Radon Emissions From a High Volume Coal Fly Ash Structural Fill Site

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ABSTRACT

The Tennessee Valley Authority's Bull Run Fossil Plant is located in east Tennessee near Oak Ridge. This plant burns eastern bituminous Appalachian Basin coal, resulting in a "Class F" fly ash. In 1992 TVA contracted with ISG Resources, Inc. (then JTM, a coal ash management company) to utilize unmarketed fly ash from Bull Run as structural fill material in development of the Lost Ridge Industrial Park located in Clinton, Tennessee. This project ultimately used over one million cubic yards of fly ash at the 42 acre site. The project was conceived as a demonstration project for fly ash structural fills in Tennessee and was partially funded by the Electric Power Research Institute (EPRI).

Radon was used as an indicator for measuring the potential for emissions of naturally occurring radioactive materials (NORM) at the structural fill site. Radon levels were measured under ambient conditions and under confined conditions (inside structures). Ambient Radon levels were measured above several locations on the structural fill and compared to control ambient conditions. Ambient Radon levels measured directly over the fly ash fill were found to be comparable to levels measured under control conditions. Radon levels measured inside structures were done under three treatments simulating different slab-on-grade conditions. Data were collected over a seven year period. Radon levels measured in all structures over fly ash fill were found to be comparable to levels measured under control conditions. Structural fill impacts on metals levels in groundwater were also investigated at the site.

INTRODUCTION

The Tennessee Valley Authority's (TVA) Bull Run Fossil Plant, located near Oak Ridge, Tennessee, is a one-unit, 900 MW generating station which burns eastern bituminous Appalachian Basin coal and produces dry "Class F" fly ash. In the early 1990's, faced with limited and expensive on-site disposal capacity at several of its eleven plants, TVA began to investigate development of an off-site structural fill project for several reasons: to develop alternatives to Class II Landfills for ash disposal; to beneficially reuse coal combustion by-products on a large scale; and to reduce the cost of by-product disposal. At that time, a Class II Landfill permit could take over a year to obtain from the state, and no provisions existed for accelerated approval of a "Permit-by-Rule" structural fill in Tennessee.

In 1992 TVA contracted with JTM, Incorporated (now ISG Resources, Inc., hereinafter referred ISG), a coal ash management company, to utilize unmarketed fly ash from Bull Run as structural fill material in development of the Lost Ridge Industrial Park located in Clinton, Tennessee. The permit application was originally prepared for a Class II ash monofill including development of the site for heavy manufacturing, but, before work began, Tennessee adopted a Permit-by-Rule notification process for beneficial projects of this type, allowing ISG to adapt the application to the new designation. With the participation of the Electric Power Research Institute (EPRI), the project became a Demonstration Structural Fill Project which included Radon and groundwater monitoring during construction of the project and continued groundwater monitoring for a period following completion. With ash placement complete in September of 2001, the project ultimately consumed over one million cubic yards of fly ash at the 42 acre site. The data collected from this project will assist TVA and others in development of future large-scale structural fill projects in its seven-state service area.

THE STRUCTURAL FILL SITE: LOST RIDGE

The 42.1-acre property is located east of US Highway 25W, approximately one mile south of Clinton, Anderson County, Tennessee between the Norfolk-Southern Rail line that is adjacent to the highway and the Clinch River at River Mile Post Number 61.7, left bank. The Clinch River is impounded at this location and is synonymously known as Melton Hill Lake. The site is characterized by undulating topography, with surface elevations ranging from approximately 794 feet to 964 feet above Mean Seal Level. The land surface slopes in an east-southeasterly direction towards the Clinch river, with the greatest relief found in the northernmost portion of the site. The normal pool lake elevation at the site is 795 feet above MSL. The property is zoned Heavy Industrial. This location is accessible by barge, rail, and truck, and it is ISG's intention to enhance the property's use as an industrial park.[1] TVA's Bull Run Fossil Plant is located approximately seven miles from the site.

