EVALUATION OF SAMPLING AND TEST METHODOLOGIES, REPORT OF LEVELS OF RADIONUCLIDES PRESENT AND TOXICITY TESTING OF SEDIMENTS AND WATER FROM ROBERT S. KERR PROJECT LANDS

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ABSTRACT

Sequoyah Fuels Corporation operates a Uranium Hexafluoride (UF_6) production facility at a location southeast of the City of Gore, Oklahoma. The effluents from this plant enter the Illinois River via outfall streams from the plant. Previous studies have documented the presence of Uranium on the Robert S. Kerr Project Lands as a result of these effluents. Sequoyah Fuels Corporation has proposed construction of a pipeline directly from the plant to the Illinois River to eliminate the problem of uranium deposition on project lands. This study was conducted to determine the current level of Uranium series radionuclides on project lands. Analysis of collected samples shows the current level to be similar to that of previous studies in the major outfall and also documents the radionuclide levels in streams inactive at the time of sampling. Sediment samples taken in the Illinois River and further downstream in the Arkansas River indicate a diluting effect on the radionuclide concentrations downstream. Uranium concentrations downstream in the waters of the Illinois and Arkansas Rivers are within the limits specified in the Oklahoma Water Quality Standards. None of the Uranium soil concentrations measured would produce an external radiation exposure dose in excess of Nuclear Regulatory Commission limits for unrestricted areas.

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OBJECTIVES

The objectives of this work are to:

A. Determine the extent and levels of uranium and uranium daughters (Uranium Series) present on Corps of Engineers project lands along the effluent and storm water discharge streams of the Sequoyah Fuels Plant and the Illinois River adjacent to the discharge streams;

B. Analyze the measurements of Uranium series members to ascertain, if possible, the origin of the radionuclides, i.e. natural vs. process effluent discharge;

C. Determine, to the extent possible, any patterns of concentration, accumulation or dilution of the radionuclides;

D. Compare measured radionuclide concentrations to applicable Federal Regulations for the release of such to unrestricted areas; and

E. Evaluate the degree of hazard associated with the determined radionuclide concentrations.

BACKGROUND

THE URANIUM DECAY SERIES

Uranium is a primordial element existing in nature in three isotopic forms: U-238; U-235 and U-234. All isotopes of Uranium are radioactive with differing half lives and belong to one of two decay series. U-238 is the parent of the "Uranium" (4n+2) series (Figure 1) and has a half life of 4.5×10^9 years. U-234 belongs to this same series. It has a short half life (2.45×10^5 years) with respect to the age of the earth ($\approx 3 \times 10^9$ years). Thus, its existence in nature is a direct result of the series decay from U-238. Other radionuclide daughters, from Thorium through Lead, also exist as a result of the U-238 parent. U-235 (half life = 7.1×10^8 years) is the parent of another series called the "Actinium" (4n+3) series. If not subjected to chemical or physical separation, a decay series will attain a state of radioactive equilibrium wherein the number of atoms of each nuclide of a given series that decay during a given interval is nearly equal to the number of decays of the nuclide that heads that series.

Due to differing half lives, the current weight % of the Uranium isotopes is: U-238 - 99.2745%; U-235 - 0.72%; and U-234 - 0.0055%. U-234 is in a small weight % compared to U-238, but since it is in radiological equilibrium with U-238 it makes an equal contribution to the radioactive specific activity of Uranium samples. U-235 is of limited significance as far as radioactivity of natural Uranium. On a radiological basis,

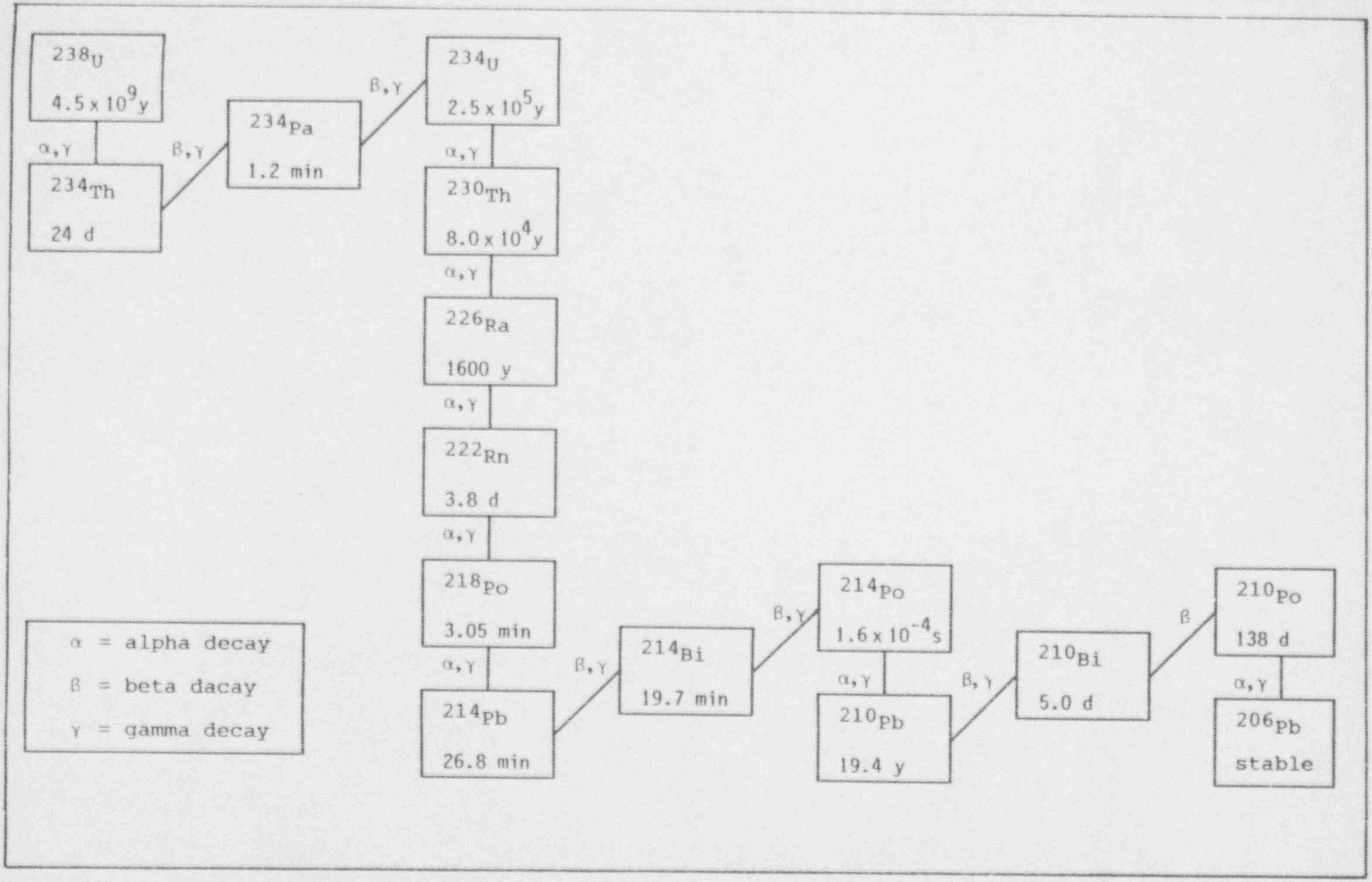


Figure 1. Uranium-238 Decay Series

one gram of Uranium yields approximately 0.33 µCi each of U-238 and U-234 and 0.015 µCi of U-235.

Although U-235 is present as less than 1% w/w of Uranium, it is the isotope responsible for the fission process in a thermal reactor. However, a sustained chain reaction is not possible in a thermal reactor using natural uranium. For criticality, the % content of U-235 must be increased. Such a process is entitled enrichment.

THE URANIUM FUEL CYCLE

The nuclear fuel cycle (Figure 2) for the production of a fission chain reaction is a multistep and multilocation process.

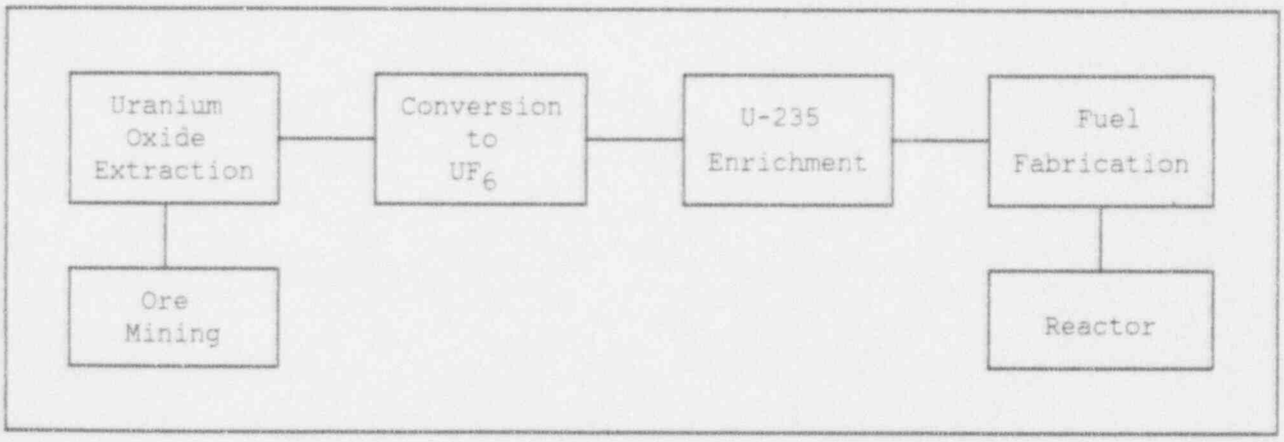


Figure 2. Uranium Fuel Cycle

After mining of an ore (normally containing Uranium in low w/w %), Uranium is extracted, usually as an oxide, from the ore, converted to a gaseous form, and then enriched in a gaseous diffusion process. The enriched uranium can then be fabricated as fuel for a reactor. In the process of extraction of the Uranium Oxide from the ore, the radioactive daughters remain behind as mill tailings. The material of interest (U_3O_8 - Yellow Cake) sent to a UF_6 (a gaseous compound of Uranium) generation facility is no longer Uranium in radioactive equilibrium which is of importance when analyzing environmental samples.

Since Uranium exists most everywhere in nature, soil and water samples will usually contain some Uranium. This concentration varies by geographic location with an "average" worldwide concentration in the range of 1-5 pCi/g (NCRP, 1987). [A pCi is a measure of radioactivity equalling 2.22 disintegrating atoms per minute. It is the approximate decay rate of 1.5 µg of natural Uranium]. Due to the decay series, radioactive daughters of the Uranium parent will also be present.

Examination of the Uranium-238 decay scheme (Figure 1) indicates that in a natural equilibrium condition, the radioactivity ratios of U-238:U-234:Th-230:Ra-226 should be unity. As a result, the ratio of natural Uranium radioactivity (U-234 and U-238) to Th-230 or Ra-226 should be two. The decay product of Ra-226 is Rn-222, a gas, and its emanation disrupts further equilibrium.

Although the process of Uranium Oxide extraction from ore is not perfect, the majority of the product (yellow cake) is Uranium with minimal daughters. The ingrowth of a radioactive daughter follows the equation

$$A_D = \frac{\lambda_D}{\lambda_D - \lambda_P} A_P^\circ [(\mathrm{Exp} - \lambda_P t) - (\mathrm{Exp} - \lambda_D t)$$

where:

A_D = Activity of the daughter radionuclide

λ_D = Decay constant of daughter radionuclide

A_P° = Initial activity of parent radionuclide

λ_P = Decay constant of parent radionuclide

t = elapsed time since separation of daughter from parent

The time (t_{eq}) for equilibrium to be reestablished between the parent and daughter is given by:

$$t_{eq} = \frac{\ln(\lambda_D / \lambda_P)}{\lambda_D - \lambda_P}$$

In the case of U-234/Th-230 parent-daughter, this time is approximately 200,000 years. Thus, an examination of the U:Th ratio of a sample can be an indication of whether or not the Uranium measured is of natural or other origin. It should also be noted that, as different elements, Uranium and Thorium have different chemical properties and soil affinities. This can affect equilibrium conditions and subsequently the ratios of uranium to its daughters.

CHEMISTRY OF URANIUM, THORIUM AND RADIUM

Uranium (atomic number 92) is a member of the group of elements known as actinides and exists in tri-, tetra-, penta- and hexapositive oxidation states. Uranium is found in the tetravalent oxidation state in primary igneous rocks and minerals but is oxidized to the penta- and hexavalent oxidation states in near surface environments. Compounds containing hexavalent uranium include uranium hexafluoride (UF_6), uranates and uranyl ion (UO_2^{+2}) complexes. Uranyl compounds are the largest class of uranium containing compounds and vary from simple salts to complex organic molecules.

Thorium, atomic number 90, is also an actinide element and exists in tri- and tetrapositive oxidation states. Thorium is found only in the tetravalent oxidation state in aqueous solutions.

Radium, atomic number 88, is not a member of the actinide elements group but, like uranium and thorium, exists as an electropositive ion. Radium has a single divalent oxidation state and may be found as free ions, in simple inorganic compounds such as radium sulfate ($RaSO_4$), or complexed with a variety of organic molecules in natural environments.

RADIOLOGICAL PROPERTIES OF URANIUM

The radioactive decay of Uranium or its daughters can result in the emission of one of 3 types of radiations (Kocher, 1985), referred to as alpha, beta or gamma radiation.

Alpha radiation is the emission of a particle identical in nature to a helium nucleus (He^{+2}). Typical alpha particle energies for the U-238 series are in the range of 4-5.5 MeV, yet travel very short distances (mm) due to their mass and charge. As a result, they are not considered an external hazard. Internal deposition of alpha emitters is of concern due to concentration of the decay energy in small volumes. Additionally, the radionuclide may have an affinity for a certain organ and intensify the effect due to bioconcentration.

Beta particles are identical to electrons and those in the U-238 series range in kinetic energy from 16 KeV to 3.3 MeV. The range of a beta particle is a function of its energy. It is generally considered that beta, like alpha, are a more significant internal, than external, hazard.

Gamma rays are electromagnetic photons which may accompany the emission of alpha or beta particles. They are highly penetrating and those of the U-238 series (Figure 3) range in energy from 63 KeV to approximately 2.5 MeV.

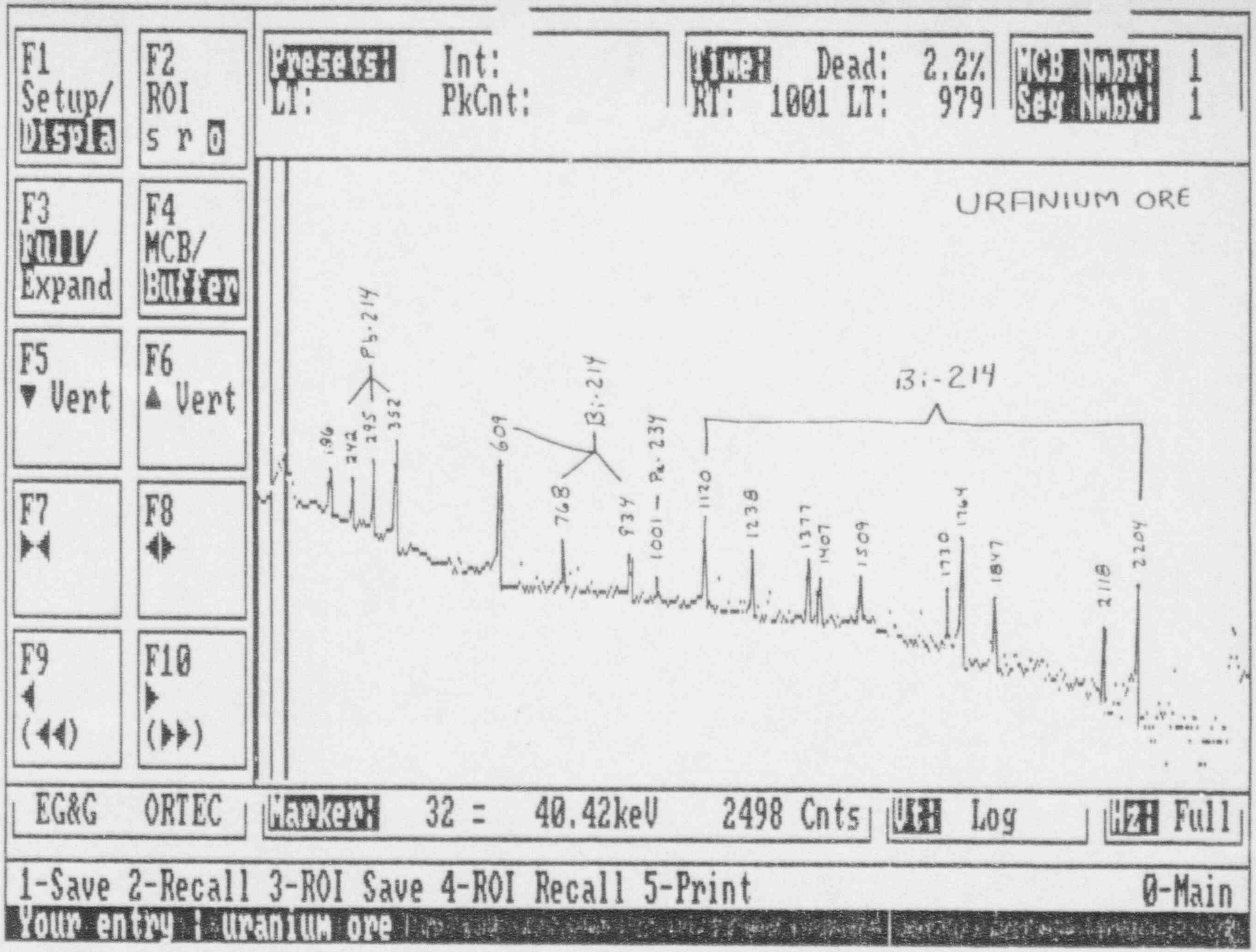


Figure 3. Gamma Ray Emission Spectrum of Uranium Ore [Uranium Series (4n+2) Daughters in Equilibrium]. Energies in KeV.

