to different analytical precision and accuracy between SRS and state laboratories. It was noted previously that SRS analyses were consistently lower than state monitoring data for the same system. However, SRS analyses were still within the range of values reported, so regardless of analytical differences, SRS systems still would be within the expected range. Analysis of split samples by both SRS and state laboratories could determine if there were analytical differences that were important.

The trend in gross alpha particle activities followed that expected for the Coastal Plain aquifers, with highest values for the upper Coastal Plain region represented by Aiken, Burke, and Richmond counties, and lower values for the middle Coastal Plain region represented by Allendale and Bamberg counties. Direct comparison with the results by aquifer type is not possible because of the inclusion of very small systems, for which the aquifer type could not be determined, in the county statistics. However, gross alpha particle activity in Coastal Plain sand aquifers generally decreases with distance from the Piedmont, reflecting loss of uranium and thorium by weathering and maturation of sediments by transport.

There were no significant differences in the distribution of gross beta activity among SRS and the surrounding counties. The highest mean value occurred in Allendale County, where the dominant aquifer is the Tertiary limestone, which also had the highest gross beta activity of all aquifer types. Aiken County had relatively high values, primarily because of inclusion of 3 very small systems with unknown well depths which had activities of 30, 10, and 9 pCi/L. Without these 3 systems, the mean gross beta activity was 2.9 pCi/L, a value similar to the mean of 2.7 pCi/L for the Cretaceous sand aquifer.

The mean gross beta activity for SRS systems was relatively low at 1.8 pCi/L, although there were 6 systems with values greater than 3 pCi/L. The highest 1986 value at SRS was 9.6 pCi/L from F Area.

There is a notable decrease in the number of available results for specific radionuclides, as well as a change in the source of the analytical measurements. Means for those counties with only 1-2 measurements should not be considered representative but are only shown for consistency. Also, many of the S.C. measurements were determined at the USC laboratory and thus are not affected by interlaboratory differences. In this comparison, there were no statistically significant differences in the Ra-226 distribution among SRS and the surrounding counties. Furthermore, the mean Ra-226 activity was 1.5 pCi/L for both Aiken County and SRS based on 14 samples from each area. The means for Ra-228 also were similar, with 1.8 pCi/L for SRS and 1.5 pCi/L for Aiken County. There were not enough data on radium values from other counties for meaningful comparisons.

The distribution of Rn-222 in public water systems at and surrounding SRS was not significantly different, based on the available results, even though the mean Rn-222 in SRS systems was the lowest measured. As a check on the validity of this conclusion, the correlation coefficient for the distribution of Rn-222 between Aiken County and SRS was calculated and found to be 0.46—a low value, but the 2 distributions were still not statistically different. All the Rn-222 samples were collected in the same manner, frequently by the same person, with the only difference being the location of the sample. Most of the county samples were collected at the wellhead, whereas only 5 of the 14 SRS samples were taken at the wellhead. But the SRS wellhead samples were essentially the same as the distribution systems (Table 1), so the sampling location should not affect comparison of the results. The very vigorous pumping rate of the SRS wells probably results in the outgassing of much of the radon prior to sampling.

There were insufficient uranium data for comparison by county; all 6 samples measured for this study were below the detection limit of 0.1 pCi/L.

Table 5. Groupings of Similarity andRankings for Various Radioactivity Measures for the Counties and SRS

Grouping	Mean (pCi/L)	Number of of Systems	County
Gross Alpha Particle Activity			
A	2.1	42	Aiken
A	2.1	9	Burke
A	2.0	8	Columbia
A	1.6	24	Richmond
A	1.5	4	Warren
A	1.2	8	Barnwell
A	1.2	6	McDuffie
A	1.1	5	Allendale
A	0.6	7	Bamberg
A	0.6	1	Edgefield
A	0.5	35	SRS
Gross Beta Activity			
A	6.0	12	Allendale
A	3.9	42	Aiken
A	2.9	1	Edgefield
A	2.5	8	Barnwell
A	2.1	7	Bamberg
A	2.1	1	Columbia
A	1.8	35	SRS
A	0.6	1	Burke
Ra-226			
A	2.8	1	Burke
A	1.5	14	Aiken
A	1.5	14	SRS
A	0.8	3	Barnwell
A	0.6	2	Columbia
A	0.5	2	Richmond
A	0.2	1	McDuffie
A	0.2	1	Bamberg

Table 5 (Contd)

Grouping	Mean (pCi/L)	Number of of Systems	County
Ra-228			
A	2.3	1	Burke
A	1.8	14	SRS
A	1.5	13	Aiken
A	1.0	1	Bamberg
A	0.9	2	Barnwell
A	0.5	1	Richmond
A	0.5	1	Columbia
Rn-222			
A	698	1	Columbia
A	583	16	Aiken
A	216	5	Barnwell
A	180	2	Bamberg
A	151	2	Allendale
A	30	14	SRS

SUMMARY

There were four main objectives of this study. The first was to define the regional radiological water quality by aquifer type. Only three distinct distributions in natural radioactivity were found among the major aquifers. The highest levels of gross alpha particle activity were found in the Tertiary sand aquifer, although the distribution of Ra-226, the major contributor to the gross alpha activity, in the Tertiary sand aquifer was not significantly different than in the other aquifers. Also, as expected, the distribution of Rn-222 in Piedmont rock wells was significantly higher than all sedimentary aquifers. The Tertiary limestone aquifer tended to have the highest gross beta activity and the lowest gross alpha particle activity. Otherwise, there were no statistically significant differences in the distribution of other measures of natural radioactivity among the major aquifer types. Interpretations could be made from the subtle trends in the means, using knowledge of the factors affecting a particular radionuclide's distribution based on additional information. For example, the mean Ra-228 was higher for the Cretaceous sand aquifer (1.7 pCi/L) compared to the Tertiary sand aquifer (0.9 pCi/L) reflecting the higher thorium content of the arkosic Cretaceous deposits over the quartzose Tertiary deposits.

The second objective was to analyze the spatial and temporal trends in radiological water quality in the region. Most of the spatial trends are a function of spatial differences in aquifer use. Counties in the upper Coastal Plain use primarily the Cretaceous sand aquifer which has high gross alpha particle activity, especially where granites occur in the adjacent Piedmont. The sediments derived from granitic source rocks tend to have higher concentrations of uranium and thorium. The presence of large masses of granite in the Piedmont in the vicinity of SRS is an important factor contributing to the higher natural radioactivity in the Coastal Plain aquifers in Aiken County when compared to other Fall Line aquifers in the region.

There are some areas of uranium enrichment in the Piedmont metasedimentary rocks, as evidenced by the very high (>200 pCi/L) uranium measured in one of the Camak wells in Warren County, Georgia. However, this uranium mineralization is very localized and has not been detected in any other public water supplies.

No temporal trends in any measure of radioactivity have been detected, a finding consistent with most other studies. Widely fluctuating radioactivity results are mostly due to variations in the relative source contribution in multiple well systems. The only other source of temporal changes would possibly be due to large changes in water level which would affect the flow path of water to the well, particularly for Piedmont wells. No such effects were observed.

The third objective was to review radiological water-quality data at SRS within the regional context to determine if there were any differences between onsite and offsite systems. Using all available data for each radioactivity measure, no significant differences were found. For gross alpha and beta activity, SRS results were among the lowest values measured. However, there is some concern that the low gross alpha particle activities were due, in part, to systematically low analytical results from SRS when compared to state results. For Ra-226 and Ra-228, levels onplant were identical or nearly so when compared to a similar number of samples from Aiken County and only slightly higher than a very few samples from Barnwell County. Rn-222 levels in the public water supplies at SRS were very low when compared to the surrounding counties.