In the mid-eighties, the site was permitted by others as a coal barge loading facility, but was never developed for this use. The private owner held the parcel as unused industrial property, and local residents used the area as a dirt track for motorcycles and four-wheel drive vehicles, thereby creating a highly disturbed site. [1]

Fly ash was delivered by covered dump truck to the site in a conditioned state near its optimum moisture content for compaction, 15-20% by weight. By the end of each work day, all loads were spread by bulldozer or grader in one-foot lifts, and each lift was compacted by a vibratory smooth drum roller. Compaction to 95% of standard proctor maximum dry density was achieved to provide the required structural integrity.[1]

In-situ soils equivalent to three feet of clay with a maximum hydraulic conductivity of 1 x 10^{-6} cm/sec were used to meet buffer requirements between the base of the fill and the seasonal high water table of the uppermost aquifer. Intermediate cover was compacted fly ash which was tested regularly to ensure structural integrity. Final cover consists of two feet of compacted soil. Soils stockpiled from clearing and grubbing operations will be used as the surface compacted soil layer and as the layer to support vegetative growth.[1]

RADON MONITORING

Radon was used as an indicator for measuring the potential for emissions of naturally occurring radioactive materials (NORM) in structures located on a large-scale fly ash fill. Radon levels were initially measured under ambient conditions and then under confined conditions for a period of seven years.

Radon-222 is an inert gas which is the first radioactive decay product of Radium-226, itself a naturally-occurring radionuclide arising from the decay of Uranium-238. Radium-226 occurs naturally in soil, rock, coal, and fly ash.[2] A system-wide study of TVA fly ash found that the Ra-226 content of TVA ash varies between about 1-8 pCi/g[3,4] with a value of about 5 pCi/g being typical.[3] Gross alpha testing provides a measure of alpha particle activity from all the alpha emitters in the tested material including Uranium-238, Uranium-234, Thorium-230, Radium-226, Radon-222, Polonium-218, Polonium-214, and Polonium-210 down through the decay chain as shown in Table 1.[3,8]

Table 1
Decay Products of Uranium 238[5]

Radionuclide	Half Life	Radiation Type
Uranium 238	$4.5x10^9$ years	α
Thorium 234	24.1 days	β, γ
Protactinium 234	1 min	β, γ
Uranium 234	$245x10^3$ years	α, γ
Thorium 230	76,000 years	α, γ
Radium 226	1,600 years	α, γ
Radon-222	3.82 days	α, γ
Polonium-218	3.05 min	α
Lead-214	26.8 min	β, γ
Bismuth-214	19.7 min	β, γ
Polonium-214	$1.6x10^{-4}$ sec	α, β, γ
Lead-210	22 years	β, γ
Bismuth-210	5 days	β, γ
Polonium-210	138 days	α
Lead 206	stable	

Based on a 1991 study of fly ash at TVA's Shawnee, Bull Run, and John Sevier Fossil Plants[2], average Radon flux (a measure of the rate of flow of Radon gas across a surface) for in situ Bull Run fly ash was 0.098 pCi/m^2s while average environmental Radon flux was 0.207 pCi/ m^2s. Combining data from all three plants yielded an average Radon flux of 0.13 pCi/ m^2s from fly ash and an average flux of 0.33 pCi/ m^2s from environmental soil. The average radium concentration was 2.35 pCi/g for fly ash but only 0.66 pCi/g for soil, indicating that, although fly ash contains more radium than environmental soil, it emits much less Radon. Thus based on this study, a fly ash fill may have over 3.5 times as much radium as soil, but fly ash has a Radon flux of less than 40 percent that of the soil in adjacent areas.[2]

A 1987 session on Land Characterization at the Conference on Indoor Radon, Present and Future Issues discussed the range of Radon flux which should be of concern:

> "Experience indicates that the Radon flux rate ranges from 0.2 to 1.0 pCi/ m^2s in soils where existing structures do not contain elevated Radon concentrations. Flux rates between 2.0 and 5.0 pCi/m^2s are considered to present a low risk, measurements from 5.0 to 10.0 pCi/m^2s are considered high risk, and measurements exceeding 10 pCi/m^2s are considered to present an extreme risk of producing elevated Radon concentrations in an enclosed structure."[6]

Open land testing was performed at Lost Ridge during June, 1993, to provide a quick "snapshot" of the background Radon levels on the site. Using a commercially-available gamma particle detector hanging inside a cardboard "tent" with soil or fly ash mounded up around the base of the tent to prevent air circulation, ISG personnel left the units in place for twenty-four (24) hours, and, when the monitoring period was complete, collected the units, and placed them in foil pouches to prevent any possibility of additional gamma particle impingement.[8]

The units were placed at four different types of locations around the site representing different types of cover:

1. Directly on the soil cover at a point two feet above the fly ash fill below;
2. In a hole dug through the two-foot thick soil cover with the unit placed directly on the fly ash fill below;
3. Directly on the fly ash in an active area with no soil cover;
4. In a control area with no fly ash below.

A total of ten data points were obtained by locating test kits at two or three different locations over each of the four cover types; an eleventh monitor, a “field blank,” was opened, labeled, and then immediately resealed.[8]

Four permanent Radon monitoring stations (one control and three test stations) were constructed and placed in service in early August, 1993. The monitoring stations were built using standard wood frame construction with flat, overhanging shingled roofs. The structures were bolted to reinforced concrete pads that are 4 feet by 6 feet by 4 inches thick. Small air louvers at the front and back of the buildings allow a small amount of air circulation past the Radon monitors. Commercially-available alpha track monitors were hung from the rafters in each of the stations.[8]

The control monitoring station (Station #1) was located in an area away from the fly ash fill, and the three test stations were constructed over approximately ten feet of fly ash fill and two feet of covering soil. The different type of foundations studied at the test stations were:

Station 1: Control - Concrete pad placed directly on the soil;
Station 2: Concrete pad underlain by 6” gravel and a 6 mill plastic moisture barrier;
Station 3: Concrete pad placed directly on fly ash fill; and
Station 4: “Cracked” concrete pad placed directly on fly ash fill.

In the case of the “cracked” concrete pad, rather than saw or break the concrete to allow any Radon gas present to pass through the foundation into the building, four 2” diameter holes were cast in the concrete to approximate the area of a 6’ long, ¼” wide crack. The holes were spaced evenly in the slab area, and a minimum of two feet apart.[8]

In addition to the open land testing, samples of soils, fly ash, and concrete were analyzed for Radium-226 and gross alpha levels to determine background levels of radioactivity in these materials. Soil and fly ash samples were taken and shipped to the laboratory on the day that the open land kits were placed. The concrete samples were taken on the day that the Radon monitoring station foundations were poured, and these samples were pulverized before analysis.[1]

GROUNDWATER MONITORING

In August, 1992, five soil test borings were drilled at locations chosen by KBK. The general approach in determining well locations was to provide one up-gradient well (KBK-1) and four down-gradient wells (KBK 2-5). Site geometry, underground utility locations, site topography, and regional hydrogeologic conditions were considered when choosing the monitoring well locations. The five soil test borings were drilled to depths ranging from 10.5 to 20 feet with 8-14-inch O.D. hollow-stem augers. Groundwater was encountered in all of the borings at depths ranging from approximately four to sixteen feet below the ground surface. None of the borings encountered auger refusal.[1]

A type II groundwater monitoring well was installed through the auger hollow in each borehole. The monitoring wells were constructed with 2-inch I.D., schedule 40 PVC pipe with the lower five to ten feet consisting of 0.010-inch slotted screen. Clean silica sand was placed in the annular space around the well screen to create a filter pack that extended approximately two feet above the top of the screened interval. A two-foot thick layer of bentonite clay was then placed to seal the screened interval. The remainder of the annular space was filled to the ground surface with cement/bentonite grout. The top of the well pipe was terminated above the ground surface and completed with a locking cap and covered with a steel well cover mounted in a concrete pad.[1]