The radiological profile for Uranium that has been separated from its daughters (Figure 4) is significantly different, with lower energy radiation ranges as well as lower frequencies of emission of specific radiations. With time, and approach to equilibrium, the profile changes.

The radiation dose (measured in Rems) to an individual in an area containing radionuclides is a function of multiple factors. These include the identity and quantity of radionuclide, depth of location, residence time of the individual, topographical conditions, and many others. The calculated annual dose for occupancy in a location containing U-238 is 6.2×10^{-2} mRem/year per pCi/gram (Napier, 1982). With time, and growth towards equilibrium, this dose rate will change. It increases to 5.2×10^{-1} and 3.5 mRem/year per pCi/g after 100 and 1000 years respectively. The annual background radiation exposure due to terrestrial radiation averages approximately 50 mRem/year in Oklahoma (NCRP, 1987). The NRC limit for induced exposure to personnel outside a restricted area is 500 mRem/year.

UF_6 PRODUCTION AT SEQUOYAH FUELS FACILITY

The source of Uranium and its daughter radionuclides in waste water discharges from the Sequoyah Facility can be seen from an examination of the UF_6 conversion procedure. This procedure (Figure 5) essentially involves wet chemical purification to convert yellow cake to pure uranium trioxide followed by dry

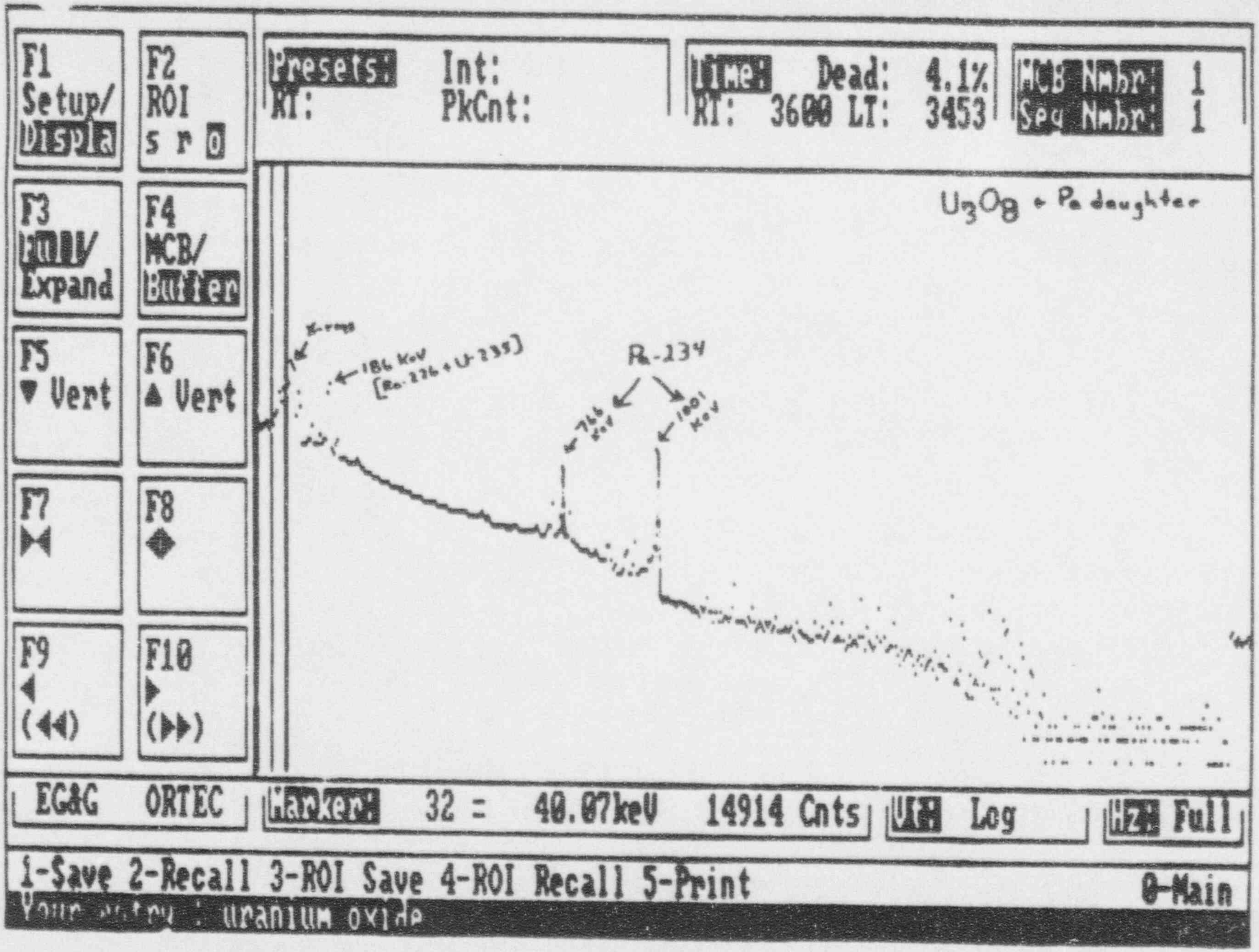


Figure 4. Gamma Ray Emission Spectrum of Uranium Oxide (with Protactinium Daughter).

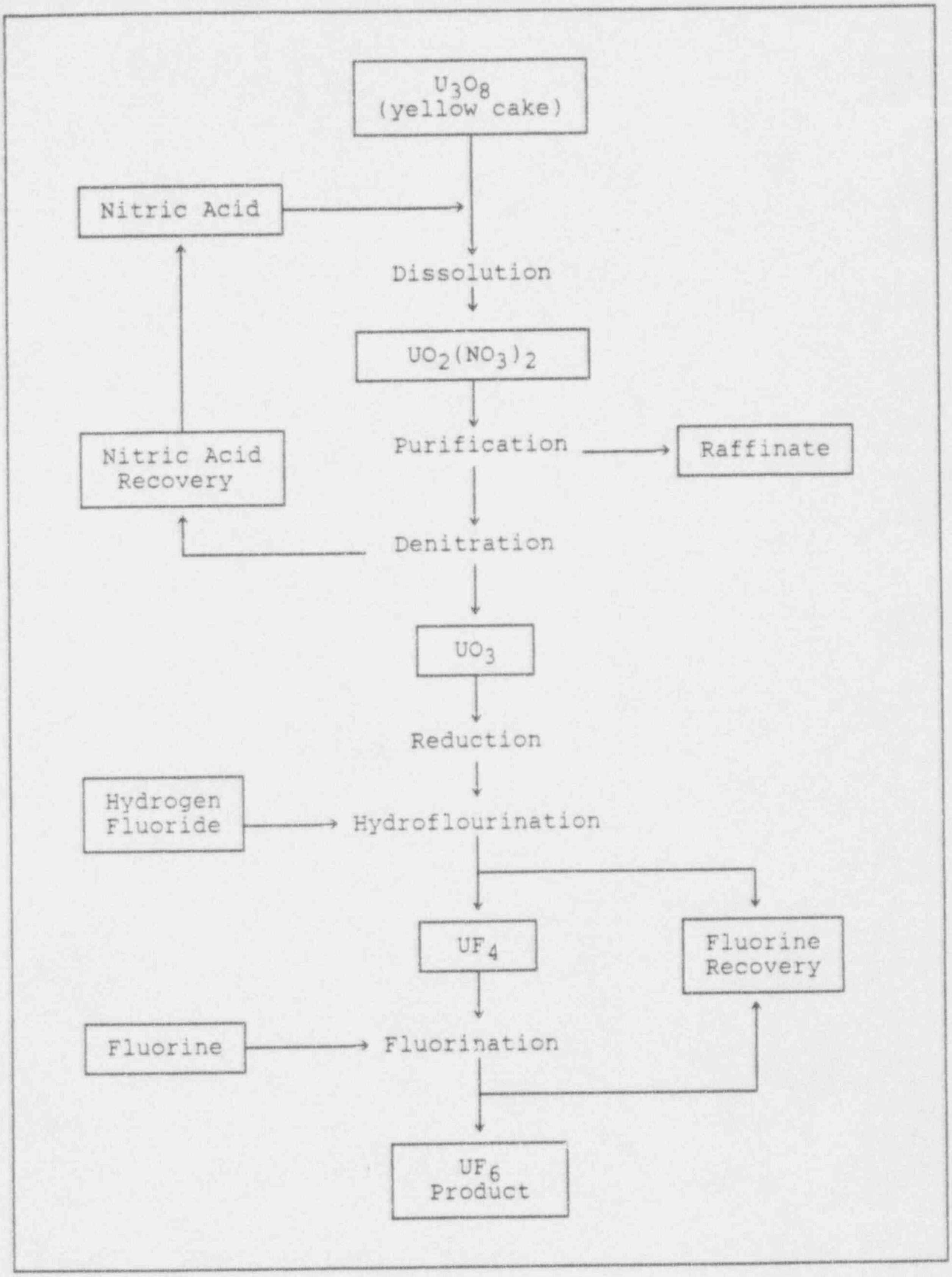


Figure 5. Conversion of U_3O_8 (Yellowcake) to UF_6 (Gas) Product

chemical reduction, hydrofluorination, and fluorination techniques to produce the Uranium hexafluoride gas.

The yellow cake is generally received as a slurry or dry concentrate and is dissolved in nitric acid for processing. This uranium solution is purified by solvent extraction and then subjected to thermal denitration to prepare uranium trioxide. Hydrogen reduction of the uranium trioxide yields uranium dioxide which is converted to uranium tetrafluoride by reaction with anhydrous hydrogen fluoride. The desired uranium hexafluoride product is formed by contacting the uranium tetrafluoride with elemental fluorine.

Each process step will yield wastes and loss which can be a source of Uranium and/or daughter radionuclides in the waste stream. These wastes/losses may end up in rainwater, sumps, solvent extraction operation, receiving and reprocessing tanks, vapors, clarifiers or scrubbers. [NOTE: a detailed description of the current operation is contained in NUREG-1157, "Environmental Assessment for Renewal of Special Nuclear Material License N. SUB-1010", Docket No. 40-8027, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards; August 1985].

URANIUM SERIES RADIONUCLIDES IN TERRESTRIAL ECOSYSTEMS

The movements of uranium and uranium daughter radionuclides in soil are dependent upon physical phenomena and complex sets of inorganic and organic chemical reactions peculiar to each different radionuclide. Numerous physical and chemical characteristics of soils and abiotic environmental factors are capable of influencing uranium-series radionuclide movement (Andersson, Torstenfelt and Allard, 1982; Gascoyne, 1982; Eisenbud, 1987). A variety of living organisms affect uranium-series radionuclide transport through adsorption, bioaccumulation, chelation or solubilization mechanisms similar to those important in the environmental cycling of other elements (Wildlung and Garland, 1980; Garten, Trabalka and Bogle, 1982; Francis, 1985; Miller, Landa and Updegraff, 1987). Uranium and radium are relatively mobile in natural environments, while thorium is generally characterized as having a much lower mobility (Osburn, 1965; Schulz, 1965). The differential transport and movement of uranium, thorium, and radium as a result of geochemistry and the effects of biota are responsible for variations in their isotopic ratios (disequilibrium) in many natural materials (Ivanovich and Harmon, 1982).

The solubility of uranium-series radionuclides in soil water and their sorption onto solid soil components are affected by soil clay content, cation exchange capacity, oxidation reduction potential, pH, temperature and the concentration of other ionic species. Soil moisture content and porosity are additional primary variables affecting the movement of solutes and the soil water solution. Radionuclides present as solutes in a saturated soil may be rapidly transported during the convective-bulk flow of the soil solution. Alternatively, in unsaturated soils the movement of the solutes and soil solution is the result of the adhesive and cohesive properties of water, and proceeds at slower rates.

Microorganisms and many species of plants are known to bioaccumulate uranium-series radionuclides and alter their movement in terrestrial habitats. Bacteria have been shown to cause the leaching of uranium from rock and soil components (Heinen and Lauwers, 1988). The common soil bacterium Thiobacillus ferrooxidans can oxidize uranium (Di Spirito and Tuovinen, 1982) and has been used in commercial mining to leach and extract uranium. Pseudomonas aeruginosa, another common soil bacterium, accumulates uranium (Strandberg, Starling and Parrott, 1981) and produces uranium- and thorium-specific chelating substances similar in structure to bacterial chelators which bind iron and enhance its solubility and bioavailability (Premuzic et.al., 1985). Many other genera of bacteria and fungi present in soils have been found to have high uranium adsorbing abilities (Nakajima and Sakaguchi, 1986). Mixed populations of sulfate reducing bacteria and pure cultures of the soil bacterium Desulfovibrio desulfuricans have been shown to leach radium from rock and geologic materials (Fedorak et.al., 1986; Landa, Miller and Updegraff, 1986).

Uranium and radium are bioaccumulated by numerous species of food crops, native plants and trees. Mosses and lichens (Sheard, 1986), alfalfa (Sheppard, Sheppard, and Thibault, 1984), grasses (Mahon and Mathews, 1982) and conifers (Sheard, 1986) are among the many species which are able to absorb and accumulate uranium and radium. Ibrahim and Whicker (1988) also report thorium may be accumulated by vegetation to a much greater extent than previously shown. A summary of the literature documenting the accumulation of uranium in various species of plants is presented in tabular form in a technical document published by the International Atomic Energy Agency (IAEA, 1985). In addition to accumulating radionuclides, the roots of plants have been found to release organic compounds which bind radionuclides. These plant-produced chelators form anionic radionuclide complexes which are highly mobile in soils (Cataldo et.al., 1987). Deer and other terrestrial animals feeding on contaminated plant biomass have been shown to bioaccumulate uranium and radium in body tissues (Mahon, 1982; Williams, 1982). In general the concentrations of radionuclides in living organisms decrease with each transfer in the food chain.

URANIUM SERIES RADIONUCLIDES IN AQUATIC ECOSYSTEMS

Uranium and the uranium-series daughter radionuclides have been shown to be partitioned between the biota, sediments and the water columns in aquatic habitats. Radionuclide transport between the different compartments in such ecosystems is dependent upon complex interactions between abiotic environmental parameters and living organisms (Eisenbud, 1987). Movement of radionuclides via biotic pathways and aquatic food chains is of primary interest because of the potential for bio-accumulation and subsequent harmful effects to both aquatic organisms and man.

Photoautotrophic organisms also known as primary producers form the base or first trophic level of aquatic food chains. Typical freshwater habitats contain large and diverse communities of primary producers composed of aquatic vascular plants, periphyton and phytoplankton. Biomass generated by primary producers then serves as food for the next trophic level of organisms known as primary consumers. Primary consumers include herbivorous fish, insects and invertebrate species. In turn, primary consumers serve as food for carnivorous secondary consumers. Secondary consumers in aquatic ecosystems include many of the common game fish species consumed by man. Benthic dwelling detritus feeders are an additional important group of organisms in aquatic ecosystems. These organisms, which also include fish, insect and invertebrate species, feed primarily on living and non-living biomass which accumulates in aquatic sediments.

Primary producers serve as one of several possible points of entry for radionuclides into aquatic food chains. Aquatic plants and algal species have been shown to be capable of adsorbing and accumulating uranium and uranium-series radionuclides (Stegnar and Kobal, 1982; Mann and Fyfe, 1985). Radionuclides may then be transferred to primary consumers and subsequently other organisms when plant and algal biomass is consumed. Alternatively, the radionuclides present in unconsumed plant and algal biomass may be transported to the sediments or exported further downstream in flowing waterways.

Uranium and uranium daughters may also enter aquatic food chains when soluble or particulate forms are ingested incidentally during feeding. Swanson (1985) studied a flowing freshwater stream and lake system in which sediments and the water column were contaminated with uranium series radionuclides at concentrations similar to those measured in effluent streams from the Sequoyah Fuels Facility. Radionuclide concentrations in organisms generally declined with each successive move up in trophic level. Transfer coefficients indicated that direct uptake of uranium and radium from the water by large fish and insects was more important than transfer up the food chain. Additionally, organisms feeding on or near sediments had higher radionuclide concentrations in their tissues than did pelagic species. Calculated dose rates to fish in this study were below levels previously shown to cause somatic effects in fish. Similarly, estimates of doses of radioactivity received by humans consuming single servings of contaminated fish weekly were low. Other authors have documented the general trends observed by Swanson indicating decreasing concentrations of uranium at higher aquatic trophic levels and greater concentrations in benthic organisms as opposed to pelagic species (Garten et.al., 1982; Stegnar and

Kobal, 1982). A summary of data from recent studies describing the accumulation of uranium and radium in aquatic organisms is given as a table of "bioaccumulation factors" in the National Council of Radiation Protection and Measurements Report Number 76 (1984).

A variety of abiotic environmental parameters also influence the distribution of uranium and uranium series radionuclides in aquatic ecosystems. Among these factors total alkalinity, bicarbonate ion and organic carbon concentrations have been shown to correlate with uranium concentrations in freshwaters (Scott, 1982; Wahlgren and Orlandini, 1982). Representative concentrations of uranium and thorium in North American rivers ranged from 0.55 μg/g to 4.71 μg/g in sediments and from 0.022 μg/l to 4.50 μg/l in water (Scott, 1982).

GEOGRAPHIC DESCRIPTION OF AREA OF INTEREST

The Sequoyah nuclear fuels processing plant is located in Sequoyah County, Oklahoma, approximately 3.0 miles southeast of the town of Gore, Oklahoma (Township 12N, Range 21E, Section 21). The plant is situated adjacent to the eastern bank of the Illinois River, 7.0 miles downstream from Tenkiller Reservoir. One mile downstream from the fuels plant, the Illinois joins the Arkansas River which in turn immediately flows into Robert S. Kerr Reservoir, part of the Kerr-McClellan Waterway.