The fourth objective was to determine analytically the specific radionuclides contributing to the gross alpha particle activities measured onsite. In nearly all cases, it was found that the gross alpha particle activity could be attributed to Ra-226. Uranium was measured in 6 samples and found to be below 0.1 pCi/L and the low levels of Rn-222 would not contribute to the gross alpha particle activity under normal sample handling.

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APPENDIX

SRS GROUND WATER RADIONUCLIDE DATA

M9005067

KEY TO APPENDIX

NOTE: All values shown are in pCi/L. For gross alpha and gross beta; the first column is the value and the second column is the counting uncertainty (shown as ±SD).

SOURCE OF DATA

EPA	U.S. Environmental Protection Agency data from Horton, 1985
DHEC	Monitoring Data from S.C. Department of Health and Environmental Control
GDNR	Monitoring Data from Georgia Department of Natural Resources
NIRS	USEPA Data from National Inorganic and Radionuclide Survey
RPI	Results from samples collected October 1987 for this study by RPI
SRS	Monitoring Data from Savannah River Site Annual Reports
USC	University of South Carolina Department of Geology Data

COUNTY ABBREVIATIONS

Georgia

BK	Burke
CO	Columbia
MC	McDuffie
RI	Richland
WA	Warren

South Carolina

AI	Aiken
AL	Allendale
BB	Bamberg
BW	Barnwell
ED	Edgefield
OR	Orangeburg

SRS GROUND WATER RADIONUCLIDE DATA

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - BK, GA									
Water Supply Delaigle Mobile Home									
GDNR	09/23/81	<2.0	-	-	-	-	-	-	-
Water Supply Girard									
GDNR	03/28/78	2.0	2.0	-	-	-	-	-	-
GDNR	11/17/82	<2.0	-	-	-	-	-	-	-
Water Supply Keysville Conv.: NU									
GDNR	06/22/78	7.0	2.0	-	-	4.10	3.00	-	-
GDNR	03/12/80	7.0	-	-	-	3.80	5.00	-	-
GDNR	05/21/80	13.0	3.0	-	-	3.90	<2.00	-	-
GDNR	05/21/80	<2.0	-	-	-	0.20	2.00	-	-
GDNR	12/30/82	8.0	1.0	-	-	2.00	<1.00	-	-
Watera Supply Mamie Joe Rhodes HAR									
GDNR	06/22/78	1.0	2.0	-	-	-	-	-	-
GDNR	07/14/82	<4.0	-	-	-	-	-	-	-
Water Supply Midville									
GDNR	11/00/81	<1.0	-	-	-	-	-	-	-
GDNR	01/20/82	<4.0	-	-	-	-	-	-	-
Water Supply Riverside Mobile Home									
GDNR	05/26/82	<4.0	-	-	-	-	-	-	-
GDNR	09/02/82	2.0	1.0	-	-	-	-	-	-
Water Supply Sardis									
GDNR	01/24/78	3.0	2.0	-	-	-	-	-	-
GDNR	11/17/82	<3.0	-	-	-	-	-	-	-
SRS	00/00/86	0.1	-	0.6	-	-	-	-	-
Water Supply Vidette									
GDNR	01/30/79	1.0	2.0	-	-	-	-	-	-
GDNR	01/21/82	<3.0	-	-	-	-	-	-	-
Water Supply Waynesboro									
GDNR	09/26/77	2.0	3.0	-	-	-	-	-	-
GDNR	06/22/81	<3.0	-	-	-	-	-	-	-

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SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - CO, GA									
Water Supply Columbia County Water									
GDNR	00/00/77	<2.0	-	-	-	-	-	-	-
GDNR	07/02/82	<3.0	-	-	-	-	-	-	-
Water Supply Grovetown									
GDNR	01/18/78	4.0	2.0	-	-	1.50	-	-	-
GDNR	04/01/81	4.0	1.0	-	-	1.30	-	-	-
GDNR	06/16/81	4.0	1.0	-	-	1.00	-	-	-
GDNR	06/16/81	3.0	1.0	-	-	-	-	-	-
GDNR	06/06/82	4.0	1.0	-	-	0.60	-	-	-
GDNR	10/07/82	<2.0	-	-	-	-	-	-	-
EPA	08/31/82	0.3	0.3	2.1	0.9	-	-	698	-
Water Supply Harlem									
GDNR	12/08/77	3.0	2.0	-	-	-	-	-	-
GDNR	03/16/82	2.0	2.0	-	-	-	-	-	-
Water Supply Hillandale Mobile Home									
GDNR	02/23/78	<1.0	-	-	-	-	-	-	-
GDNR	02/16/83	<2.0	-	-	-	-	-	-	-
Water Supply Martinez Water Assoc.									
GDNR	11/00/81	-	2.0	-	-	0.10	<1.00	-	3.0
GDNR	11/06/81	5.0	2.0	-	-	<0.10	-	-	-
Water Supply Mobile City Map									
GDNR	04/11/78	-	1.0	-	-	-	-	-	-
GDNR	02/15/83	<2.0	-	-	-	-	-	-	-
Water Supply Pine Needle Trailer									
GDNR	10/11/78	2.0	2.0	-	-	-	-	-	-
GDNR	02/15/83	<2.0	-	-	-	-	-	-	-
Water Supply Windy Acres Mobile Home									
GDNR	11/15/77	-	1.0	-	-	-	-	-	-
GDNR	02/16/83	<2.0	-	-	-	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - MC, GA									
Water Supply Bealle Meade Country									
GDNR	12/06/78	2.0	2.0	-	-	-	-	-	-
GDNR	11/18/82	<2.0	-	-	-	-	-	-	-
Water Supply Dearing									
GDNR	11/16/77	3.0	2.0	-	-	-	-	-	-
GDNR	07/19/82	<2.0	-	-	-	0.20	-	-	-
Water Supply Green Acres Mobile Home									
GDNR	12/08/77	-	-	-	-	-	-	-	-
GDNR	09/24/81	<1.0	-	-	-	-	-	-	-
Water Supply Reese Trailer Park									
GDNR	06/06/78	1.0	1.0	-	-	-	-	-	-
GDNR	09/24/81	<1.0	-	-	-	-	-	-	-
Water Supply Thomson									
GDNR	09/26/77	1.0	1.0	-	-	-	-	-	-
GDNR	07/01/83	<2.0	-	-	-	-	-	-	-
Water Supply Wilshir Mobile Home									
GDNR	06/22/78	-	1.0	-	-	-	-	-	-
GDNR	08/24/83	1.0	1.0	-	-	-	-	-	-
County, State -RI, GA									
Water Supply Augusta									
GDNR	05/25/78	<1.0	-	-	-	-	-	-	-
Water Supply Augusta Youth-Development									
GDNR	11/00/81	<2.0	2.0	-	-	-	-	-	-
GDNR	02/04/83	2.0	2.0	-	-	-	-	-	-