After the wells were in place, all of the wells were developed by removing a minimum of three well-volumes of groundwater with a clean, disposable, PVC bailer. The purpose of the well development was to remove fine sediments from the sand pack and the screen interval allowing fresh groundwater to flow into the well.[1]

Prior to each round of groundwater sampling, three well volumes of water were removed from each well. The wells were allowed to recover and were then sampled with a clean, disposable PVC bailer. Field measurements of temperature, specific conductivity and pH were measured and recorded for each sample. The pH and conductivity readings were taken in quadruplicate. Each sample was placed in a decontaminated, labeled, and sealed sample container. The sample containers were then placed in an ice-filled cooler for transportation to the certified analytical laboratory. The samples were analyzed for the eight RCRA inorganics: Silver (Ag), Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Lead (Pb) and Selenium (Se).[1]

Toxic Characteristic Leachate Procedure (TCLP) analysis of Bull Run dry fly ash performed in 1995 showed that the leachate exceeded the PDWS for Arsenic, Cadmium, Chromium, and Selenium as shown in Table 2.[7]

Table 2
Bull Run Fly Ash
TCLP

Metal	PDWS* Limit	TCLP
As	0.05	0.270
Ba	1	<0.010
Cd	0.01	0.016
Cr	0.05	0.055
Pb	0.05	<0.001
Hg	0.002	<0.0002
Se	0.01	0.043
Ag	0.05	<0.010

*Primary Drinking Water Standard

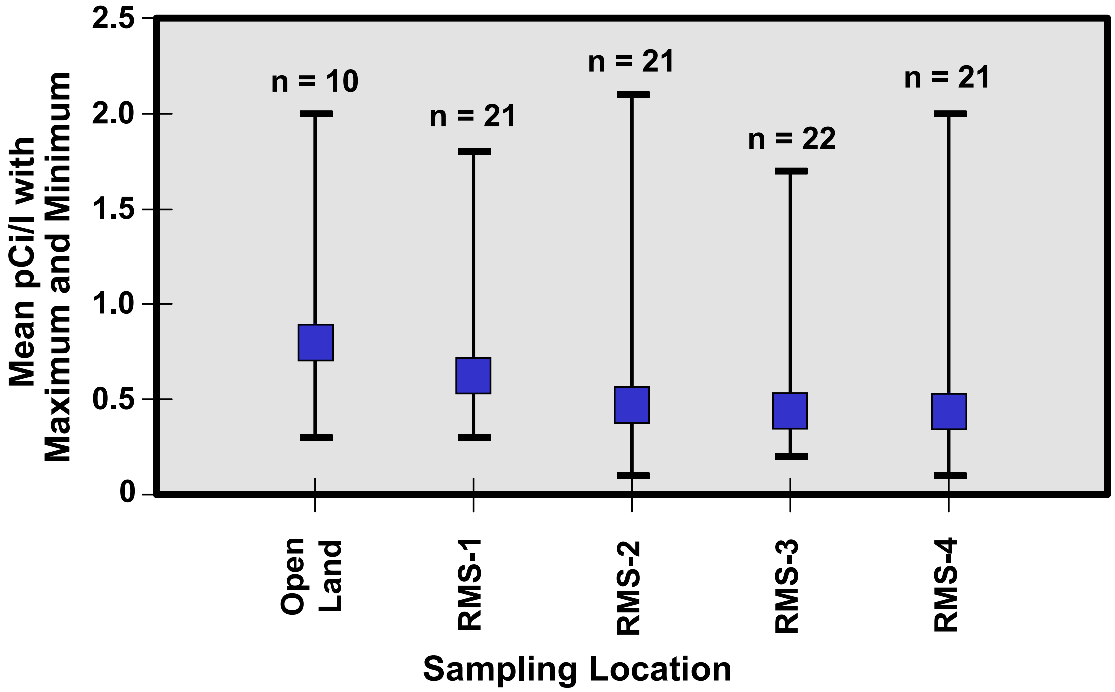
RADON RESULTS

Open land Radon measurements taken in June, 1993, show mean background Radon levels of 0.8 pCi/l and a range from <0.03 to 2.0 pCi/l (Figure 1). According to the distributor of the test units, the laboratory results obtained by using the tent method over bare ground may be two to ten times higher than would be expected in an ordinary building (a house with an airtight crawl space) constructed over the tested spot;[8] therefore, the actual range of open land Radon levels could be as low as <0.03 to 0.2 pCi/l.