CHARACTERIZATION OF SOIL AT AREA OF INTEREST

Soils along the Illinois River in the area of the Sequoyah fuels plant are predominantly of the Rosebloom and Mason soil series. The soil in the area of interest is further characterized as a Mason silt loam. Soils of this class are moderately permeable, well drained and extend relatively deep into the subsurface profile. Surface horizons of Mason series soils are typically composed of brown silt loams or brown silty clay loams and are of moderate to high fertility (USDA, 1970). Well drained and permeable soils should provide opportunity for subsurface transport of mobile radionuclides.

PROPOSED CHANGE OF DISCHARGE PROCEDURE BY SEQUOYAH FUELS CORP.

Studies (Appendix A) conducted by the Sequoyah Fuels Corporation (SFC) facility staff document that releases of radioactive materials to the unrestricted area (i.e. off-site) are below the levels specified in 10CFR20 (Standards for Protection Against Radiation). However, accumulation of uranium in the sediment or soil along the waste streams has reached a significant level and SFC has proposed an alternative discharge method which involves access to land and waterways under the jurisdiction of the Army Corps of Engineers.

The proposal entails construction of a pipeline to replace the effluent flow through the Outfall 001 natural drainage chan-

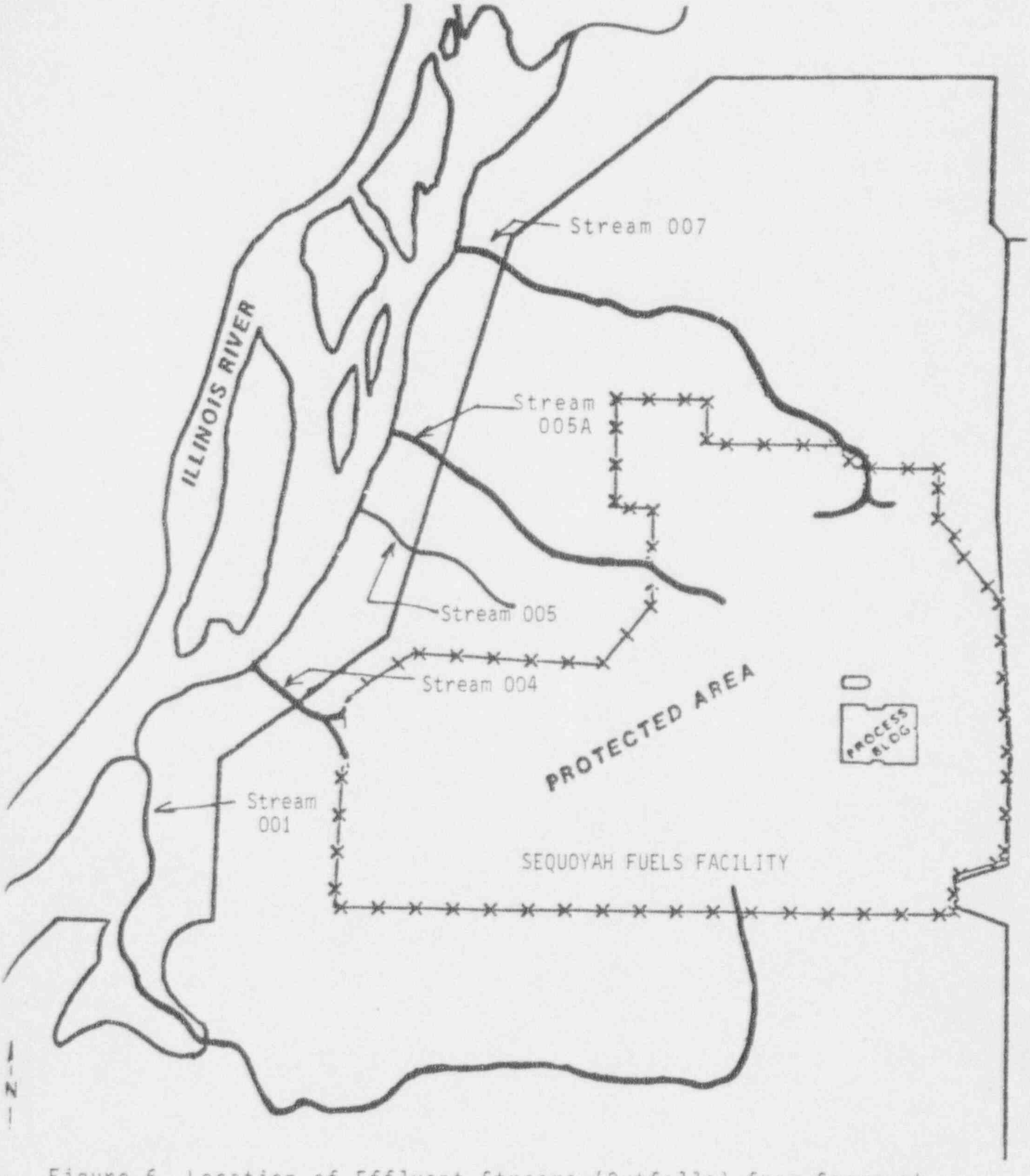


Figure 6. Location of Effluent Streams (Outfalls) from Sequoyah Fuels Facility Leading to Illinois River.

nel (Figure 6). This pipeline would empty the plant process water directly into the Illinois River. The soil and sediment along the natural channel would be surveyed after pipeline installation and sediments and soils with elevated uranium levels would be removed for proper disposal.

As a result of the request of SFC to the Corps of Engineers for permission to construct this pipeline a need exists to know the present levels of radionuclide contamination that may exist on the government lands involved. To fill this need a study was conducted to collect samples for independent analytical determination of radionuclide levels. This report contains a summary of the sample collection and measurement of radionuclide levels in these samples (Appendix B) and is an analysis of the results obtained.

SAMPLING METHODOLOGY

The current discharge of waters and wastes from the Sequoyah Fuels plant includes four streams discharging into the Illinois River (Figure 6). The streams are the process waste water stream and three storm water streams. Each discharge stream was sampled for sediment and upland soil contamination of uranium, radium-226, thorium-230 and gross alpha emission. Sediment samples were also collected at the location of entry of each stream bed to the Illinois River. Water samples were collected from Stream 001 and both the Illinois and Arkansas Rivers. Background control samples were collected from three locations on government property at a minimum distance of one mile from the Sequoyah property upstream and downstream of the sampling area. Outfall streams were sampled on 29 and 30 June and Illinois and Arkansas River samples were collected on 1 July 1988.

Outfall 001 is the longest of the streams involved and at the time of sampling was the only one containing water. Sampling locations (Figure 7) for this stream were at distances of approximately 25, 200, 400, 500 and 700 feet from the Facility property line. Subsurface stream bed sediment samples were collected by sediment sampler at each sampling distance. Soil surface samples were collected by hand trowel along a transect perpendicular to the stream. If possible, a sample was collected at the bank and then at increasing distances from the stream depending on the terrain. Since this stream contained flowing water, a

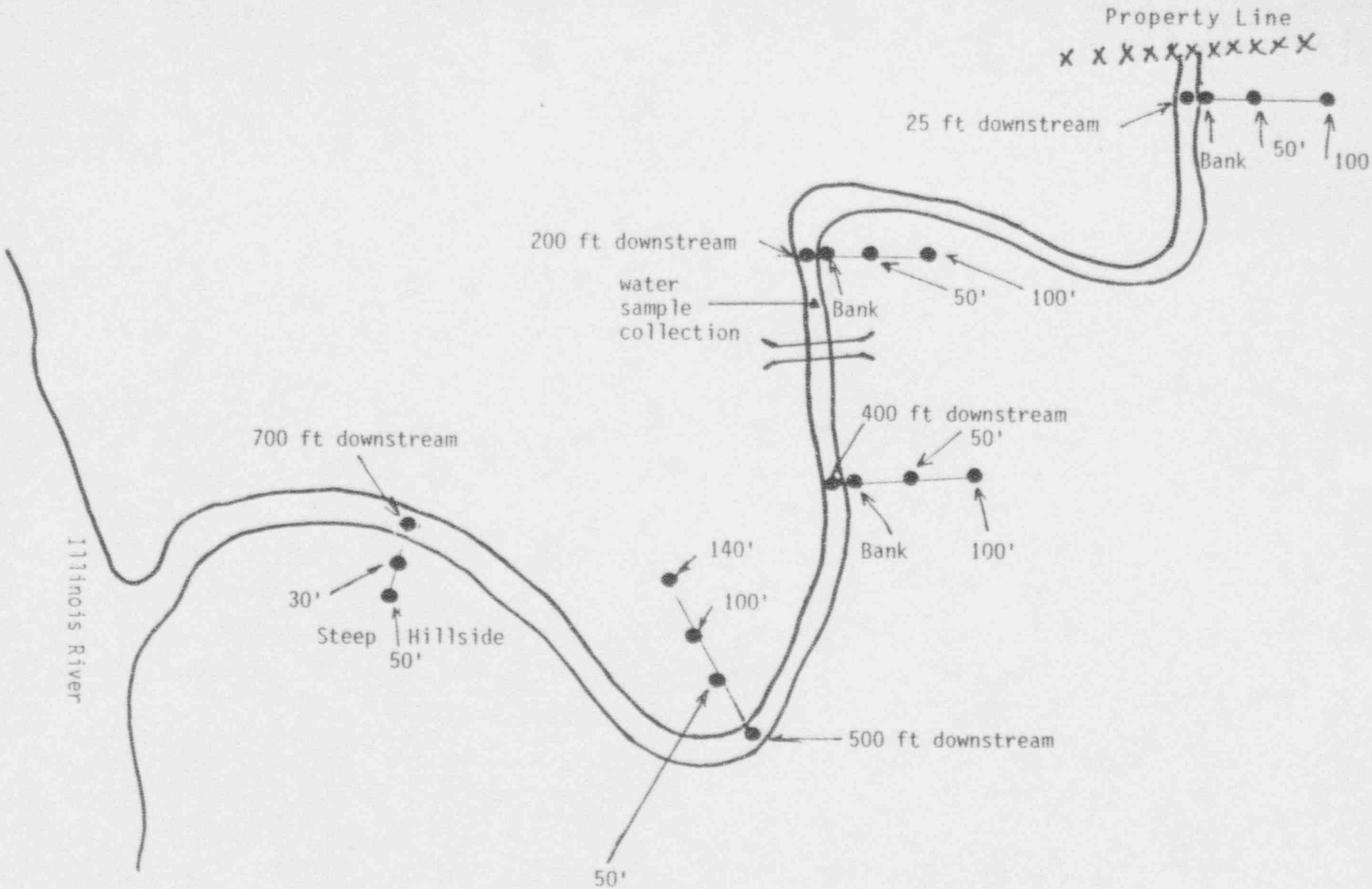


Figure 7. Sampling Locations for Outfall 001

sample of the effluent was collected at a distance of approximately 250 feet downstream from the property line. Multiple sediment samples were collected at the entry point of the stream into the Illinois River. One sample was taken at the point of entrance of the stream into the river. Additional samples were taken at 50 and 100 feet distances into the River along diagonals of 45° to the upstream bank, 90° to the bank and 45° to the downstream bank. Additional subsurface sediment samples were taken along the eastern bank of the river at downstream distances of approximately 500 and 1000 feet from the 001 stream mouth.

The 004 stream was dry and stream bed soil samples were collected from it at distances of approximately 20, 50 and 100 feet from the property line (Figure 8). Two upland soil samples were taken at approximately 25 feet distances from the stream bed on opposite sides. A subsurface sediment sample was taken at the entry point of the stream into the Illinois River.

The 005 stream (Figure 9) was dry and stream bed soil samples were collected at distances of approximately 50 and 80 feet as well as in a depression in the stream bed just short of its entry into the Illinois River. Additional upland soil samples were collected at distances of 25 feet either side of the center stream bed locations. A subsurface sediment sample was taken at the entry point of the stream into the Illinois River.

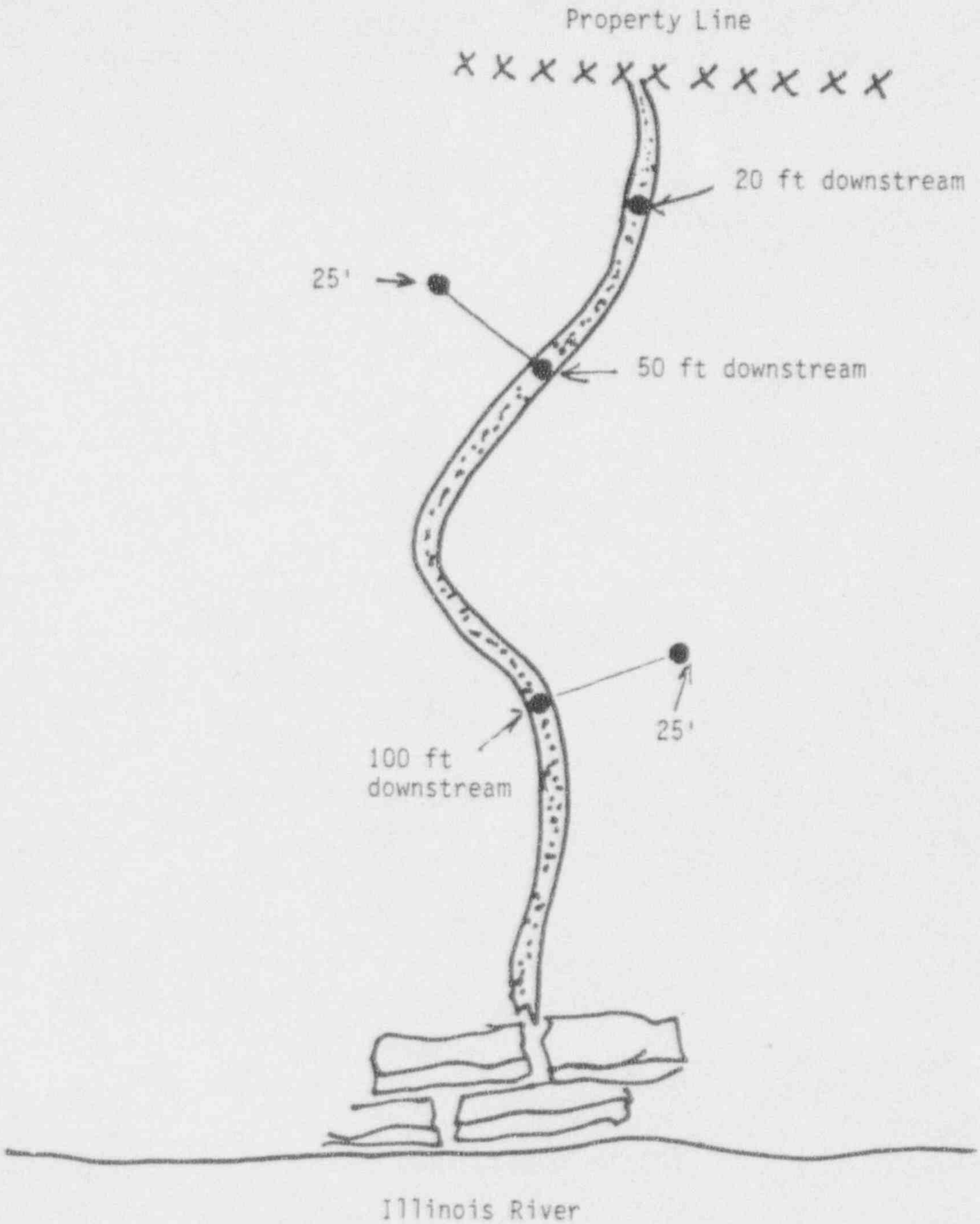


Figure 8. Sampling Locations for Outfall 004

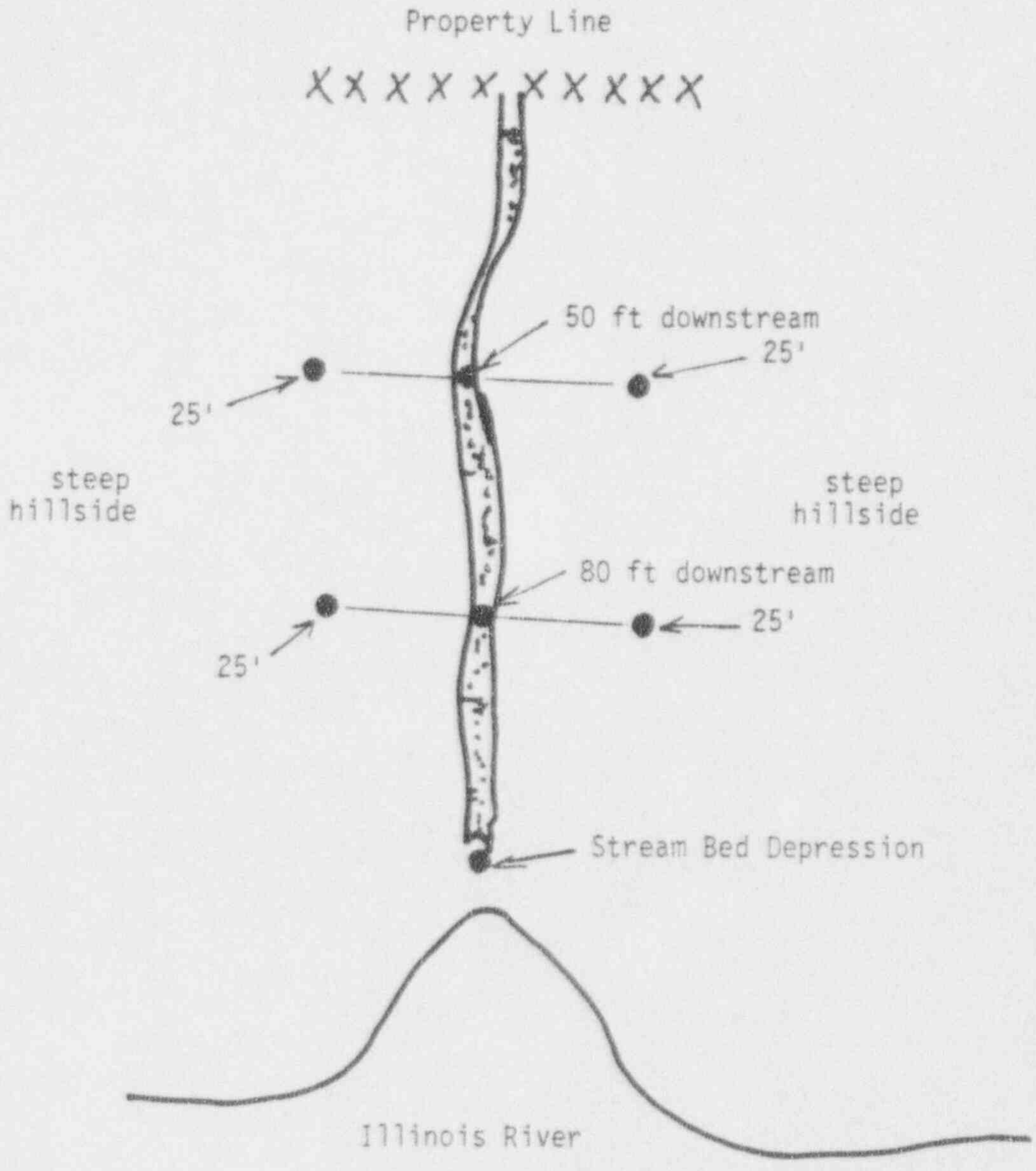


Figure 9. Sampling Locations for Outfall 005

Samples for stream 005A (Figure 10) included dry stream bed soil at distances of approximately 50 and 150 from the property line. At these distances upland soil samples were collected at 50, 150 and 300 feet distances on opposite sides of the stream. An additional sample was taken from the soils at a high water mark near a group of large boulders at the stream's terminus. A near subsurface sediment sample was collected from the area of the entry point of the stream into the Illinois River.