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SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
Water Supply Blythe									
GDNR	09/20/77	2.0	2.0	-	-	-	-	-	-
GDNR	03/31/82	2.0	1.0	-	-	-	-	-	-
Water Supply Byron Trailer Park									
GDNR	04/24/80	1.0	2.0	-	-	-	-	-	-
GDNR	06/16/83	<1.0	-	-	-	-	-	-	-
Water Supply Castle Pines Mobile Home									
GDNR	11/00/81	<2.0	-	-	-	-	-	-	-
GDNR	11/10/81	<2.0	-	-	-	-	-	-	-
Water Supply Continental Forest									
GDNR	01/04/80	<2.0	-	-	-	-	-	-	-
Water Supply El Ro Ka Mobile Home									
GDNR	01/17/78	3.0	2.0	-	-	-	-	-	-
GDNR	02/04/83	<1.0	-	-	-	-	-	-	-
Water Supply Gaskins Mobile Home									
GDNR	10/15/78	-	1.0	-	-	-	-	-	-
GDNR	06/16/83	<2.0	-	-	-	-	-	-	-
Water Supply Gate 5 Mobile Home									
GDNR	11/00/81	<1.0	-	-	-	-	-	-	-
GDNR	01/06/82	<2.0	-	-	-	-	-	-	-
Water Supply Gracewood State School									
GDNR	11/28/77	4.0	2.0	-	-	0.90	-	-	-
GDNR	05/27/83	<2.0	-	-	-	-	-	-	-
Water Supply Hephzibah									
GDNR	04/20/78	2.0	2.0	-	-	-	-	-	-
GDNR	01/27/82	<2.0	-	-	-	-	-	-	-
Water Supply Hephzibah Well #4									
GDNR	01/22/81	2.0	1.0	-	-	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State -RI, GA, Contd									
Water Supply Heritage Mobile Home Park									
GDNR	05/18/83	2.0	1.0	-	-	-	-	-	-
Water Supply Mars Trailer Park									
GDNR	01/18/78	2.0	1.0	-	-	-	-	-	-
GDNR	03/17/83	2.0	2.0	-	-	-	-	-	-
Water Supply Mobile Home Country									
GDNR	06/27/78	2.0	2.0	-	-	-	-	-	-
Water Supply Oak Ridge Water Works									
GDNR	11/02/78	1.0	1.0	-	-	-	-	-	-
GDNR	05/18/83	<1.0	-	-	-	-	-	-	-
Water Supply Oakdale Trailer Park									
GDNR	10/10/79	1.0	1.0	-	-	-	-	-	-
GDNR	05/19/83	2.0	1.0	-	-	-	-	-	-
Water Supply Pine De Rosa									
GDNR	06/28/79	2.0	1.0	-	-	-	-	-	-
Water Supply Richmond County WS #106									
GDNR	06/23/82	<2.0	-	-	-	-	-	-	-
Water Supply Richmond County Water									
GDNR	05/03/79	-	1.0	-	-	-	-	-	-
GDNR	06/23/82	<2.0	-	-	-	-	-	-	-
GDNR	08/19/82	<3.0	-	-	-	-	-	-	-
Water Supply South Atlantic Mobile Home Park									
GDNR	06/17/80	6.0	1.0	-	-	-5	<1.00	-	-
Water Supply The Timbers Trailer Park									
GDNR	00/00/77	1.0	2.0	-	-	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State -RI, GA, Contd									
Water Supply Woodland Trailer Park									
GDNR	06/20/78	1.0	1.0	-	-	-	-	-	-
Water Supply Wylds Trailer Court									
GDNR	09/27/79	-	1.0	-	-	-	-	-	-
GDNR	05/19/83	<1.0	-	-	-	-	-	-	-
County, State -WA, GA,									
Water Supply Norwood									
GDNR	11/04/82	2.0	2.0	-	-	-	-	-	-
GDNR	01/12/83	<4.0	-	-	-	-	-	-	-
Water Supply Town of Camak									
GDNR	11/16/77	104.0	7.0	-	-	2.00	0.50	-	80.0
GDNR	04/01/80	22.0	3.0	-	-	-	-	-	45.0
GDNR	07/03/80	97.0	10	-	-	-	-	-	96.0
GDNR	11/18/81	108.0	8.0	-	-	1.00	<1.00	-	75.0
GDNR	11/04/82	128.0	8.0	-	-	2.00	<1.00	-	80.0
GDNR	06/16/83	16.0	2.0	-	-	1.30	<1.00	-	30.0
GDNR	11/04/83	33.0	2.0	-	-	1.30	<1.00	-	85.0
GDNR	02/07/84	17.0	1.0	-	-	0.80	<1.00	-	9.0
Water Supply Town of Camak Well #1									
GDNR	06/17/83	134.0	6.0	-	-	43.0	2.10	-	230.0
GDNR	11/04/83	126.0	4.0	-	-	3.00	<1.00	-	261.0
GDNR	02/07/84	149.0	6.0	-	-	3.00	<1.00	-	187.0
GDNR	05/24/84	-	-	-	-	-	-	-	-
Water Supply Town of Camak Well #2									
GDNR	06/16/83	3.0	1.0	-	-	-	-	-	-
GDNR	11/04/83	3.0	1.0	-	-	-	-	-	-
GDNR	02/07/84	5.0	1.0	-	-	0.40	-	-	-
GDNR	05/24/84	-	-	-	-	-	-	-	-
GDNR	05/24/84	-	-	-	-	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State -WA, GA, Contd									
Water Supply Town of Camak Well #3									
GDNR	01/11/83	3.0	2.0	-	-	0.60	-	-	-
GDNR	06/16/83	2.0	1.0	-	-	-	1.70	-	-
GDNR	11/04/83	3.0	1.0	-	-	-	-	-	-
GDNR	02/07/84	<2.0	-	-	-	-	-	-	-
GDNR	05/24/84	2.0	1.0	-	-	-	-	-	-
Water Supply Warrenton									
GDNR	12/29/77	-	1.0	-	-	-	-	-	-
GDNR	05/12/82	<2.0	-	-	-	-	-	-	-
County, State - AI, SC									
Water Supply Aiken									
DHEC	11/10/86	1.8	1.0	4.0	1.3	-	-	-	-
DHEC	05/18/78	0.6	0.7	3.9	1.3	-	-	-	-
DHEC	08/01/78	0.9	0.8	3.3	1.2	-	-	-	-
DHEC	04/26/79	1.4	0.6	8.4	1.3	-	-	-	-
DHEC	06/12/79	1.0	1.4	2.2	1.5	-	-	-	-
DHEC	07/12/79	0.9	0.9	2.1	1.0	-	-	-	-
DHEC	01/29/79	1.6	1.3	1.5	1.3	-	-	-	-
DHEC	01/24/80	0.4	0.5	1.9	1.0	-	-	-	-
DHEC	10/09/80	0.7	0.5	1.3	0.6	-	-	-	-
DHEC	04/16/81	1.2	0.7	1.9	0.9	-	-	-	-
DHEC	04/24/81	1.2	0.6	2.5	1.0	-	-	-	-
DHEC	02/28/83	1.3	0.7	2.0	0.9	-	-	-	-
DHEC	01/29/85	0.6	0.4	1.1	0.6	-	-	-	-
DHEC	01/19/87	0.9	0.8	2.8	1.2	-	-	-	-
DHEC	04/03/87	0.8	0.7	2.4	1.1	-	-	-	-
EPA	07/27/81	0.4	0.3	1.1	0.8	-	-	454	-
EPA	07/27/81	0.6	0.3	1.6	0.8	-	-	216	-
SRS	00/00/86	0.3	-	1.0	-	-	-	-	-
Water Supply Aiken State Park									
USC	00/00/80	-	-	-	-	0.70	2.90	64	-
USC	00/00/80	-	-	-	-	0.80	3.30	-	-
USC	00/00/80	-	-	-	-	0.40	1.20	-	-