Indoor measurements taken between August, 1993, and August, 2000, show that Radon Monitoring Station-1, the control structure that was located away from the ash fill, had a mean Radon reading higher than the mean readings for Stations 2-4 as summarized in Figure 1. Also, the Radon measurements for all four structures showed neither a downward nor an upward trend during the study.

Figure 1

Lost Ridge Radon Measurements



GROUNDWATER RESULTS

Results of these data are shown on Table 3 and Figures 2-5. Groundwater monitoring is planned to continue for at least two more years post-closure to complete the data set.

Analysis of the eight metals indicate a total of ten occasions when the Federal Primary Drinking Water Standards (PDWS) were exceeded for one or more metals. Of these occasions, eight of the ten occurred on the first day of sampling before ash placement began at the site. This suggests sample contamination or laboratory error. Of the remaining two occurrences, one exceedance of the Lead PDWS occurred in the upgradient well and therefore is not related to ash placement. The last occurrence was an exceedance of the PDWS for Cadmium which occurred in KBK W-2 in the second year of the project and has not reoccurred since. Therefore this result is likely unrelated to ash placement and is more likely due to sample contamination or laboratory error.

Conductivity has risen in all of the wells since July 1996, but more noticeably in KBK W-4 since June 1999. Since all wells, including the upgradient well have been affected, this is probably due to the influence of upgradient factors or recent long-term drought which has affected regional groundwater quality. A rise in pH has also been noted in all wells since 1994, but pH has decreased in all wells since the fall of 1998. Again, this would tend to indicate regional groundwater quality changes, not changes attributable to the ash fill.

Table 3: Lost Ridge Structural Fill

Comparison of Groundwater data with Primary Water Quality Standards.

MCL WELL ID	Ag (0.1) (mg/l)	As (0.05) (mg/l)	Ba (2.0) (mg/l)	Cd (0.005) (mg/l)	Cr (0.1) (mg/l)	Hg (0.002) (mg/l)	Pb (0.05) (mg/l)	Se (0.05) (mg/l)	TOTAL
Upgradient Wel KBK W - 1	0/34[b]	0/34	0/34	0/34	0/34	0/34	**1/34[a]**	0/34	**1/272**
KBK W - 2	0/34	0/34	0/34	**1/34**	0/34	0/34	**1/34[c]**	0/34	**2/272**
KBK W - 3	0/29	0/29	**1/29[c]**	**1/29[c]**	**1/29[c]**	**1/29[c]**	**1/29[c]**	0/29	**5/232**
KBK W - 4	0/34	0/34	0/34	0/34	0/34	0/34	**1/34[c]**	0/34	**1/272**
KBK W - 5	0/34	0/34	0/34	0/34	0/34	0/34	**1/34[c]**	0/34	**1/272**
TOTAL	**0/165**	**0/165**	**1/165**	**2/165**	**1/165**	**1/165**	**5/165**	**0/165**	**10/1320[c]**

a - KBK W-1 is the upgradient well
b - Number of analyses exceeding the drinking water standard over the total number of analyses
c - Eight of the ten exceedences occured on the first day of sampling before any ash was placed on site.
This suggests that those exceedances are not related to the Lost Ridge Project.