Stream 007 (Figure 11) was short and only 3 soil samples were collected. Besides the stream bed sample at a distance of approximately 40 feet from the property line, upland soil samples were taken at a distance of approximately 25 feet either side of the stream bed. A subsurface sediment sample was collected from the area where the stream enters the Illinois River. An additional Illinois River subsurface sediment sample was collected at a point approximately midway between the 007 and 005A stream.

In addition to the water sample from the 001 stream, water samples were also collected from the junction of the Illinois and Arkansas Rivers and downstream in the Arkansas River at the Interstate 40 bridge.

Background soil/sediment samples were collected from the Gore Landing site (upstream) and at the Junction of Interstate 40 and Highway 100. Background water samples were collected at Gore

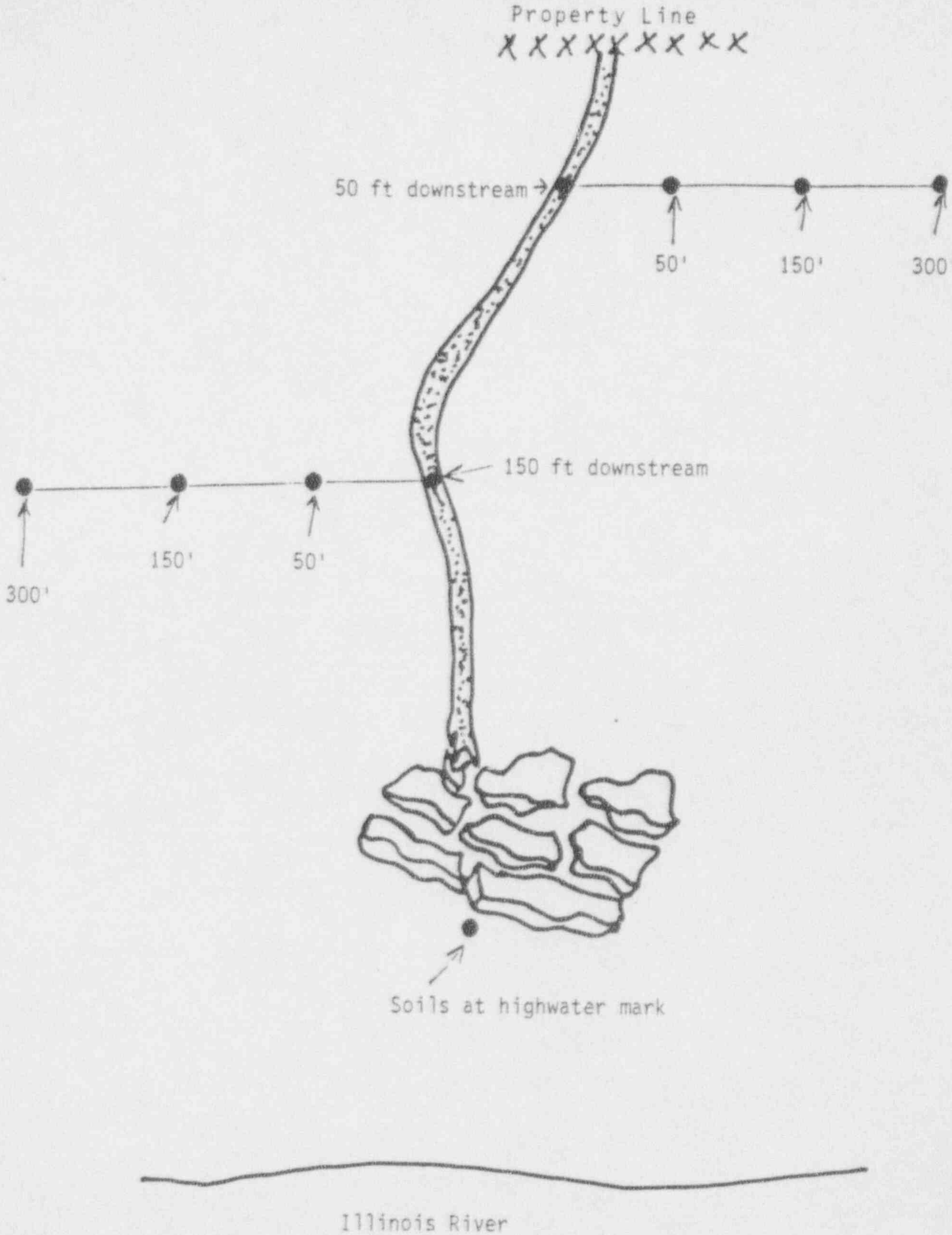


Figure 10. Sampling Locations for Outfall 005A

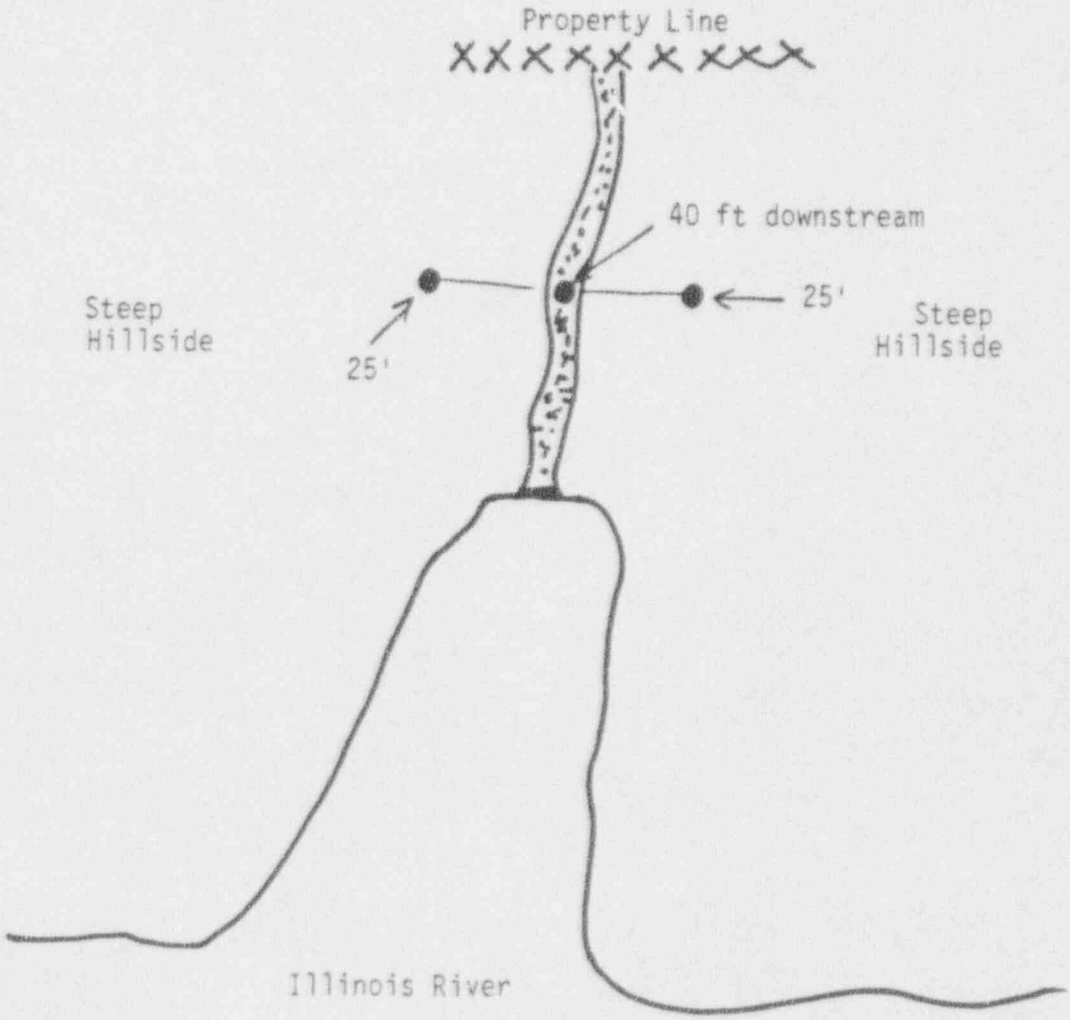


Figure 11. Sampling Locations for Outfall 007

Landing and from the Arkansas River approximately 1500 feet upstream from the junction with the Illinois River.

Soil and sediment samples with accompanying Chain of Custody Records were delivered to Core Laboratories (420 West First St., Casper, Wyoming 82601) for radiochemical analysis. Water samples were delivered to Southwest Laboratory of Oklahoma (1700 W. Albany, Suite C, Broken Arrow, OK 74012) for radiochemical analysis. All samples were analyzed according to Standard Methods (APHA, 1985) for Uranium (natural), gross alpha, Thorium-230 and Radium-226. Assay results (Appendix B) for soil and sediment samples were reported in pCi/gram for soil and sediment and pCi/liter for water samples.

RESULTS AND DISCUSSION

The results of radiochemical analysis of all samples collected in this study are detailed in Appendix B. Two additional studies are included as appendices as they can be used for limited comparisons of radioactivity levels at different sampling times. Appendix A contains the results of a soil/sediment survey conducted by Sequoyah Fuels Corporation in 1986 in response to an NRC License Condition. This document is of additional importance as it proposes a pipeline as a mitigation step. This proposed activity was a factor in the decision to conduct the current study. Appendix C details results from samples of soil, sediment and water collected by the Corps of Engineers from Outfall 001 in December of 1986.

STREAM 001

Table 1 lists the results of the radionuclide analysis of samples of Stream 001. The Uranium concentrations (pCi/g) along this stream are portrayed in Figure 12. Of all the streams surveyed, 001 is the longest. It was also the only streambed containing water and thus appears to be the active outfall from the facility at that time (30 June 1988). Uranium concentrations in soil and sediment are statistically above background in most cases. Analysis of the U:Th ratios indicates that these elevated concentrations are probably of process origin (i.e. Uranium separated from its daughters during ore processing) rather than from naturally occurring Uranium in the locale.

Table 1. Results of Radionuclide Analysis of Samples of Stream 001

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha pCi/g	Th-230 pCi/g	Ra-226 pCi/g
25 feet	streambed	28.0	54.0	1.9	1.7
	southbank	16.0	31.0	0.5	0.8
	50 ft south	3.1	14.0	2.0	2.8
	100 ft south	1.7	14.0	2.5	0.8
200 feet	streambed	19.0	19.0	1.4	1.3
	southbank	8.9	19.0	1.2	1.3
	50 ft south	19.0	26.0	1.1	1.6
	100 ft south	8.3	15.0	5.5	2.9
400 feet	streambed	19.0	26.0	1.4	1.0
	southbank	14.0	25.0	1.7	1.1
	50 ft south	21.0	44.0	1.0	1.7
	100 ft south	38.0	59.0	3.0	2.7
500 feet	streambed	21.0	33.0	1.4	1.4
	50 ft north	27.0	35.0	1.9	1.6
	100 ft north	50.0	96.0	1.1	0.6
	140 ft north	97.0	108.0	1.1	3.2
700 feet	streambed	16.0	23.0	1.1	0.7
	30 ft south	12.0	25.0	0.9	1.4
	50 ft south	32.0	69.0	3.8	2.7
Water Sample 250 ft downstream (All values are pCi/l)		554.6	459.0	0.7	0.1
		548.7	359.0	0.6	0.1

****Calculated Isotopic Ratios****

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha: U-nat	U:Th	U:Ra	Th:Ra
25 feet	streambed	28.0	1.9	14.7	16.5	1.1
	southbank	16.0	1.9	32.0	20.0	0.6
	50 ft south	3.1	4.5	1.6	1.1	0.7
	100 ft south	1.7	8.2	0.7	2.1	3.1
200 feet	streambed	19.0	1.0	13.6	14.6	1.1
	southbank	8.9	2.1	7.4	6.8	0.9
	50 ft south	19.0	1.4	17.3	11.9	0.7
	100 ft south	8.3	1.8	1.5	2.9	1.9
400 feet	streambed	19.0	1.4	13.6	19.0	1.4
	southbank	14.0	1.8	8.2	12.7	1.5
	50 ft south	21.0	2.1	21.0	12.4	0.6
	100 ft south	38.0	1.6	12.7	14.1	1.1
500 feet	streambed	21.0	1.6	15.0	15.0	1.0
	50 ft south	27.0	1.3	14.2	16.9	1.2
	100 ft south	50.0	1.9	45.5	83.3	1.8
	140 ft south	97.0	1.1	88.2	30.3	0.3
700 feet	streambed	16.0	1.4	14.5	22.9	1.6
	30 ft south	12.0	2.1	13.3	8.6	0.6
	50 ft south	32.0	2.2	8.4	11.9	1.4

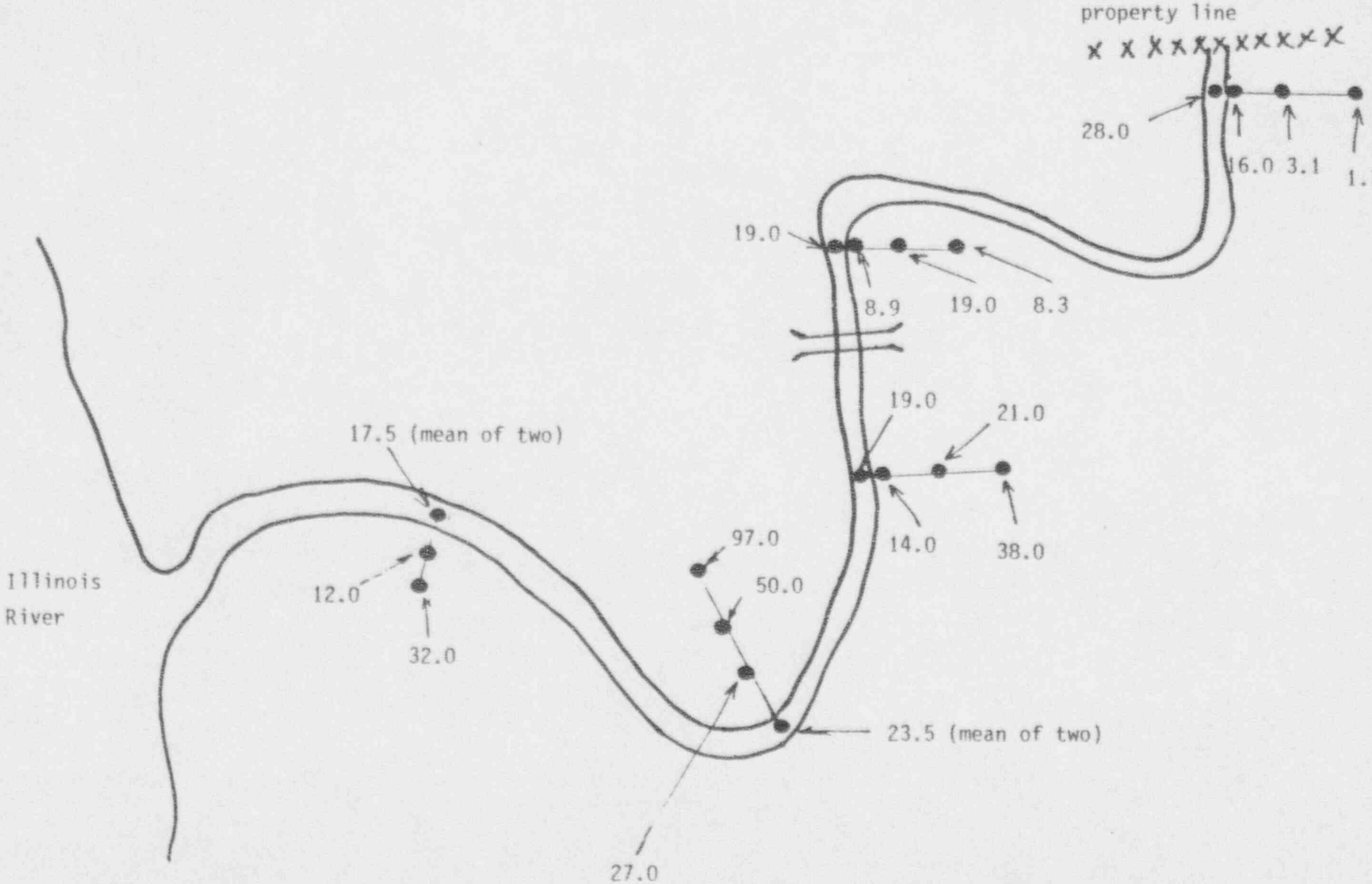


Figure 12. Uranium Concentrations in pCi/g along the 001 Stream.