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SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Ashley Grove S/D									
DHEC	05/09/79	9.8	2.8	17.3	3.1	1.20	-	-	-
DHEC	08/13/79	28.4	4.7	30.7	4.1	2.40	-	-	-
DHEC	11/28/79	36.5	3.9	49.9	3.7	11.50	-	-	-
DHEC	02/25/80	12.6	0.7	20.3	0.7	2.60	-	-	-
Water Supply Bath									
DHEC	06/13/79	0.4	0.9	0.6	0.9	-	-	-	-
DHEC	09/27/79	1.4	1.2	1.7	1.1	-	-	-	-
DHEC	12/19/79	1.0	1.3	1.4	1.1	-	-	-	-
DHEC	03/10/80	1.3	1.1	1.4	1.0	-	-	-	-
DHEC	08/23/83	1.7	0.5	1.8	0.6	-	-	-	-
DHEC	07/16/85	1.0	0.5	1.8	0.7	-	-	-	-
EPA	07/27/81	0.5	0.6	1.3	0.9	-	-	131	-
USC	00/00/80	-	-	-	-	0.51	0.80	110	-
SRS	00/00/86	0.3	-	0.2	-	-	-	-	-
Water Supply Beech Island									
DHEC	06/13/79	0.7	0.8	1.3	0.9	-	-	-	-
DHEC	09/27/79	0.6	0.5	1.2	0.8	-	-	-	-
DHEC	12/19/79	0.6	0.8	1.1	1.2	-	-	-	-
DHEC	03/28/80	0.2	0.4	0.6	0.6	-	-	-	-
DHEC	08/23/83	0.6	0.4	1.0	0.6	-	-	-	-
DHEC	08/22/85	1.1	0.4	1.9	0.5	-	-	-	-
EPA	07/27/81	0.5	0.3	1.9	0.9	-	-	196	-
USC	00/00/80	-	-	-	-	0.20	0.30	186	-
USC	00/00/80	-	-	-	-	0.30	1.10	80	-
Water Supply Breezy Hill									
DHEC	04/12/79	1.3	1.1	1.0	1.1	-	-	-	-
DHEC	07/02/79	1.1	0.7	2.4	1.0	-	-	-	-
DHEC	10/22/79	0.9	0.7	0.6	0.8	-	-	-	-
DHEC	01/07/80	0.9	0.9	2.4	3.0	-	-	-	-
DHEC	08/23/83	1.8	0.4	2.4	0.6	-	-	-	-
DHEC	09/13/85	1.1	0.4	4.7	0.6	-	-	-	-
EPA	07/27/81	0.2	0.2	0.2	0.5	-	-	183	-
EPA	07/27/81	0.4	0.3	1.1	0.8	-	-	191	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Burnettown									
DHEC	04/16/79	0.9	1.0	4.5	1.8	-	-	-	-
DHEC	07/02/79	1.1	0.7	5.2	1.3	-	-	-	-
DHEC	10/22/79	1.2	0.7	2.8	1.1	-	-	-	-
DHEC	01/09/80	1.0	1.3	1.4	2.6	-	-	-	-
DHEC	08/23/83	1.4	0.5	3.6	0.8	-	-	-	-
DHEC	10/18/85	1.6	0.6	3.6	0.8	-	-	-	-
EPA	07/27/81	0.2	0.3	1.9	0.9	-	-	79	-
Water Supply Carolina Springs Mobile Home Park									
DHEC	01/03/79	0.3	0.6	4.6	1.8	-	-	-	-
DHEC	04/12/79	0.3	0.6	3.9	1.7	-	-	-	-
DHEC	07/02/79	1.9	0.9	5.5	1.3	-	-	-	-
DHEC	10/22/79	4.3	0.5	6.7	1.5	-	-	-	-
DHEC	09/19/83	1.6	0.6	2.6	0.7	-	-	-	-
DHEC	06/17/86	1.6	0.4	3.5	0.5	-	-	-	-
Water Supply Carpenters Trailer Park									
DHEC	12/12/78	0.5	0.6	2.2	1.4	-	-	-	-
DHEC	03/19/79	1.4	1.4	2.5	1.6	-	-	-	-
DHEC	08/01/79	1.4	0.6	3.8	1.9	-	-	-	-
DHEC	11/26/79	0.9	1.2	2.7	1.8	-	-	-	-
DHEC	02/21/80	0.7	1.2	0.6	1.5	-	-	-	-
SRS	00/00/86	0.3	-	2.0	-	-	-	-	-
Water Supply College Acres									
DHEC	06/27/79	1.6	1.0	3.6	1.2	-	-	-	-
DHEC	09/24/79	2.5	1.2	2.5	1.1	-	-	-	-
DHEC	12/20/79	0.1	0.5	2.8	1.5	-	-	-	-
DHEC	03/20/80	1.3	0.8	3.3	1.1	-	-	-	-
DHEC	04/22/83	2.3	0.8	1.9	0.7	-	-	-	-
DHEC	07/18/85	2.6	0.5	3.5	0.5	-	-	-	-
Water Supply Country Squire Mobile Home Park									
DHEC	12/11/76	1.0	0.5	2.6	0.6	-	-	-	-
DHEC	03/08/79	1.3	1.0	6.3	2.0	-	-	-	-
DHEC	06/12/79	1.3	0.7	3.7	1.3	-	-	-	-
DHEC	09/19/79	1.1	1.4	4.3	3.1	-	-	-	-
DHEC	08/23/83	3.3	0.8	2.4	0.9	-	-	-	-
DHEC	06/10/86	3.5	0.6	3.1	0.6	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Family Community									
DHEC	05/16/79	3.7	0.5	10.3	0.7	-	-	-	-
DHEC	08/10/79	5.9	0.5	10.4	2.4	1.30	-	-	-
DHEC	11/20/79	6.8	1.6	12.3	1.9	1.30	-	-	-
DHEC	02/11/80	1.4	0.7	8.5	1.6	-	-	-	-
DHEC	07/05/83	0.4	0.3	1.6	0.6	-	-	-	-
DHEC	01/08/86	7.8	0.2	10.3	0.2	1.00	-	-	-
Water Supply Fort Belvedere									
EPA	07/27/81	0.3	0.3	1.2	0.8	-	-	59	-
Water Supply Gloverville									
DHEC	05/05/81	0.8	0.4	2.0	0.6	-	-	-	-
DHEC	08/28/81	0.4	0.2	1.6	0.4	-	-	-	-
DHEC	10/30/81	0.6	0.3	0.9	0.5	-	-	-	-
DHEC	11/12/81	0.4	0.1	1.5	0.3	-	-	-	-
DHEC	09/02/82	0.3	0.2	0.8	0.3	-	-	-	-
DHEC	10/19/83	0.6	0.6	2.0	0.7	-	-	-	-
EP	07/27/81	0.2	0.3	0.7	0.9	-	-	19	-
USC	00/00/80	-	-	-	-	0.70	2.73	59	-
Water Supply Graniteville									
DHEC	05/17/79	1.2	1.0	1.5	1.0	-	-	-	-
DHEC	08/01/79	0.8	1.3	1.7	1.4	-	-	-	-
DHEC	11/26/79	0.8	0.9	1.8	1.0	-	-	-	-
DHEC	02/21/80	0.1	0.3	0.2	0.7	-	-	-	-
DHEC	07/14/83	0.6	0.4	1.5	0.6	-	-	-	-
DHEC	01/08/86	1.2	0.5	1.9	0.6	-	-	-	-
Water Supply Green Acres Trailer Park									
DHEC	02/21/79	0.2	0.8	0.6	1.2	-	-	-	-
DHEC	05/17/79	-	0.2	1.4	0.8	-	-	-	-
DHEC	08/01/79	3.1	1.6	5.4	1.9	-	-	-	-
Water Supply Hidden Haven Mobile Home Park									
DHEC	01/19/87	1.2	0.5	2.1	0.7	-	-	-	-
Water Supply Independent Mobile Home Park									
DHEC	07/23/86	0.7	0.3	2.2	0.4	-	-	-	-