Figure 2
Depth to Groundwater

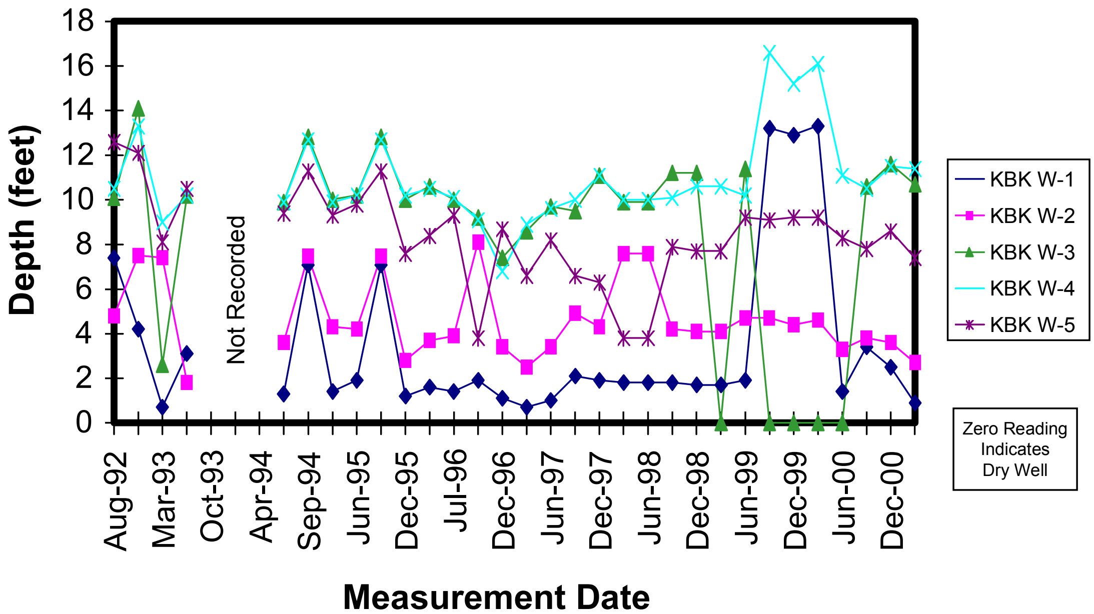


Figure 3
Groundwater Temperature

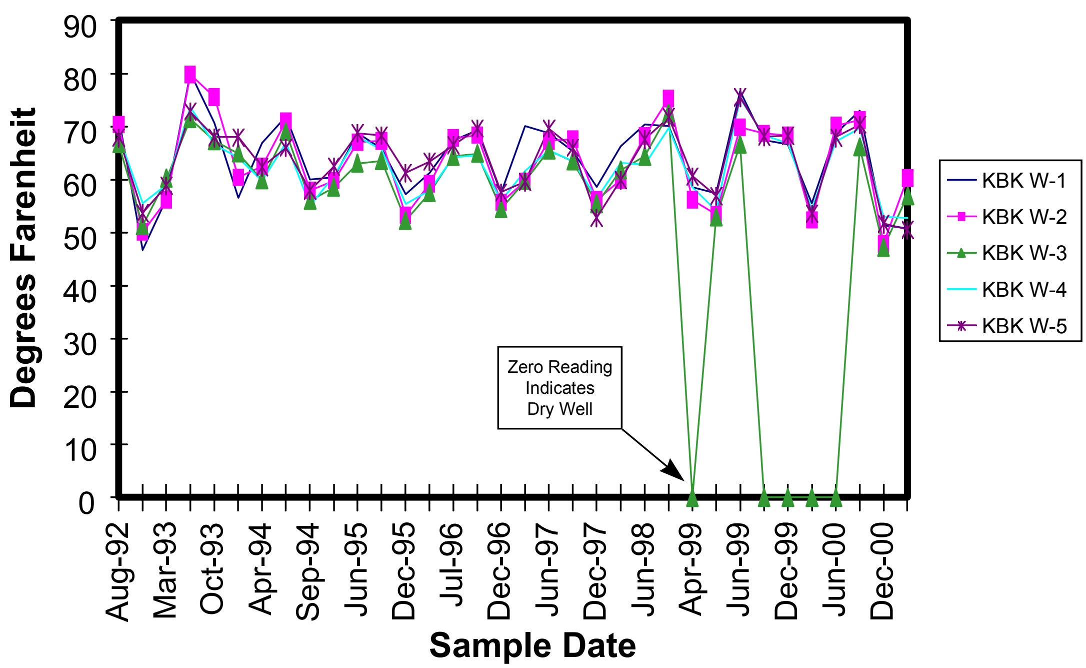