Duplicate water samples taken at a location approximately 250 ft. downstream from the property line indicate an average concentration of 551 pCi/liter. This value is well within the NRC limit of 30,000 pCi/liter. Although the sample was not taken at the exact entry from the property (restricted area) into the open (unrestricted area) stream area, it is reasonable to assume the concentrations will be fairly similar. This assumption is based on the premise that all the flow originates in the restricted area and there is no significant dilution factor between the boundary and the sampling location. The Th-230 and Ra-226 concentrations of this effluent are essentially background. This is noted in respect to the premise that isotopic ratios can be an indicator of "natural" or "process" origin in samples with elevated radionuclide concentrations. Although this is a one time sample, it does lend support to the hypothesis that a sample with an elevated uranium concentration and high U:Th ratio is of "process" origin.

STREAM 004

Values for this stream are listed in Table 2 and Uranium concentrations portrayed in Figure 13. All samples are essentially background values and no significant radionuclide concentrations are found in the.locations samples.

STREAM 005

Table 3 lists the results of the radionuclide analysis of soil and sediment samples of stream 005. The Uranium concentra-

Table 2. Results of Radionuclide Analysis of Soil and Sediment Samples of Stream 004.

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha pCi/g	Th-230 pCi/g	Ra-226 pCi/g
Prop. +20	streambed	1.1	18.0	2.3	1.5
Prop. +50	streambed	1.2	9.3	0.1	1.4
	25 ft north	2.2	8.8	1.5	1.8
Prop. + 100	streambed	2.2	18.0	1.7	2.1
	25 ft south	3.3	10.0	1.8	1.7

****Calculated Isotopic Ratios****

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha: U-nat	U:Th	U:Ra	Th:Ra
Prop. +20	streambed	1.1	16.4	0.5	0.7	1.5
Prop. +50	streambed	1.2	7.8	12.0	0.9	0.1
	25 ft north	2.2	4.0	1.5	1.2	0.8
Prop. + 100	streambed	2.2	8.2	1.3	1.0	0.8
	25 ft south	3.3	3.0	1.8	1.9	1.1

Table 3. Results of Radionuclide Analysis of Soil and Sediment Samples of Stream 005.

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha pCi/g	Th-230 pCi/g	Ra-226 pCi/g
Prop. +50	streambed	7.9	32.0	1.1	1.2
	25 ft south	4.2	29.0	1.6	1.4
	25 ft north	5.6	35.0	1.4	1.4
Prop. +80	streambed	18.0	55.0	2.7	1.9
	25 ft north	254.0	551.0	101.0	2.7
	25 ft south	4.1	40.0	2.0	1.8
Sed. base Ditch		289.0	578.0	97.0	3.3

****Calculated Isotopic Ratios****

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha: U-nat	U:Th	U:Ra	Th:Ra
Prop. +50	streambed	7.9	4.1	7.2	6.6	0.9
	25 ft south	4.2	6.9	2.6	3.0	1.1
	25 ft north	5.6	6.3	4.0	4.0	1.0
Prop. +80	streambed	18.0	3.1	6.7	9.5	1.4
	25 ft north	254.0	2.2	2.5	94.1	37.4
	25 ft south	4.1	9.8	2.1	2.3	1.1
Sed. base Ditch		289.0	2.0	3.0	87.6	29.4

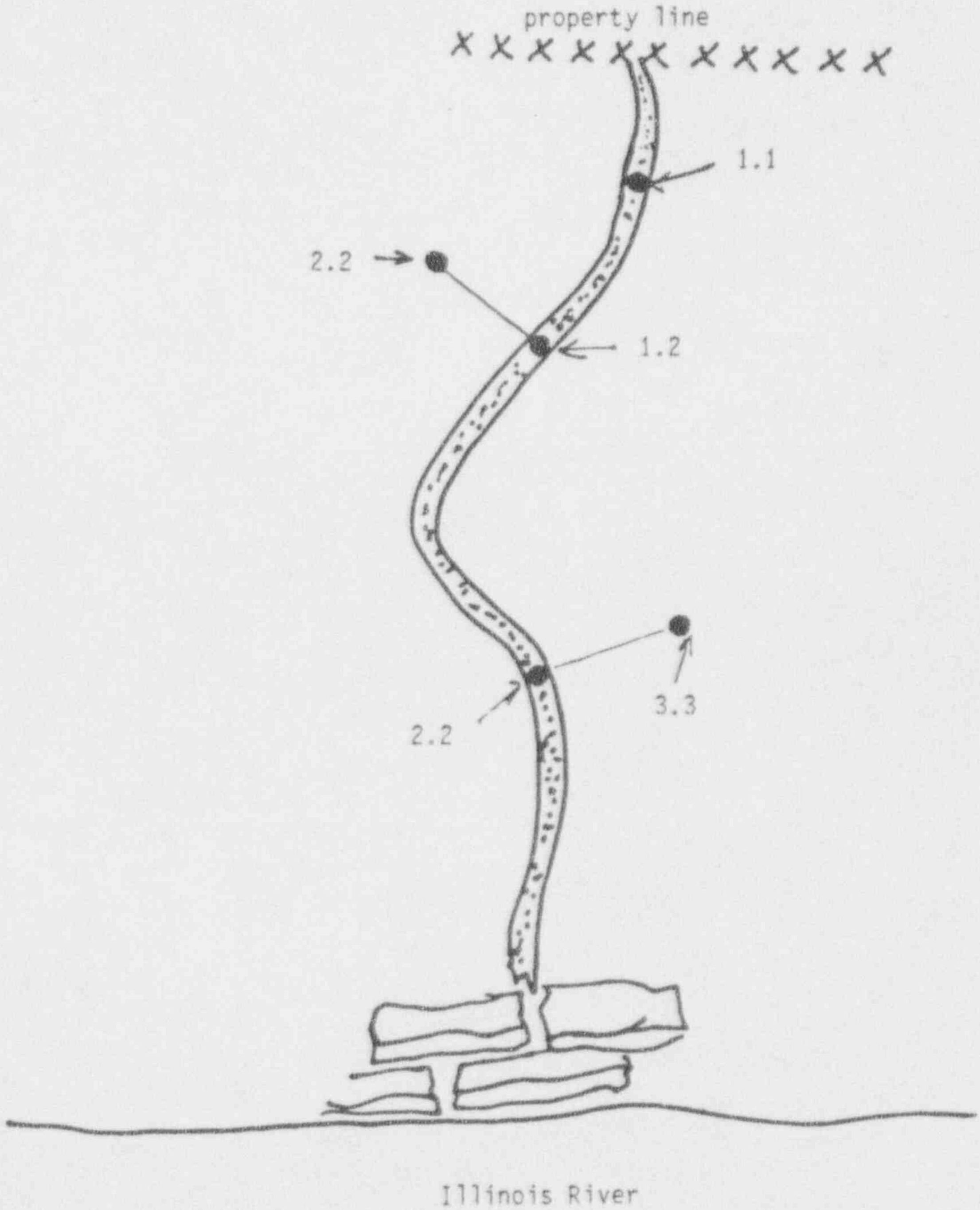


Figure 13. Uranium Concentrations in pCi/g along the 004 Stream.

tions are portrayed in Figure 14. Two locations of this stream area show elevated Uranium concentrations. A Uranium concentration of 254 pCi/g was measured in a soil sample taken 25 ft. north of the streambed location 80 feet downstream from the property line. The same sample also had a Th-230 concentration of 101 pCi/g. The sample collected from a depression in the streambed just short of its entry into the Illinois River showed similar levels with a Uranium concentration of 289 pCi/g and a Th-230 level of 97 pCi/g. With the exception of the samples from the two above mentioned locations, other samples from this outfall were only slightly above background. These results indicate the possibility that the elevated levels may be of natural origin or are the effluent from processes of other than the normal type.

STREAM 005A

Assay results for samples from this stream are listed in Table 4 and Uranium concentrations portrayed in Figure 15. The sediment and soil values from this dry streambed and bank are generally only slightly elevated above background level. One sample showed elevated levels of both Uranium and Thorium. This sample was taken from the soil at the highwater mark among a group of large rocks in the streambed near its terminus. The U:Th ratio suggests a natural origin as well as a geological area that concentrates Thorium from a mixed flow of naturally occurring radionculides.

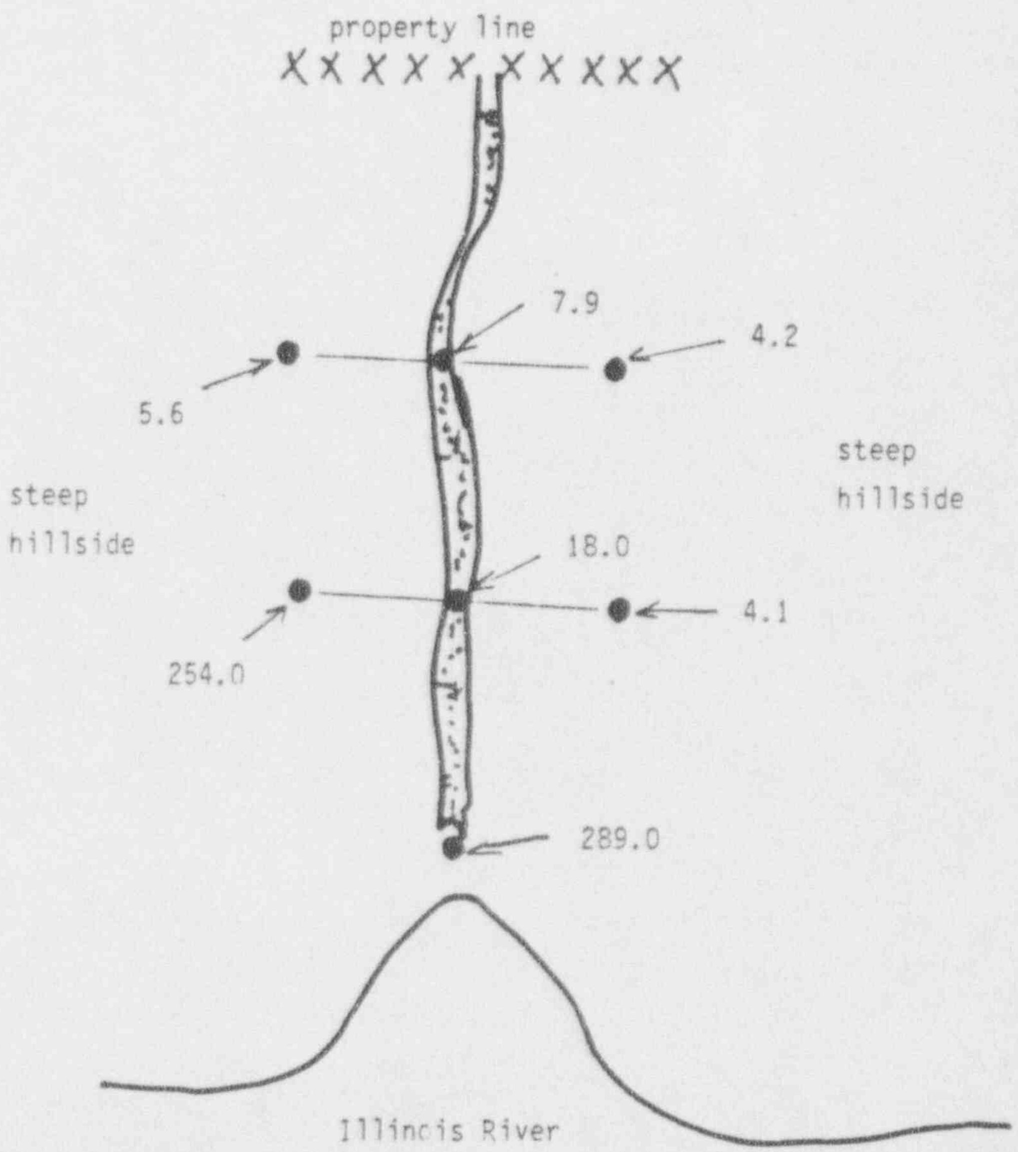


Figure 14. Uranium Concentrations in pCi/g along the 005 Stream.

Table 4. Results of Radionuclide Analysis of Soil and Sediment Samples of Stream 005A.

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha pCi/g	Th-230 pCi/g	Ra-226 pCi/g
Prop. +50	streambed	6.5	54.0	1.1	1.1
	50 ft south	6.5	48.0	3.3	0.9
	150 ft south	9.4	19.0	0.6	1.1
	300 ft south	2.1	15.0	0.2	0.5
Prop. +100	streambed	2.8	12.0	2.5	1.7
	50 ft north	7.4	29.0	0.8	1.3
	150 ft north	4.8	24.0	0.9	1.5
	300 ft north	6.8	18.0	0.6	0.5
Highwater mark		83.0	483.0	159.0	2.9

****Calculated Isotopic Ratios****

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha: U-nat	U:Th	U:Ra	Th:Ra
Prop. +50	streambed	6.5	8.3	5.9	5.9	1.0
	50 ft south	6.5	7.4	2.0	7.2	3.7
	150 ft south	9.4	2.0	15.7	8.5	0.5
	300 ft south	2.1	7.1	10.5	4.2	0.4
Prop. +100	streambed	2.8	4.3	1.1	1.6	1.5
	50 ft north	7.4	3.9	9.3	5.7	0.6
	150 ft north	4.8	5.0	5.3	3.2	0.6
	300 ft north	6.8	2.6	11.3	13.6	1.2
Highwater mark		83.0	5.8	0.5	28.6	54.8

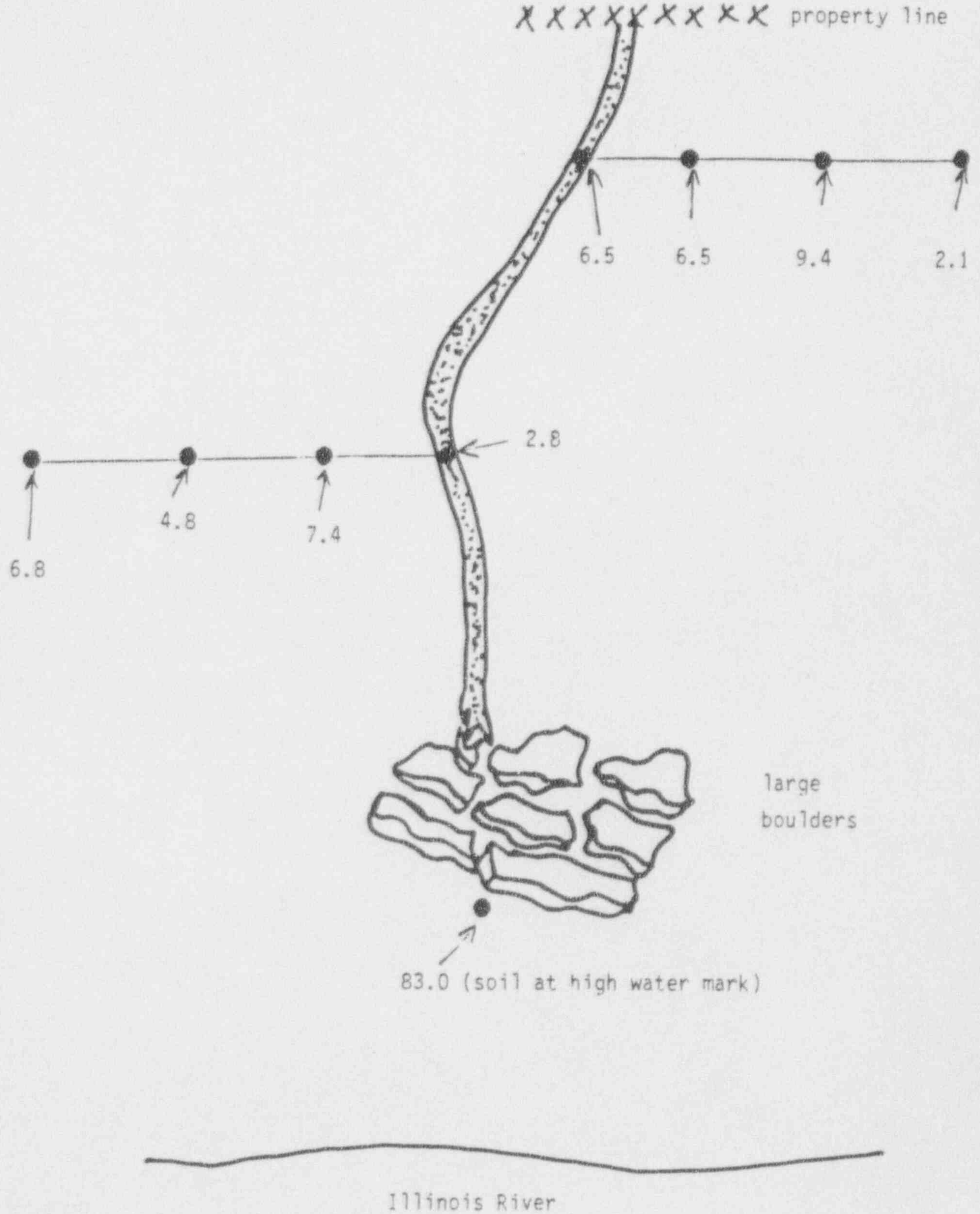


Figure 15. Uranium Concentrations in pCi/g along the 005A Stream.

STREAM 007

Table 5 details the analytical results for stream 007. Uranium concentrations for the sampling locations are portrayed in Figure 16. The dry streambed sample indicates an elevated Uranium level while soil samples taken either side of the stream are only slightly elevated above background.