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SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Jackson									
DHEC	03/17/78	2.9	2.0	6.9	1.5	-	-	-	-
DHEC	03/17/78	2.9	2.0	5.5	1.6	-	-	-	-
DHEC	12/20/77	2.5	1.4	5.5	1.6	-	-	-	-
DHEC	09/14/78	0.1	0.5	0.3	1.0	-	-	-	-
DHEC	12/20/77	2.5	1.9	5.5	1.8	-	-	-	-
DHEC	05/18/81	0.8	0.4	5.9	1.3	-	-	-	-
DHEC	08/31/81	16.6	2.2	10.2	1.7	1.60	-	-	-
DHEC	10/30/81	1.4	0.8	1.6	1.2	-	-	-	-
DHEC	11/12/81	0.7	0.4	0.3	0.7	-	-	-	-
DHEC	12/30/82	2.2	0.7	1.8	0.8	-	-	-	-
DHEC	02/25/83	0.6	0.6	1.6	1.7	-	-	-	-
DHEC	05/11/83	1.1	0.6	2.4	1.0	-	-	-	-
DHEC	03/12/85	1.8	0.9	1.9	1.2	-	-	-	-
DHEC	11/10/86	1.9	1.4	2.2	1.9	-	-	-	-
DHEC	01/19/87	1.1	0.7	1.5	1.1	-	-	-	-
DHEC	04/03/87	1.4	0.4	1.9	0.6	-	-	-	-
EPA	07/27/81	1.7	0.5	1.1	0.6	-	-	394	-
USC	00/00/80	-	-	-	-	2.20	0.97	680	-
USC	00/00/80	-	-	-	-	17.14	4.80	480	-
SRS	00/00/86	1.0	2.1	-	-	-	-	-	-
RPI	10/23/87	-	-	-	-	2.60	3.10	73	<0.1
Water Supply Langley									
DHEC	06/13/79	0.5	0.5	3.0	1.1	-	-	-	-
DHEC	09/27/79	0.8	0.6	3.5	1.1	-	-	-	-
DHEC	12/19/79	0.4	0.6	2.7	1.4	-	-	-	-
DHEC	03/10/80	1.7	0.8	3.7	1.1	-	-	-	-
DHEC	04/22/83	2.6	0.7	3.7	0.8	-	-	-	-
DHEC	06/20/85	0.3	0.3	2.9	0.7	-	-	-	-
EPA	07/27/81	0.3	0.2	1.8	0.9	-	-	73	-
SRS	00/00/86	1.4	-	2.2	-	-	-	-	-
Water Supply Lawhead Mobile Home Park (Deleted)									
DHEC	07/23/86	2.5	0.5	3.6	0.5	-	-	-	-
Water Supply Midland Valley									
DHEC	05/21/79	0.2	0.3	1.0	0.8	-	-	-	-

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SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Suppl;y Mobile Home Estates									
DHEC	12/12/78	0.6	0.6	3.3	1.7	-	-	-	-
DHEC	03/19/79	0.6	0.6	1.3	1.4	-	-	-	-
DHEC	06/13/79	0.6	0.6	3.1	1.2	-	-	-	-
DHEC	09/27/79	0.7	0.8	2.3	1.1	-	-	-	-
DHEC	08/23/83	0.7	0.3	3.0	0.4	-	-	-	-
DHEC	06/11/86	2.8	0.5	4.0	0.5	-	-	-	-
Water Supply Monetta									
DHEC	12/14/78	2.1	1.6	2.9	4.7	-	-	-	-
DHEC	03/15/79	0.6	0.6	8.5	2.8	-	-	-	-
DHEC	06/18/79	3.3	1.3	9.3	4.1	-	-	-	-
DHEC	09/12/79	1.2	0.9	6.7	3.9	-	-	-	-
DHEC	08/28/81	1.2	0.4	5.5	0.6	-	-	-	-
DHEC	10/15/81	1.1	0.7	5.8	1.0	-	-	-	-
DHEC	04/12/82	4.2	0.5	6.5	0.5	-	-	-	-
DHEC	07/12/82	1.7	0.7	5.1	1.3	-	-	-	-
DHEC	04/22/83	3.3	0.7	6.8	0.9	-	-	-	-
DHEC	06/18/85	0.6	0.6	4.2	1.4	-	-	-	-
Water Supply Monetta Well #1									
USC	00/00/78	-	-	-	-	0.50	0.60	1767	-
Water Supply Monetta Well #2									
USC	00/00/78	-	-	-	-	0.90	0.30	3854	-
Water Supply Monetta Well #3									
USC	00/00/78	-	-	-	-	0.50	0.30	3126	-
Water Supply Monetta Well #4									
USC	00/00/78	-	-	-	-	3.10	0.90	6667	-
Water Supply Monetta Well #5									
USC	00/00/78	-	-	-	-	1.30	1.80	6310	-
Water Supply Monetta Well #6									
USC	00/00/78	-	-	-	-	1.10	1.00	8920	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Monetta Well #7									
USC	00/00/78	-	-	-	-	6.70	7.30	9210	-
Water Supply Monetta Well #8									
USC	00/00/78	-	-	-	-	10.50	11.90	14800	-
Water Supply Montmorenci - Couchton									
DHEC	04/02/79	1.9	0.9	4.7	1.3	-	-	-	-
DHEC	07/05/79	1.9	2.3	11.3	4.7	-	-	-	-
DHEC	10/09/79	2.7	2.0	3.8	3.0	-	-	-	-
DHEC	01/14/80	1.0	1.3	2.6	2.8	-	-	-	-
DHEC	06/09/83	0.8	0.9	2.1	1.8	-	-	-	-
DHEC	10/18/85	3.3	1.6	5.8	2.2	-	-	-	-
USC	00/00/80	-	-	-	-	0.40	0.40	296	-
USC	00/00/80	-	-	-	-	0.70	0.90	198	-
Water Supply New Ellenton									
DHEC	03/17/78	1.3	0.8	3.1	1.6	-	-	-	-
DHEC	01/18/78	1.1	0.9	2.6	1.3	-	-	-	-
DHEC	07/28/78	0.6	0.9	1.2	1.3	-	-	-	-
DHEC	09/14/78	1.1	1.0	1.9	1.2	-	-	-	-
DHEC	04/22/83	1.0	0.8	2.7	1.1	-	-	-	-
DHEC	05/22/85	0.6	0.2	0.9	0.4	-	-	-	-
DHEC	11/10/86	1.8	0.9	3.6	1.2	-	-	-	-
DHEC	01/19/87	0.7	0.6	1.5	1.0	-	-	-	-
DHEC	04/03/87	0.3	0.5	4.0	1.3	-	-	-	-
EPA	07/27/81	0.3	0.3	0.9	0.9	-	-	155	-
RPI	10/23/87	-	-	-	-	<1.00	1.10	23	-
SRS	00/00/86	1.2	-	2.1	-	-	-	-	-
Water Supply New Holland									
DHEC	04/02/79	0.6	0.5	2.0	0.9	-	-	-	-
DHEC	07/05/79	0.9	0.9	3.1	1.5	-	-	-	-
DHEC	10/09/79	0.4	0.4	1.6	0.9	-	-	-	-
DHEC	01/14/80	0.3	0.4	1.4	0.8	-	-	-	-
DHEC	06/06/83	0.6	0.4	1.8	0.6	-	-	-	-
DHEC	12/12/85	0.8	0.1	2.2	0.1	-	-	-	-
DHEC	11/13/85	1.7	0.4	2.9	0.5	-	-	-	-
DHEC	02/20/87	1.0	0.5	3.0	0.7	-	-	-	-
DHEC	04/03/87	1.1	0.3	3.4	0.5	-	-	-	-
USC	00/00/80	-	-	-	-	0.30	1.14	-	-