Figure 4
Groundwater pH

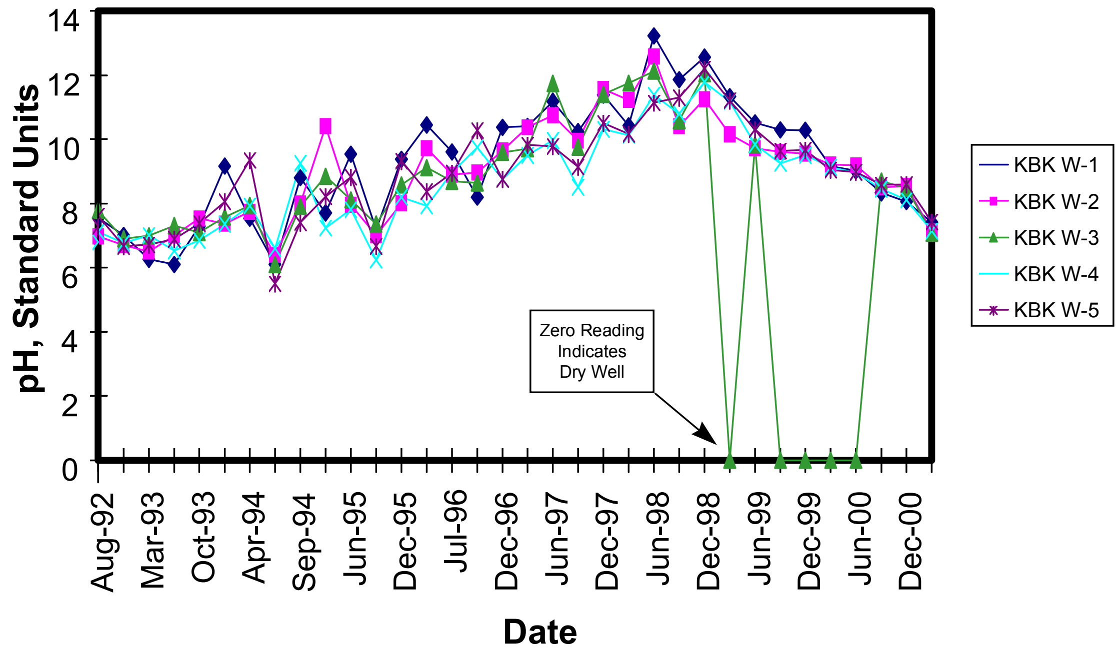
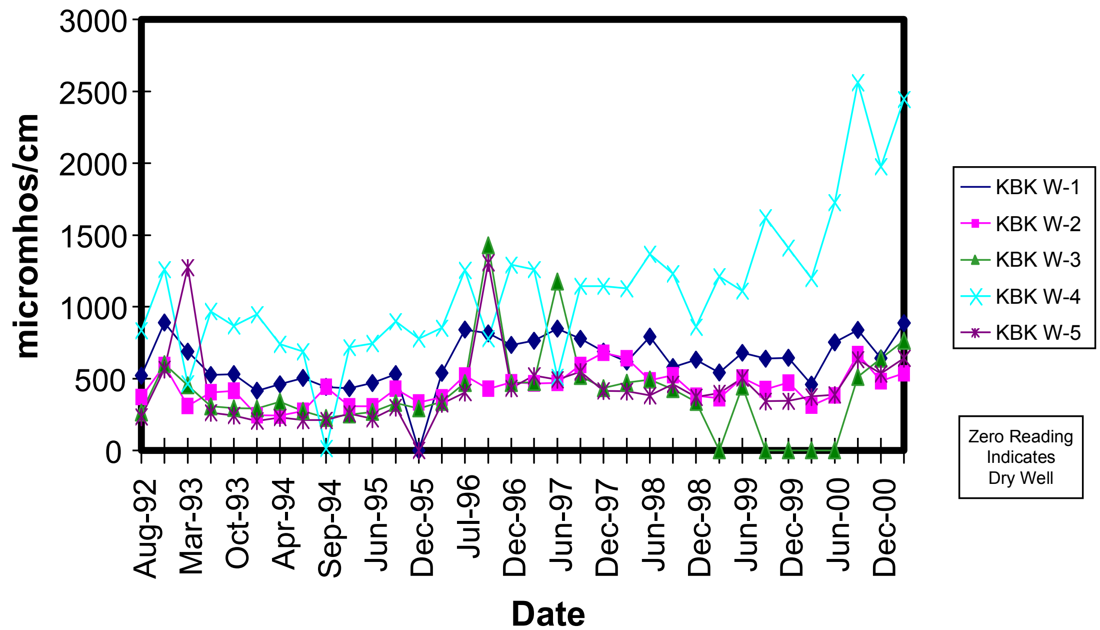