ILLINOIS RIVER

In addition to samples of various individual streambed areas, soil/sediment samples were collected at the point of entry of each stream into the Illinois River. A background sample was obtained at Gore Landing which is approximately 2 miles upstream from the facility site. Analytical results from these samples are detailed in Table 6 and the respective Uranium concentrations portrayed in Figure 17. The only significantly elevated level seen is from the sample collected at the mouth of the 005 stream. This sample also indicated an elevated Th-230 concentration. These results are consistent with that seen in the analytical picture of the streambed itself and indicate a possible localization of natural Uranium and daughters.

The multiple samples taken in the area of the mouth of Outfall 001 indicate a slightly elevated level of radioactivity near the shoreline with reduced levels further out into the river itself. The elevated levels near the mouth are significantly reduced from those found in the stream itself (Table 1 and Figure 12) indicating the river's diluting effect.

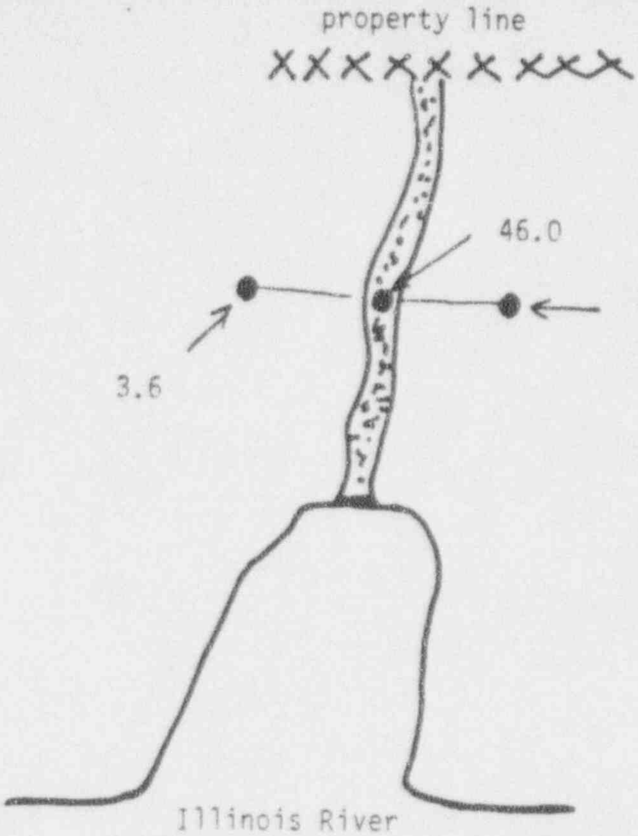


Figure 16. Uranium Concentrations in pCi/g along the 007 Stream.

Table 5. Results of Radionuclide Analysis of Soil and Sediment Samples of Stream 007.

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha pCi/g	Th-230 pCi/g	Ra-226 pCi/g
Prop. +40	streambed	46.0	72.0	5.1	1.7
	25 ft south	2.7	22.0	1.2	1.2
	25 ft north	3.6	15.0	1.8	2.9

****Calculated Isotopic Ratios****

Distance Downstream	Sample Location	U-nat pCi/g	Gross Alpha: U-nat	U:Th	U:Ra	Th:Ra
Prop. +40	streambed	46.0	1.6	9.0	27.1	3.0
	25 ft south	2.7	8.1	2.3	2.3	1.0
	25 ft north	3.6	4.2	2.0	1.2	0.6

Table 6. Results of Radionuclide Analysis of Sediment Samples from the Illinois River.

Sample Location	U-nat pCi/g	Gross Alpha pCi/g	Th-230 pCi/g	Ra-226 pCi/g
Gore Landing mouth	1.4	12.0	0.4	0.7
Mouth of stream 007	1.1	18.0	1.8	1.2
Midway between 007&005A	1.4	14.0	1.2	0.9
Mouth of stream 005A	2.0	17.0	9.8	1.9
Mouth of stream 005	32.0	139.0	56.0	1.0
Mouth of stream 004	2.9	21.0	0.8	1.2
Mouth of stream 001	4.1	9.6	0.7	0.5
(duplicate)	3.3	14.0	1.0	0.4
45°N, 50 ft	2.6	4.8	5.0	1.1
90°,50 ft	4.2	11.0	1.0	0.9
90°,100 ft	1.6	2.1	0.9	0.4
45°S, 50 ft	3.8	5.2	0.5	0.7
45°S, 100 ft	1.2	0.0	1.0	0.5
500 ft S of mouth	1.2	4.0	0.8	0.7
1000 ft S of mouth	1.8	5.3	0.8	0.7
I-40 & Hwy 100	1.2	14.0	3.0	1.1
(duplicate)	1.1	3.3	1.1	2.2

****Calculated Isotopic Ratios****

Sample Location	U-nat pCi/g	Gross Alpha: U-nat	U:Th	U:Ra	Th:Ra
Gore Landing mouth	1.4	8.6	3.5	2.0	0.6
Mouth of stream 007	1.1	8.6	3.5	2.0	0.6
Midway between 007&005A	1.4	8.6	3.5	2.0	0.6
Mouth of stream 005A	2.0	8.5	0.2	1.1	5.2
Mouth of stream 005	32.0	4.3	0.6	32.0	56.0
Mouth of stream 004	2.9	7.2	3.6	2.4	0.7
Mouth of stream 001	4.1	2.3	5.9	8.2	1.4
(duplicate)	3.3	1.8	0.5	2.4	4.5
45°N, 50 ft	2.6	2.6	4.2	4.7	1.1
90°,50 ft	4.2	1.3	1.8	4.0	2.3
90°,100 ft	1.6	1.4	7.6	5.4	0.7
45°S, 50 ft	3.8	0.0	1.2	2.4	2.0
45°S, 100 ft	1.2	3.3	1.5	1.7	1.1
500 ft S of mouth	1.2	2.9	2.3	2.6	1.1
1000 ft S of mouth	1.8	4.2	3.3	7.8	2.4
I-40 & Hwy 100	1.2	11.7	0.4	1.1	2.7
(duplicate)	1.1	3.0	1.0	0.5	0.5

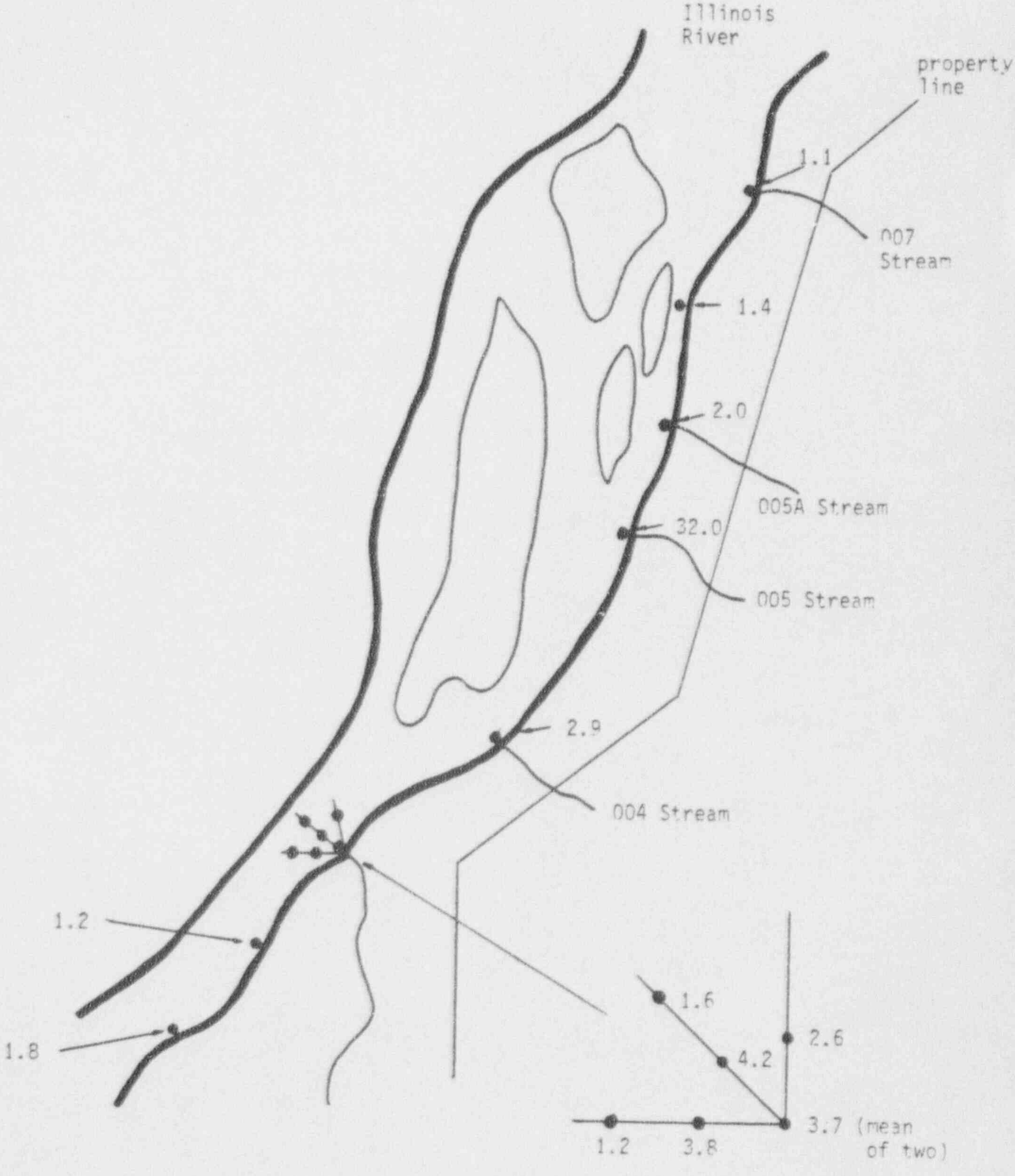


Figure 17. Uranium Concentrations in pCi/g along the Illinois River.

Samples taken along the shoreline of the Illinois River downstream from the mouth of Outfall 001 are of background level. The sediment sample collected at the shoreline of a small island in the Illinois River between the 007 and 005A streams was not significantly different from the background sample.

WATER SAMPLES

Table 7 lists the results of radionuclide analysis of the limited number of water samples collected in this study. Comparison of values for the 001 stream concentration with that of the Illinois River - Arkansas River junction and also downstream in the Arkansas River show a significant dilution effect. The Illinois River and Arkansas River concentrations are within those specified in the Oklahoma Water Quality Standards (OWRD 1985).

Table 7. Results of Radionuclide Analyses of Water Samples.

Sample Location	U-nat pCi/l	Gross Alpha pCi/l	Th-230 pCi/l	Ra-226 pCi/l
Gore Landing	0.59	0.0	0.1	0.1
	0.20	0.0	0.1	0.1
Illinois	4.72	3.7	0.3	0.1
River Mouth	5.30	2.8	1.1	0.1
Arkansas River	2.95	0.0	0.1	0.1
Upstream	2.36	3.1	0.2	0.1
Arkansas River	0.59	29.0	0.5	0.1
Downstream	1.48	0.0	1.5	0.1
Stream 001	554.60	459.0	0.7	0.1
(250 ft)	548.70	359.0	0.6	0.1

COMPARISON OF CURRENT AND PREVIOUS STUDIES

Tables 8-10 compare the results of three separate studies (Appendices A, B and C) of the sediment in the 001 stream. Although the locations of the sampling points are not exactly identical, they are in close enough proximity to make some comparison. It appears that the sedimentation of radionuclides is relatively uniform along the first few hundred feet of the stream and gradually decreases further downstream. The radioactivity levels of Uranium and Thorium in 1986 are higher than those of the 1987 and 1988 studies. This could be a reflection of activity at the facility. It is significant to note that the level <u>decreases</u> rather than <u>increases</u>. This would indicate the levels of radionuclides along the streambeds are not building up with time.

Table 8. Uranium Activities (pCi/g) in 1986, 1987 and 1988 Sediment Samples from the 001 Stream

Distance (ft)[a]	1986 Sample #[b]	1986 Activity[c]	1987 Sample #[d]	1987 Activity	1988 Sample #[e]	1988 Activity
0	001-33	47.0	1	16.5	SF-1-AO	28.0
50			2	19.4		
100			3	12.9		
150			4	21.2		
200			5	14.1	SF-1-BO	19.0
250			7	29.5		
300	001-36	54.0	9	21.2		
350						
400					SF-1-CO	19.0
450						
500					SF-1-DO	21.0
550						
600	000-39	30.0				
650						
700					SF-1-EO	16.0
750						
800						
850						
900	001-42	37.0				
river	001-R[f]	19.0			SF-S-07[f]	4.1

[a] Distance down 001 Stream from federal property line towards Illinois River.

[b] Samples taken at 300 ft intervals beginning near federal property line.

[c] The mean of two samples.

[d] Samples taken at 50 ft intervals beginning at the federal property line, except sample no. 9 was taken half way to the stream mouth.

[e] Samples taken at 100 or 200 ft intervals beginning 25 ft from the federal property line.

[f] Samples from river sediments near 001 Stream mouth.

Table 9. Thorium Activities (pCi/g) in 1986, 1987 and 1988 Sediment Samples from the 001 Stream

Distance	1986		1987		1988	
(ft)[a]	Sample #[b]	Activity[c]	Sample #[d]	Activity	Sample #[e]	Activity
0	001-33	2.74	1	No Data	SF-1-AO	1.9
50			2	N.D.		
100			3	N.D.		
150			4	N.D.		
200			5	N.D.	SF-1-BO	1.4
250			7	N.D.		
300	001-36	4.59	9	N.D.		
350						
400					SF-1-CO	1.4
450						
500					SF-1-DO	1.4
550						
600	001-39	3.55				
650						
700					SF-1-EO	1.1
750						
800						
850						
900	001-42	0.70				
river	001-R[f]	1.09			SF-S-07[f]	0.7

[a] Distance down 001 Stream from federal property line towards Illinois River.

[b] Samples taken at 300 ft intervals beginning near federal property line.

[c] The mean of two samples.

[d] Samples taken at 50 ft intervals beginning at the federal property line, except sample no. 9 was taken half way to the stream mouth.

[e] Samples taken at 100 or 200 ft intervals beginning 25 ft from the federal property line.

[f] Samples from river sediments near 001 Stream mouth.

Table 10. Radium Activities (pCi/g) in 1986, 1987 and 1988 Sediment Samples from the 001 Stream

Distance (ft)[a]	1986 Sample #[b]	1986 Activity[c]	1987 Sample #[d]	1987 Activity	1988 Sample #[e]	1988 Activity
0	001-33	0.93	1	2.5	SF-1-AO	1.7
50			2	1.3		
100			3	1.6		
150			4	1.5		
200			5	2.0	SF-1-BO	1.3
250			7	3.1		
300	001-36	1.27	9	1.4		
350						
400					SF-1-CO	1.0
450						
500					SF-1-DO	1.4
550						
600	001-39	1.41				
650						
700					SF-1-EO	0.7
750						
800						
850						
900	001-42	1.55				
river	001-R[f]	0.92			SF-S-07[f]	0.5

a Distance down 001 Stream from federal property line towards Illinois River.

b Samples taken at 300 ft intervals beginning near federal property line.

c The mean of two samples.

d Samples taken at 50 ft intervals beginning at the federal property line, except sample no. 9 was taken half way to the stream mouth.

e Samples taken at 100 or 200 ft intervals beginning 25 ft from the federal property line.

f Samples from river sediments near 001 Stream mouth.

SOIL NITRATE AND MOLYBDENUM

Soil nitrate concentrations at selected sample sites along the 004, 005, 005A and 007 streams are shown in Figures 18, 19, 20 and 21; and in Tables 11, 12, 13 and 14. Soil nitrate concentrations were not found to consistently coincide with or statistically correlate well with soil uranium, thorium or radium concentrations or with the various isotopic ratios. The maximum soil nitrate concentration of 49.9 mg/kg occurred at the high water mark sample site near the mouth of the 005A Stream. The nitrate concentration in the soil/sediment sample with the maximum uranium activity, which was collected near the mouth of the 005 Stream, was 4.3 mg/kg. This concentration is among the lowest nitrate concentrations reported. Nitrate concentrations in soils may vary widely due to fertilization and other factors; 14.0 mg of nitrate per kg of soil is a typical concentration (Lindsay, 1979). Variations in soil nitrate concentrations at sites described in this report are most probably a function of local concentrations of soil organic matter and quantities of vegetation present at the sites. Soil molybdenum concentrations (Appendix B) remained consistently less than 15.0 mg/kg, the minimum level of detection, at all sampling sites.

Table 11. Nitrate Concentrations Along the 004 Stream.

Distance Downstream	Sample Location	Nitrate Concentration (mg/kg)
Prop. +20	streambed	11.5
Prop. +50	streambed	11.9
	25 ft north	24.0
Prop. + 100	streambed	15.5
	25 ft south	37.0

Table 12. Nitrate Concentrations Along the 005 Stream.