M9005067

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply North Augusta									
DHEC	09/14/78	0.4	0.4	1.4	0.9	-	-	-	-
DHEC	06/16/78	0.4	0.4	1.4	1.4	-	-	-	-
DHEC	03/17/78	0.6	1.0	4.8	1.8	-	-	-	-
DHEC	12/20/77	0.2	0.7	3.6	1.7	-	-	-	-
DHEC	03/21/79	0.8	0.6	2.7	0.7	-	-	-	-
DHEC	06/22/79	0.2	0.6	0.8	1.1	-	-	-	-
DHEC	09/14/79	0.4	0.6	2.2	1.1	-	-	-	-
DHEC	12/11/79	0.4	0.4	2.3	1.1	-	-	-	-
DHEC	03/20/80	0.4	0.4	2.2	1.6	-	-	-	-
DHEC	06/20/80	0.2	0.4	3.8	1.2	-	-	-	-
DHEC	09/26/80	0.4	0.4	0.6	1.2	-	-	-	-
DHEC	12/19/80	0.4	0.4	1.9	0.6	-	-	-	-
DHEC	02/28/83	0.3	0.5	2.0	1.0	-	-	-	-
DHEC	03/12/85	1.0	0.5	3.3	0.8	-	-	-	-
SRS	00/00/86	0.2	-	0.8	-	-	-	-	-
Water Supply Oak Hill Development									
DHEC	05/23/79	1.1	0.7	2.2	1.0	-	-	-	-
DHEC	08/22/79	1.0	0.6	3.4	1.1	-	-	-	-
DHEC	11/27/79	1.8	0.9	5.6	1.4	-	-	-	-
DHEC	02/11/80	0.9	0.6	2.5	1.0	-	-	-	-
DHEC	07/18/83	1.8	0.6	2.3	0.7	-	-	-	-
DHEC	02/18/86	1.7	0.4	2.7	0.4	-	-	-	-
Water Supply Parker Trailer Park									
DHEC	12/13/78	0.1	0.4	1.6	1.3	-	-	-	-
DHEC	03/19/79	0.7	0.8	2.5	1.4	-	-	-	-
DHEC	06/13/79	1.4	0.8	2.4	1.0	-	-	-	-
DHEC	09/27/79	0.5	0.5	1.9	0.9	-	-	-	-
DHEC	08/23/83	0.5	0.5	2.4	1.0	-	-	-	-
DHEC	06/11/86	0.3	0.5	0.8	1.0	-	-	-	-
Water Supply Perry									
DHEC	06/21/79	7.8	2.5	7.4	2.1	0.80	-	-	-
DHEC	12/08/78	3.1	1.7	3.2	1.6	-	-	-	-
DHEC	10/04/79	8.7	1.9	9.7	1.7	2.10	-	-	-
DHEC	04/10/80	9.3	1.9	13.9	2.0	1.20	-	-	-
DHEC	02/25/83	8.0	0.3	5.8	0.3	3.70	-	-	-
DHEC	08/05/83	6.9	0.8	6.2	0.7	3.70	-	-	-
DHEC	08/17/83	8.4	0.9	5.0	0.7	-	-	-	-
DHEC	11/18/83	9.1	1.1	8.0	1.0	3.70	-	-	-
DHEC	02/17/84	9.7	0.7	8.0	0.6	3.70	-	-	-
DHEC	05/23/85	7.4	0.7	5.3	0.6	6.90	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Perry, Contd									
DHEC	11/20/85	9.8	0.4	8.5	0.3	2.30	-	-	-
DHEC	02/12/86	8.3	1.1	8.5	1.0	2.10	-	-	-
DHEC	06/12/86	8.9	1.1	7.0	1.0	4.50	-	-	-
DHEC	11/13/86	14.3	2.3	13.4	2.0	4.30	1.80	-	-
DHEC	02/20/87	6.8	0.3	6.7	0.3	-	-	-	-
DHEC	04/03/87	7.4	1.0	7.3	1.0	-	-	-	-
Water Supply Pine Acres Trailer Park									
DHEC	12/14/78	0.4	0.8	2.1	1.4	-	-	-	-
DHEC	03/15/79	0.5	0.9	1.3	1.3	-	-	-	-
DHEC	06/18/79	0.5	0.5	2.1	0.9	-	-	-	-
DHEC	09/12/79	0.4	0.4	1.9	0.9	-	-	-	-
DHEC	08/16/83	0.5	0.5	3.2	0.8	-	-	-	-
DHEC	06/10/86	3.1	0.5	3.9	0.5	-	-	-	-
Water Supply Riveria Mobile Home Park									
DHEC	01/16/79	3.2	0.9	10.1	2.4	-	-	-	-
DHEC	04/19/79	5.8	0.7	12.4	0.8	0.80	-	-	-
DHEC	07/24/79	12.1	2.1	15.4	2.1	1.70	-	-	-
DHEC	10/15/79	4.2	1.3	8.1	1.5	1.10	-	-	-
DHEC	09/21/83	4.4	0.4	4.5	0.4	-	-	-	-
Water Supply Salley									
DHEC	12/08/78	5.3	2.9	5.2	2.0	0.80	-	-	-
DHEC	09/30/77	2.1	1.4	1.9	1.4	-	-	-	-
DHEC	12/01/76	3.2	1.6	3.6	1.6	-	-	-	-
DHEC	09/18/76	1.2	1.0	1.5	1.2	-	-	-	-
DHEC	04/10/80	4.8	1.7	8.1	1.7	0.60	-	-	-
DHEC	04/22/83	2.6	1.0	3.2	1.2	-	-	-	-
DHEC	04/05/85	1.0	0.4	2.6	0.7	-	-	-	-
DHEC	11/13/86	2.1	0.9	5.9	1.4	-	-	-	-
DHEC	02/20/87	2.5	0.7	6.5	1.0	-	-	-	-
DHEC	04/03/87	1.0	0.4	3.4	0.7	-	-	-	-
USC	00/00/80	-	-	-	-	0.58	0.96	-	-
Water Supply Silver Bluff Trailer Park									
DHEC	01/10/79	0.1	0.4	3.1	1.5	-	-	-	-
DHEC	04/02/79	1.1	0.7	3.3	1.1	-	-	-	-
DHEC	07/05/79	0.7	0.7	1.6	1.2	-	-	-	-
DHEC	10/09/79	0.5	0.5	1.2	0.8	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AI, SC, Contd									
Water Supply Talatha									
DHEC	06/27/79	3.7	1.2	7.5	1.5	-	-	-	-
DHEC	09/24/79	3.0	1.1	7.6	1.5	-	-	-	-
DHEC	12/20/79	0.5	0.7	1.5	1.2	-	-	-	-
DHEC	03/04/80	1.3	0.8	1.3	0.8	-	-	-	-
DHEC	05/11/83	2.5	0.9	2.3	1.0	-	-	-	-
DHEC	08/23/83	4.4	0.4	5.5	0.3	-	-	-	-
DHEC	09/13/85	1.5	0.4	3.5	0.5	-	-	-	-
EPA	07/27/81	0.7	0.3	0.5	0.5	-	-	344	-
EPA	07/27/81	1.3	0.4	1.4	0.7	-	-	373	-
Water Supply Wagener									
DHEC	12/08/78	4.0	1.7	6.3	2.0	0.60	-	-	-
DHEC	09/24/77	1.6	1.1	5.3	1.8	-	-	-	-
DHEC	09/18/76	1.6	1.1	2.9	1.5	-	-	-	-
DHEC	02/10/76	3.1	1.5	10.2	2.4	-	-	-	-
DHEC	03/20/80	3.2	1.6	3.9	1.7	-	-	-	-
DHEC	02/25/83	1.3	0.7	2.2	0.9	-	-	-	-
DHEC	04/05/85	0.1	0.2	1.3	0.6	-	-	-	-
DHEC	11/13/86	1.7	0.8	4.8	1.3	-	-	-	-
DHEC	02/20/87	1.2	0.5	3.3	0.7	-	-	-	-
DHEC	04/03/87	0.6	0.6	3.0	1.1	-	-	-	-
Water Supply Wagener, Contd									
EPA	07/27/81	0.3	0.2	1.6	0.8	-	-	226	-
USC	00/00/80	-	-	-	-	0.54	1.27	-	-
USC	00/00/80	-	-	-	-	0.28	0.71	-	-
RPI	10/23/87	-	-	-	-	<1.00	<1.00	21	-
Water Supply Warrenville									
DHEC	04/16/79	1.1	1.0	1.6	1.3	-	-	-	-
DHEC	07/02/79	1.7	0.9	3.3	1.1	-	-	-	-
DHEC	10/22/79	3.1	1.1	3.1	1.1	-	-	-	-
DHEC	01/07/80	0.3	0.9	1.0	2.5	-	-	-	-
DHEC	06/09/83	0.2	0.3	0.7	0.5	-	-	-	-
DHEC	11/06/05	0.6	0.4	1.1	0.4	-	-	-	-
USC	00/00/80	-	-	-	-	0.30	0.50	146	-
Water Supply Watkins Mobile Home Park									
DHEC	07/23/86	2.3	0.6	4.0	0.8	-	-	-	-
DHEC	11/10/86	2.0	0.6	4.8	0.8	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