Figure 5
Groundwater Conductivity



DISCUSSION

The results of this long-term study indicate that a large-scale fly ash structural fill does not increase the presence of Radon-222 or other α-emitters in concrete, wood-frame structures located above the fill. The study was not intended to provide an accounting of Radon produced by local soils or the fly ash but was designed, instead, to provide evidence that Radon should not be a major concern when locating a structure on a properly designed and constructed fill.

Perhaps the design of the structural fill itself can account for the lower mean concentrations of Radon in structures RMS-2, -3, and -4. Radon flux is sensitive to moisture[9] and a fly ash fill which is constructed at optimum moisture to obtain 95% compaction could significantly reduce the flux. The glassy nature of fly ash particles may also contribute to the reduction of flux as observed in the study of Radon flux at three TVA plants.[2]

Although the open-land measurements may be exaggerated by as much as an order of magnitude and are probably meaningless for the purpose of providing a control, Structure RMS-1 provides an adequate comparison by its location away from the ash fill.

The groundwater results at Lost Ridge demonstrate that a low permeability soil buffer, a fly ash fill compacted to 95% of standard Proctor maximum density, and a surface cover of two feet of compacted soil did not adversely affect the quality of the local groundwater. Daily compaction of the fly ash also provided a low permeability crust which prevented water intrusion into the fill. The trends in water quality observed in the upgradient and downgradient wells over the study period are similar and probably reflect regional trends.

CONCLUSIONS

As a previous study found, fly ash may contain more radium but emit less Radon than local soils in the vicinity of Bull Run.[2] The lower Radon flux of fly ash, compaction of the fly ash fill, compacted soil surface cover, and isolation from underlying soils and bedrock contribute to a mitigation of environmental Radon in the area of this fly ash structural fill.

The water quality trends observed in the upgradient well tracked those of the downgradient wells, indicating that this large-scale structural fill did not negatively impact groundwater through the production of a metal-containing leachate. The construction period would be the time of most risk to groundwater, but, once the entire site is covered with two feet of compacted soil, further monitoring should continue to produce results similar to those observed over the past seven years.

RECOMMENDATIONS

The design of the Radon portion of this study provides a simple and inexpensive method for approximating the indoor concentrations of Radon which may be observed in structures constructed on large-scale fly ash structural fills. Similar Radon monitoring stations intended for long-term use could also be constructed at closed fly ash disposal sites.

The groundwater portion of this study will continue for two years post-closure, and the complete data set will provide technical validation for the structural fill design employed at Lost Ridge and for the Permit-by-Rule designation in Tennessee and other states. This information should be integrated into future applications for dry fly ash disposal and beneficial utilization.

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