Distance Downstream	Sample Location	Nitrate Concentration (mg/kg)
Prop. +50	streambed	42.8
	25 ft south	4.0
	25 ft north	3.0
Prop. +80	streambed	9.5
	25 ft north	23.0
	25 ft south	5.5
Sed. base Ditch		4.3

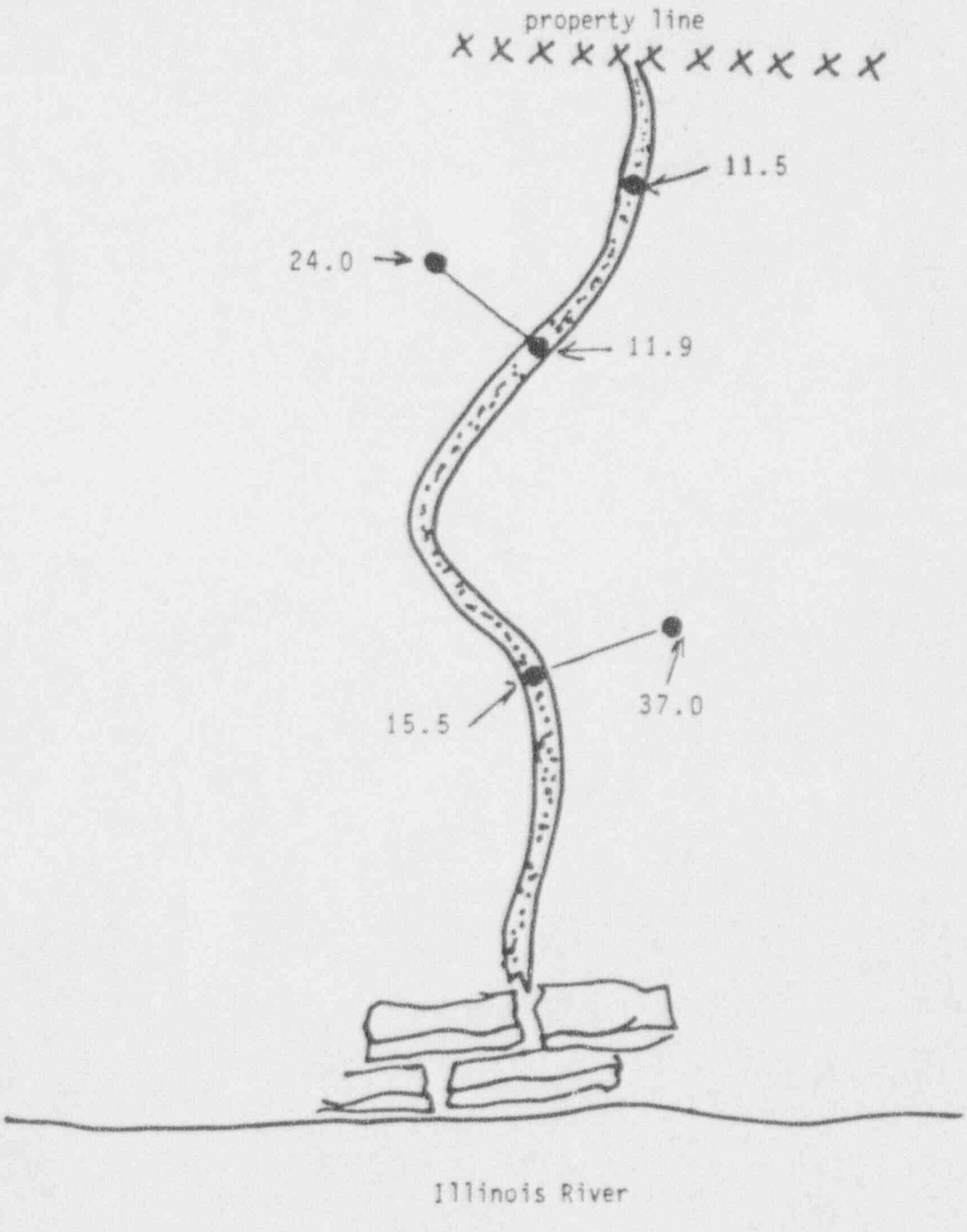


Figure 18. Nitrate Concentrations in mg/kg along the 004 Stream.

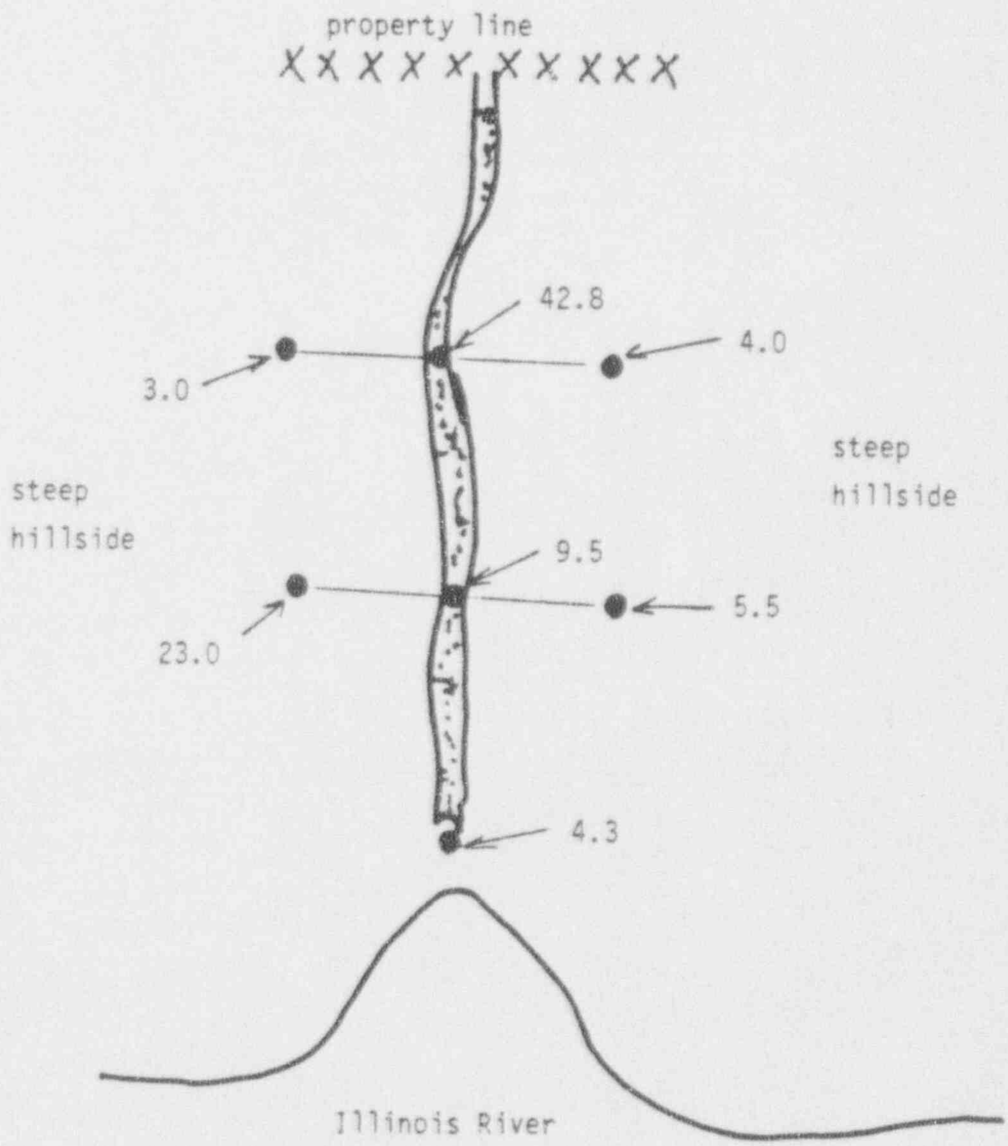


Figure 19. Nitrate Concentrations in mg/kg along the 005 Stream.

Table 13. Nitrate Concentrations Along the 005A Stream.

Distance Downstream	Sample Location	Nitrate Concentration (mg/kg)
Prop. +50	streambed	30.2
	50 ft south	19.9
	150 ft south	18.3
	300 ft south	13.1
Prop. +100	streambed	16.9
	50 ft north	14.5
	150 ft north	16.9
	300 ft north	11.5
Highwater mark		49.9

Table 14. Nitrate Concentrations Along the 007 Stream.

Distance Downstream	Sample Location	Nitrate Concentration (mg/kg)
Prop. +40	streambed	11.0
	25 ft south	3.0
	25 ft north	4.5

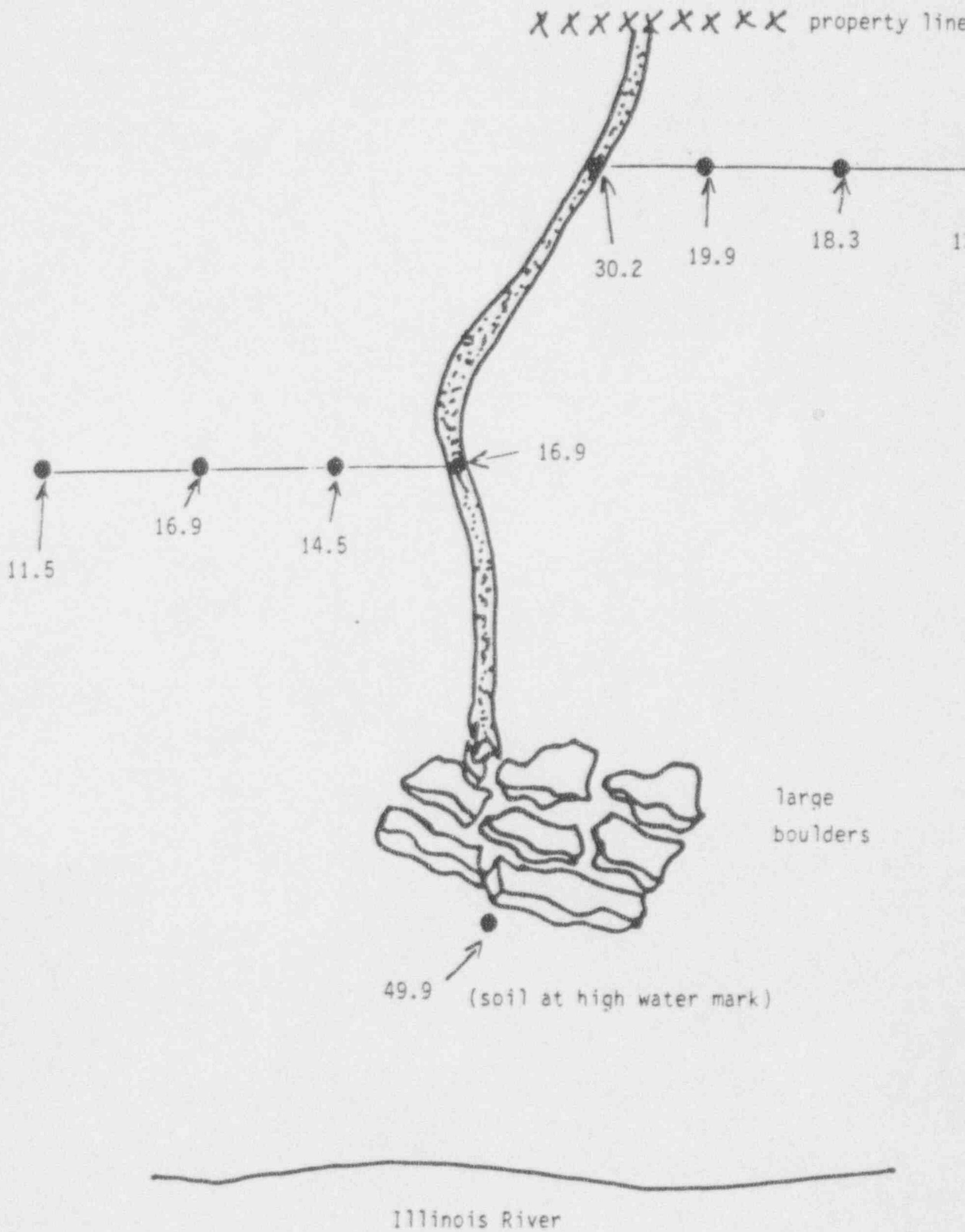


Figure 20. Nitrate Concentrations in mg/kg Along the 005A Stream.

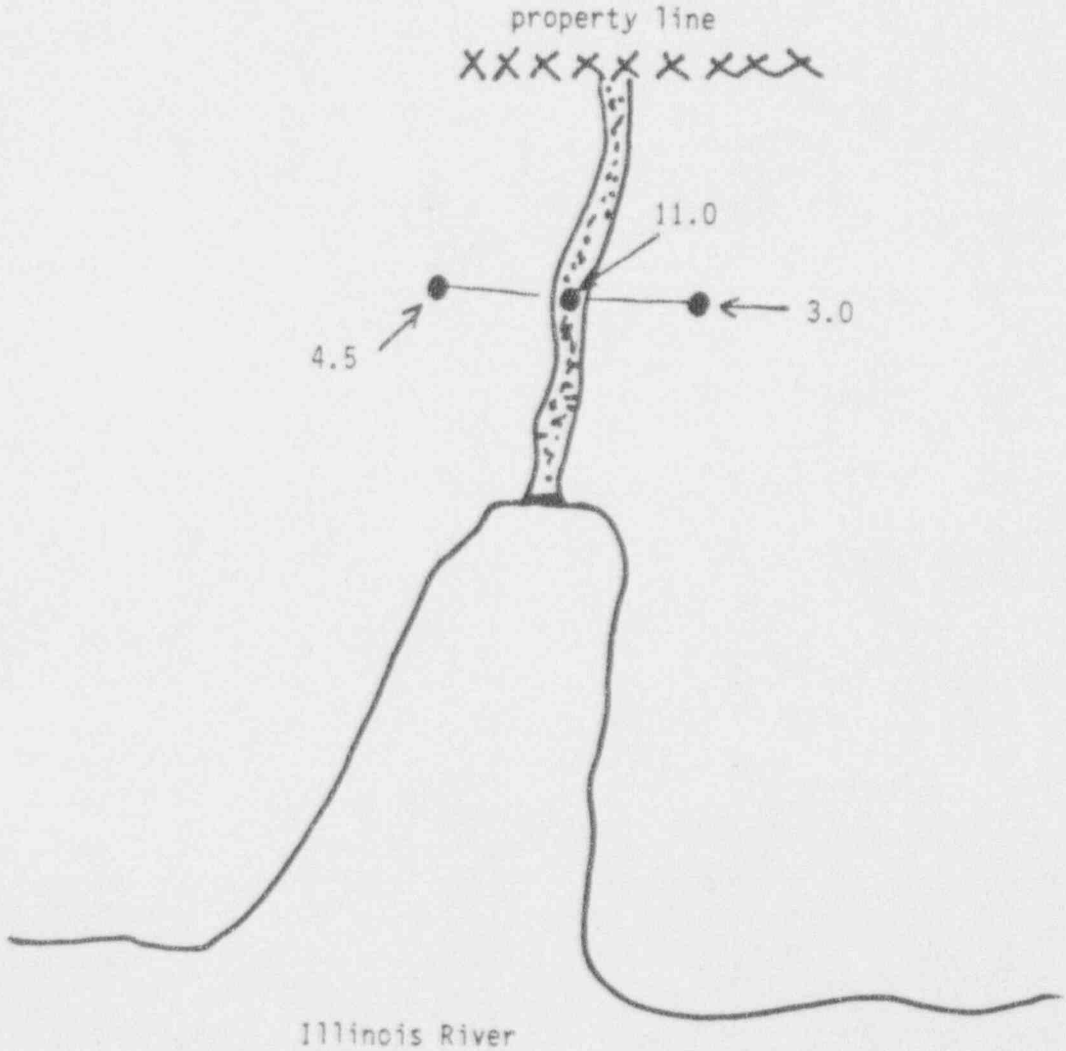


Figure 21. Nitrate Concentrations in mg/kg along the 007 Stream.

COMMENTS AND CONCLUSIONS

Results of this study confirm the presence of Uranium in the effluent from Sequoyah Fuels Facility and that the concentration of Uranium at the time of measurement was within NRC Guidelines for the release of such to unrestricted areas. Uranium concentrations are documented in the outfall streambeds and radionuclide concentrations above background were present in soil samples taken on the banks of streams 001, 005, 005A and 007. An area of elevated radionuclide concentration in Stream 005 could possibly be of natural origin. None of these concentrations would produce an external radiation exposure dose in excess of NRC limits for unrestricted areas.

The downstream sediment and water samples indicate a diluting effect on the radionuclide concentrations and the concentration of Uranium downstream in the waters of the Illinois and Arkansas Rivers are within the limits specified in the Oklahoma Water Quality Standards.

Soil nitrate and molybdenum concentrations were not found to be appreciably greater than naturally occurring concentrations.

Construction of a pipeline directly from the facility to the Illinois River would reduce the potential for surface contamination but would probably increase the concentrations of radionuclides in the waters of the rivers. The degree of increase can only be predicted from detailed effluent analysis. Such sampling was not included in this study.

REFERENCES

American Public Health Association, "Examination of Water and Wastewater for Radioactivity, Part 700," **Standard Methods for the Examination of Water and Wastewater**, 16th ed., APHA, Washington, D.C., 1985.

Anderson, I., B. Torstenfelt and B. Allard, "Sorption Behavior of Long-Lived Radionuclides in Igneous Rock," in: **Environmental Migration of Long Lived Radionuclides**, pp. 111-132, IAEA-SM-257/20, International Atomic Energy Agency, Vienna, 1982.

Cataldo, C.E. et.al., **Plant Rhizosphere Processes Influencing Radionuclide Mobility in Soil**, Pacific Northwest Laboratory, Richland, WA, for: United States Nuclear Regulatory Commission, NUREG/CR-4976, PNL-6277, 1987.

Di Spirito, A.A. and O.H. Tuovinen, "Kinetics of Uranous Ion and Ferrous Iron Oxidation by Thiobacillus ferrooxidans," **Archives of Microbiology**, 133, pp. 33-37, 1982.

Eisenbud, M., "Transport in Aquatic Surface Systems," in: **Environmental Radioactivity**, pp. 105-120, Academic Press, New York, 1987.

Fedorak, P.M. et.al., "Microbial Release of Ra-226 from (Ba, Ra)SO_4 Sludges from Uranium Mine Wastes," **Applied and Environmental Microbiology**, 52(2), pp. 262-268, 1986.

Francis, A.J., "Low Level Radioactive Wastes in Subsurface Soils," in: **Soil Reclamation Processes**, Marcell Dekker, New York, 1985.

Garten, C.T., J. R. Trebalka and M.A. Bogle, "Comparative Food Chain behavior and Distribution of Actinide Elements In and Around a Contaminated Freshwater Pond," in: **Environmental Migrations of Long Lived Radionuclides**, pp. 299-310, IAEA-SM-257/71, International Atomic Energy Agency, Vienna, 1982.