County, State - AI, SC, Contd

Water Supply Wilkins Trailer Park

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
DHEC	12/12/78	0.9	0.8	2.4	1.4	-	-	-	-
DHEC	03/27/79	2.7	1.4	5.8	1.9	-	-	-	-
DHEC	06/27/79	3.0	1.1	6.0	1.4	-	-	-	-
DHEC	09/24/79	2.8	0.5	5.3	1.3	-	-	-	-
DHEC	08/15/83	2.1	0.4	3.4	0.5	-	-	-	-
DHEC	06/13/86	2.2	0.4	3.7	0.5	-	-	-	-

County, State - AL, SC

Water Supply Allendale

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
DHEC	04/26/79	1.4	1.9	10.6	2.9	-	-	-	-
DHEC	01/25/78	1.8	1.4	11.2	2.0	-	-	-	-
DHEC	12/14/78	1.8	1.4	11.2	2.0	-	-	-	-
DHEC	08/01/78	0.2	0.8	9.6	2.0	-	-	-	-
DHEC	10/31/83	1.9	1.8	2.8	1.4	-	-	-	-
DHEC	12/05/83	3.1	1.7	4.4	1.6	-	-	-	-
DHEC	12/29/86	0.6	0.5	6.1	1.0	-	-	-	-
DHEC	02/27/87	2.3	2.0	4.4	1.6	-	-	-	-
DHEC	05/11/87	0.6	0.6	0.9	0.7	-	-	-	-
EPA	07/28/81	0.4	0.7	1.7	1.0	-	-	227	-
SRS	00/00/86	0.1	-	0.8	-	-	-	-	-

Water Supply Fairfax

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
DHEC	01/17/79	0.3	1.0	3.4	1.9	-	-	-	-
DHEC	04/26/79	1.0	1.5	8.6	2.4	-	-	-	-
DHEC	07/23/79	0.6	0.4	7.3	2.4	-	-	-	-
DHEC	10/25/79	0.3	0.8	4.5	2.1	-	-	-	-
DHEC	11/17/83	1.4	0.9	8.8	1.2	-	-	-	-
DHEC	12/19/86	0.3	0.1	3.0	0.2	-	-	-	-
EPA	07/28/81	0.2	0.3	2.4	1.0	-	-	74	-

Water Supply Indian Park Water District

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
DHEC	06/28/79	0.3	0.7	7.3	1.7	-	-	-	-
DHEC	09/20/79	2.0	1.5	7.8	1.8	-	-	-	-
DHEC	12/20/79	0.7	1.4	7.5	2.4	-	-	-	-
DHEC	03/04/80	2.0	1.5	8.0	1.8	-	-	-	-
DHEC	11/17/83	2.9	1.4	8.0	1.8	-	-	-	-
DHEC	12/27/86	1.2	0.6	7.6	0.8	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AL, SC, Contd									
Water Supply Sycamore									
DHEC	04/26/79	1.4	0.7	10.1	1.4	-	-	-	-
DHEC	06/28/79	2.6	1.9	9.2	1.9	-	-	-	-
DHEC	09/20/79	1.9	1.5	6.9	1.7	-	-	-	-
Water Supply Ulmers									
DHEC	12/13/78	0.6	0.6	0.2	1.1	-	-	-	-
DHEC	03/07/79	0.9	1.4	9.0	3.9	-	-	-	-
DHEC	06/28/79	0.2	1.5	1.0	1.8	-	-	-	-
DHEC	09/20/79	0.7	1.7	2.7	2.1	-	-	-	-
DHEC	10/31/83	1.2	1.4	2.5	1.3	-	-	-	-
DHEC	12/19/86	0.1	0.2	2.2	0.3	-	-	-	-
Water Supply B. T. Darnell Trailer Park									
DHEC	01/24/79	0.6	0.6	4.1	4.6	-	-	-	-
DHEC	04/18/79	1.0	0.6	4.8	0.6	-	-	-	-
DHEC	07/18/79	0.6	0.6	2.3	1.7	-	-	-	-
DHEC	10/18/79	0.1	0.8	2.0	2.9	-	-	-	-
Water Supply Bamberg									
DHEC	05/04/87	0.6	0.6	1.5	0.6	-	-	-	-
DHEC	07/14/81	0.2	0.3	1.1	0.8	-	-	-	-
DHEC	12/07/78	0.4	1.7	2.5	1.8	-	-	-	-
DHEC	03/20/79	1.1	1.7	5.2	3.6	-	-	-	-
DHEC	06/25/79	1.3	2.1	2.7	3.2	-	-	-	-
DHEC	09/26/79	1.6	1.1	4.0	3.6	-	-	-	-
DHEC	12/22/83	0.9	0.3	2.4	0.4	-	-	-	-
NIRS	10/17/86	-	-	-	-	0.20	1.00	149	0.1
Water Supply Denmark									
DHEC	05/04/87	0.6	0.6	0.7	1.2	-	-	-	-
EPA	07/14/81	0.4	0.3	1.6	0.8	-	-	211	-
DHEC	01/24/79	0.5	1.9	3.8	4.8	-	-	-	-
DHEC	04/18/79	0.6	1.9	2.0	1.8	-	-	-	-
DHEC	07/18/79	1.7	1.8	3.3	1.8	-	-	-	-
DHEC	10/18/79	0.1	1.1	3.5	3.4	-	-	-	-
DHEC	01/09/84	0.9	1.2	0.7	1.2	-	-	-	-
DHEC	05/04/87	0.6	0.6	0.7	1.2	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - AL, SC, Contd									
Water Supply Ehrhardt									
DHEC	05/11/87	0.6	0.6	1.6	0.4	-	-	-	-
DHEC	01/24/79	0.6	0.6	5.6	5.2	-	-	-	-
DHEC	04/18/79	0.6	0.6	2.2	1.8	-	-	-	-
DHEC	07/18/79	0.6	0.6	4.9	2.2	-	-	-	-
DHEC	10/18/79	0.6	0.6	1.6	1.6	-	-	-	-
DHEC	01/09/84	0.6	0.6	1.6	1.4	-	-	-	-
DHEC	05/11/87	0.6	0.6	1.6	0.4	-	-	-	-
Water Supply Govan									
DHEC	05/18/87	0.1	0.4	0.3	0.6	-	-	-	-
DHEC	03/20/79	0.6	0.6	1.7	1.6	-	-	-	-
DHEC	05/22/79	0.6	0.6	0.9	1.0	-	-	-	-
DHEC	08/21/79	0.1	0.8	1.2	1.7	-	-	-	-
DHEC	11/01/79	0.6	0.6	1.6	1.6	-	-	-	-
DHEC	01/24/84	0.6	0.6	0.5	0.6	-	-	-	-
Water Supply Grigsby Mobile Home Park									
DHEC	05/04/87	0.6	0.7	1.3	1.2	-	-	-	-
Water Supply Olar									
DHEC	05/11/87	0.6	0.6	0.7	0.6	-	-	-	-
DHEC	02/27/79	0.5	0.7	4.7	1.8	-	-	-	-
DHEC	05/22/79	0.1	0.5	1.4	1.0	-	-	-	-
DHEC	08/21/79	1.0	1.1	0.8	0.9	-	-	-	-
DHEC	11/01/79	0.6	0.6	0.3	0.8	-	-	-	-
DHEC	01/24/84	0.6	0.6	0.8	0.6	-	-	-	-
County, State - BW, SC									
Water Supply Barnwell									
DHEC	12/19/86	0.3	0.3	1.3	0.5	-	-	-	-
DHEC	02/27/87	1.1	0.9	2.1	1.1	-	-	-	-
DHEC	05/06/87	0.6	0.6	0.6	0.6	-	-	-	-
EPA	07/19/81	0.4	0.3	1.1	0.7	-	-	339	-
SRS	00/00/86	0.3	-	0.9	-	-	-	-	-
RPI	10/23/87	-	-	-	-	<1.00	<1.00	14	-
RPI	10/23/87	-	-	-	-	<1.00	<1.00	14	-

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SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - BW, SC, Contd									
Water Supply Blackville									
DHEC	01/16/87	2.8	1.6	9.4	1.9	-	-	-	-
EPA	07/19/81	13.4	1.2	0.2	-	0.40	-	341	-
SRS	00/00/86	0.1	-	1.4	-	-	-	-	-
Water Supply Edisto Experimental Station									
DHEC	02/27/87	0.5	0.6	3.2	0.8	-	-	-	-
Water Supply Elko									
DHEC	02/27/87	0.4	2.0	3.7	4.3	-	-	-	-
Water Supply Hilda									
DHEC	02/27/87	0.1	0.6	3.1	1.3	-	-	-	-
Water Supply Jackson Mobile Home Park									
DHEC	05/06/87	1.2	0.5	2.3	0.5	-	-	-	-
Water Supply Rogers Trailer Park									
DHEC	05/06/87	0.4	0.2	1.0	0.4	-	-	-	-
Water Supply Williston									
DHEC	12/12/86	1.0	0.5	2.7	0.5	-	-	-	-
DHEC	01/16/87	3.1	1.2	3.4	0.8	-	-	-	-
DHEC	05/04/87	0.4	0.2	0.8	0.3	-	-	-	-
EPA	07/27/81	1.2	0.4	1.2	0.6	-	-	345	-
SRS	00/00/86	0.6	-	0.8	-	-	-	-	-
RPI	10/23/87	-	-	-	-	1.50	1.20	26	<0.1
County, State - ED, SC									
Water Supply Edgefield Authority									
DHEC	06/18/790	0.7	0.9	3.0	1.2	-	-	-	-
DHEC	09/12/79	0.2	0.2	2.7	1.0	-	-	-	-
DHEC	12/03/79	0.6	0.6	2.1	1.1	-	-	-	-
DHEC	03/19/80	0.7	0.8	2.7	1.1	-	-	-	-
DHEC	02/25/83	0.7	0.6	3.8	0.8	-	-	-	-
DHEC	01/10/85	0.6	0.6	3.3	1.2	-	-	-	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - OR, SC									
Water Supply Springfield									
RPI	10/23/87	-	-	-	-	<1.00	<1.00	50	-
County, State - SR, SC									
Water Supply F Area									
RPI	10/23/87	-	-	-	-	2.80	1.30	15	-
Water Supply Forestry Building									
RPI	10/23/87	-	-	-	-	2.20	1.10	5	<0.1
Water Supply Gate 7									
RPI	10/23/87	-	-	-	-	<1.00	<1.00	69	-
Water Supply Gate 8									
RPI	10/23/87	-	-	-	-	<1.00	<1.00	51	-
Water Supply H Area									
RPI	10/23/87	-	-	-	-	1.90	4.40	19	<0.1
Water Supply K Area									
RPI	10/23/87	-	-	-	-	<1.00	<1.00	2	-
Water Supply Par Pond Lab									
RPI	10/23/87	-	-	-	-	<1.00	<1.00	133	<0.1
Water Supply Pistol Range									
RPI	10/23/87	-	-	-	-	2.70	1.90	24	-
Water Supply TC									
RPI	10/23/87	-	-	-	-	1.00	<1.00	39	-
Water Supply Well 101-F									
RPI	10/23/87	-	-	-	-	1.10	2.30	15	-

SRS GROUND WATER RADIONUCLIDE DATA, Contd

Source of Data	Date Sampled	Gross Alpha Value	Gross Alpha ±SD	Gross Beta Value	Gross Beta ±SD	Ra-226	Ra-228	Rn-222	Total Uranium
County, State - SR, SC, Contd									
Water Supply Well 79-F									
RPI	10/23/87	-	-	-	-	2.90	3.00	15	-
Water Supply Well 905-66-H									
RPI	10/23/87	-	-	-	-	1.60	2.60	13	-
Water Supply Well 905-80-H									
RPI	10/23/87	-	-	-	-	1.70	3.60	12	-
Water Supply Well 905-88-H									
RPI	10/23/87	-	-	-	-	1.80	2.90	12	-

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