Gascoyne, M., "Geochemistry of the Actinides and Their Daughters," in: **Uranium Series Disequilibrium: Applications to Environmental Problems**, M. Ivanovich and R.S. Harmon, eds., Clarendon Press, Oxford, 1982.

Heinen, W. and A.M. Lauwers, "Leaching of Silica and Uranium and Other Quantitative Aspects of the Lithobiontic Colonization in a Radioactive Thermal Spring," **Microbial Ecology**, 15, pp. 135-149, 1988.

Ibrahim, S.A. and F.W. Whicker, "Comparative Uptake of U and Th by Native Plants at a U Production Site," **Health Physics**, 54(4), pp. 413-419, 1988.

International Atomic Energy Agency, **Uranium Biochemistry: A Bibliography and Report on the State of the Art**, IAEA-TECDOC-327, Vienna, 1985.

Ivanovich, M. and R. S. Harmon (eds.), **Uranium Series Disequilibrium: Applications to Environmental Problems**, Clarendon Press, Oxford, 1982.

Kocher, D.C., **Radioactive Decay Tables. A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments**, DOE/TIC-11026, Technical Information Center, Department of Energy, Oak Ridge, TN, 1985.

Landa, E.R., C.L. Miller and D.M. Updegraff, "Leaching of Ra-226 from U Mill Tailings by Sulfate-Reducing Bacteria," **Health Physics**, 51(4), pp. 509-518, 1986.

Lindsay, W.L., **Chemical Equilibria in Soils**, Wiley and Sons, New York, 1979.

Mahon, D.C., "Uptake and Translocation of Naturally Occurring Radionuclides of the Uranium Series," **Bulletin of Environmental Contamination and Toxicology**, 29, pp. 697-703, 1982.

Mahon, D.C. and R.W. Mathews, "Uptake of Naturally Occurring Radioisotopes by Vegetation in a Region of High Radioactivity," **Canadian Journal of Soil Science**, 63, pp. 281-290, 1982.

Mann, H. and W. S. Fyfe, "Algal Uptake of U and Some Other Metals: Implications for Global Geochemical Cycling," **Precambrian Research**, 30, pp. 337-349, 1985.

Miller, C.L., E.R. Landa and D.M. Updegraff, "Ecological Aspects of Microorganisms Inhabiting Uranium Mill Tailings," **Microbial Ecology**, 14, pp. 141-155, 1987.

Nakajima, A. and T. Sakaguchi, "Selective Accumulation of Heavy Metals by Microorganisms," **Applied Microbiology and Biotechnology**, 24, pp. 59-64, 1986.

Napier, B.A., **A Method for Determining Allowable Residual Contamination Levels of Radionuclide Mixtures in Soil**. Pacific Northwest Laboratory, Richland, WA for: United States Department of Energy, PNL-3852, 1982.

National Council on Radiation Protection and Measurements, **Radiological Assessment: Predicting the Transport, Bioaccumulation and Uptake by Man of Radionuclides Released to the Environment**, NCRP 76, NCRP, Bethesda, MD, 1984.

National Council on Radiation Protection and Measurements, **Exposure of the Population in the United States and Canada from Natural Background Radiation**, NCRP 94, NCRP, Bethesda, MD, 1987.

Oklahoma Water Resources Board, **Oklahoma's Water Quality Standards**, OWRB, Oklahoma City, 1985.

Osburn, W.S., "Primordial Radionuclides: Their Distribution, Movement and Possible Effect Within Terrestrial Ecosystems," **Health Physics**, 11, pp. 1275-1295, 1965.

Premuzic, E.T. et.al., "Induced Formation of Chelating Agents by Pseudomonas aeruginosa Grown in the Presence of Thorium and Uranium," **Archives of Environmental Contamination and Toxicology**, **14**, pp. 759-768, 1985.

Schulz, R.K., "Soil Chemistry of Radionuclides," **Health Physics**, 11, pp. 1317-1324, 1965.

Scott, M.R., "The Chemistry of Uranium and Thorium Series Nuclides in Rivers," in: **Uranium Series Disequilibrium: Applications to Environmental Problems**, M. Ivanovich and R.S. Harmon, eds., Clarendon Press, Oxford, 1982.

Sheard, J.W., "Distribution of Uranium Series Radionuclides in Upland Vegetation of Northern Saskatchewan. I. Plant and Soil Concentrations," **Canadian Journal of Botany**, **64**, pp. 2446-2452, 1986.

Sheppard, M.I., S.C. Sheppard and D.H. Thibault, "Uptake by Plants of Uranium and Chromium in Field Lysimeters," **Journal of Environmental Quality**, 13(3), pp. 357-361, 1984.

Stegnar, P. and I. Kobal, "Uptake and Distribution of Radium and Uranium in the Aquatic Food Chain," in: **Environmental Migration of Long Lived Radionuclides**, pp. 364-373, IAEA-SM-257/87P, International Atomic Energy Agency, Vienna, 1982.

Strandberg, G.W., E.S. Starling and J.R. Parrott, "Microbial Cells as Biosorbents for Heavy Metals: Accumulation of Uranium by Saccharomyces cerevisiae and Pseudomonas aeruginosa," **Applied and Environmental Microbiology**, **41**(1), pp. 237-245, 1981.

Swanson, S.A., "Food Chain Transfer of U-Series Radionuclides in a Northern Saskatchewan Aquatic System," **Health Physics**, 49(S), pp. 747-770, 1985.

United States Department of Agriculture, Soil conservation Service and Oklahoma Agricultural Experiment Station, **Soil Survey Sequoyah County, Oklahoma**, U.S. Government Printing Office, Washington D.C., 1970.

Wahlgren, M.A. and K.A. Orlandini, "Comparison of the Geochemical Behavior of Plutonium, Thorium and Uranium in Selected North American Lakes," in: **Environmental Migration of Long Lived Radionuclides**, pp. 757-774, IAEA-SM-257/89, International Atomic Energy Agency, Vienna, 1982.

Wildlung, R.E. and T.R. Garland, "The Relationship of Microbial Processes to the Fate and Behavior of Transuranic Elements in Soils, Plants, and Animals,: in: **Transuranic Elements in the Environment**, W. Hanson, ed., DOE/TIC-22800, United States Department of Energy, Washington D.C., 1980.

Williams, A.R., "Biological Uptake and Transfer of Radium-226: A Review," in: **Environmental Migration of Long Lived Radionuclides**, pp. 207-222, IAEA-SM-257/92, International Atomic Energy Agency, Vienna, 1982.

APPENDIX A

Sequoyah Fuels Corporation Survey of

Soil/Sediment for Outfall 001 - 1986

SEQUOYAH FUELS CORPORATION

POST OFFICE BOX 25861 • OKLAHOMA CITY OKLAHOMA 73125

September 19, 1986

FEDERAL EXPRESS

William T. Crow, Acting Chief
Uranium Fuel Licensing Branch
Division of Fuel Cycle & Material Safety
Office of Nuclear Material Safety & Safeguards
United States Nuclear Regulatory Commission
Washington, D. C. 20555

Re: License SUB-1010; Docket 40-8027
Condition 17

Dear Mr. Crow:

Attached for your information is Sequoyah Fuels Corporation's report in response to License Condition 17 addressing the comprehensive soil/sediment radiological survey of the effluent stream (001) and the facility intermittent stormwater run-off drainages.

Should you have any questions, please contact me at your earliest convenience.

Sincerely,

J. C. Stauter

J. C. Stauter, Director
Nuclear Licensing & Regulation

Enc.: 8 copies

JCS/sc

Sequoyah Fuels Corporation
Effluent Stream Soil and Sediment
Radiological Survey and Mitigation Program

Introduction

Sequoyah Fuels Corporation source material license SUB 1010, renewed on September 20, 1985, stipulated in Condition 17 that:

> "The licensee shall conduct a comprehensive soil/sediment radiological survey to determine the extent of uranium accumulation along the length of the effluent stream (001), at the confluence upstream and downstream of the Illinois River, and along the intermittent runoff areas identified in Condition 14." (Sic 15)

This document reports the results of the comprehensive survey and mitigation measures that are appropriate.

Effluent Drainage Ways

The effluent drainage ways surveyed were the NPDES permitted combination stream (outfall 001) and various ditches that carry stormwater runoff, designated as outfalls 004, 005 and 006-7. An application to permit these latter outfalls was submitted to EPA on June 12, 1984 and remains under EPA review.

Outfall 001 discharges the plant process waste water. Outfall 004 discharges stormwater runoff from the areas west of Pond 2 and from the northern portion of Clarifier A area. Outfall 005 discharges runoff from the areas west of the sanitary lagoon, west, north and northeast of Basin 1, and east of Clarifier A. Outfall 006-7 discharges runoff from the UF_6 cylinder concrete storage pad and other areas in the northeast portion of the facility property. The location of each of the outfalls and the drainage courses are schematically shown in the attached Figure 1.

Survey Program

Soil and sediment samples were collected at 300-foot intervals along the length of each of the outfall drainage ways. Using a small garden trowel, approximately 500 grams of sediment, consisting of silt and sand, were taken at each sample point, placed in "zip-lock" plastic bags and sealed.

Outfall 001 has continuous flow and the width of the stream varies widely; consequently, two samples were obtained at each of the intervals at a point one-third the stream width in from each bank. The other outfalls have intermittent flow and single samples were collected at the center of the channel at each of the intervals. Because these channels are directly on or within a few inches of bedrock, sediment and soil was sparse. Most of the samples had to be obtained from small silted depressions in the channel near the 300-foot spacings.

In addition to the outfall channel sampling, sediment was collected in the Illinois River at points upstream and downstream of the outfalls, as well as at the outfalls. These samples were obtained using a weight-operated clam shell sampler.

All samples were analyzed at the Kerr-McGee Technical Center for U-nat, Th-230, and Ra-226.

As part of the comprehensive radiological survey, gamma measurements were also made at ground level at the sediment collection locations. These measurements were taken using an unshielded micro-R scintilation gamma meter placed directly on the sediments in the dry runoff channels. Gamma measurements along the 001 outfall stream were taken immediately above ground surface.

Survey Results

The radionuclide and gamma measurement data for outfall 001 are in Table 1. Data for the two samples taken at each location are shown individually and as the average for each location. The data for the other outfalls are in Table 2. The data show that for each outfall drainage, there are some areas where concentrations of either uranium or thorium or both are elevated.

The uranium levels along outfall 001 reflect buildup in the sediment from long term discharge of the plant process water. Although the concentration of uranium in the discharge stream is far below permitted release criteria, some soil accumulation is apparent.

Outfall 004, with the exception of one sample location inside the controlled area fence, does not show elevated uranium. Outfall 005 shows elevated levels of both thorium and uranium along the upper reach of the drainage way. Outfall 006-7 shows uranium levels are elevated generally along the length of the drainage channel. While the gamma measurements along outfall 006-7 exceed background at three sample locations, the gamma fields detected are not associated with the uranium or thorium in the soil sediment. The elevated readings are due to the UF_6 cylinders stored in the immediate vicinity.

None of the survey results indicates that the presence of the slightly elevated levels poses a threat to health or the environment.

Mitigation Program

Outfall 001 was addressed in SFC's letter of August 9, 1985 to the NRC. Briefly, a pipeline will be constructed, eliminating use of the present natural drainage channel for plant process water. An application for a right-of-way for the pipeline has been submitted to the U.S. Corps of Engineers. The uranium-containing soil and sediment along the natural channel will be resurveyed after pipeline installation and the elevated sediments/soils will be removed and properly disposed of.

The origin of the elevated uranium and thorium along the reaches of outfalls 005 and 006-7 were addressed in SFC's December 19, 1985 submittal in response to License Conditions 15 and 16. Following completion of the mitigation activities described in that submittal, the stream channels will be resurveyed, and removal and disposal of the elevated uranium and thorium-containing soil and sediment will be undertaken.

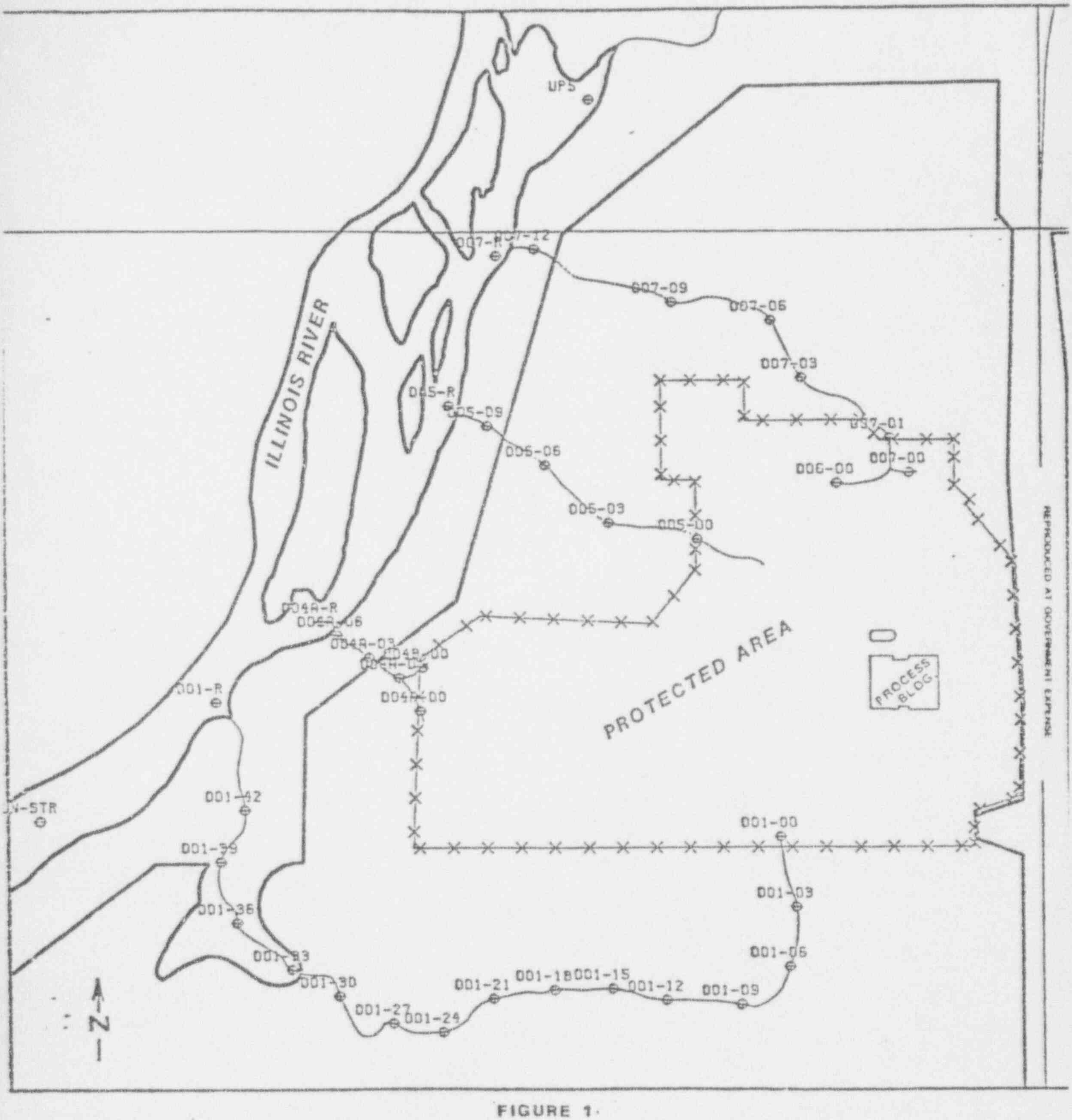


FIGURE 1
OUT FALL SAMPLE LOCATIONS
SCALE 1"=600'

TABLE I
SOIL/SEDIMENT SAMPLES
SEQUOYAH FUELS CORPORATION
OUTFALL DRAINAGE SURVEY

OUTFALL SAMPLE NO.	URANIUM (nat) (pCi/g) RIGHT	LEFT	AVG	THORIUM 230 (pCi/g) RIGHT	(+-)	LEFT	(+-)	AVG	RADIUM 226 (pCi/g) RIGHT	(+-)	LEFT	(+-)	AVG	GAMMA (uR/hr)
001-00	255	288	271	6.93	0.07	8.87	0.08	7.90	1.25	0.28	1.39	0.28	1.32	3
001-03	168	101	134	2.61	0.26	3.22	0.05	2.92	0.61	0.21	1.53	0.34	2.61	3
001-06	94	101	97	2.68	0.04	2.05	0.04	2.37	1.20	0.44	1.40	0.42	1.30	4
001-09	107	121	114	2.64	0.04	4.58	0.19	3.61	1.50	0.40	1.84	0.43	1.67	3
001-12	114	168	141	3.54	0.17	4.72	0.21	4.13	1.28	0.20	1.35	0.35	1.32	3
001-15	67	141	104	1.19	0.09	4.23	0.23	2.71	1.88	0.25	2.10	0.24	1.99	3
001-18	147	141	144	2.90	0.15	1.18	0.11	2.04	1.88	0.37	1.80	0.39	1.84	3
001-21	101	51	76	1.44	0.12	1.61	0.12	1.53	1.36	0.24	1.33	0.32	1.35	3
001-24	64	29	46	1.49	0.11	1.5[illegible]	0.12	1.54	1.68	0.34	1.16	0.28	1.42	3
001-27	54	87	70	0.98	0.24	0.98	0.09	0.98	1.28	0.21	1.60	0.35	1.44	3
001-30	80	94	87	7.43	0.40	4.20	0.23	5.82	1.40	0.28	1.24	0.24	1.32	4
001-33	34	60	47	3.70	0.25	1.78	0.14	2.74	0.96	0.24	0.91	0.27	0.93	4
001-36	54	54	54	4.74	0.24	4.44	0.36	4.59	1.26	0.20	1.28	0.33	1.27	3
001-39	27	34	30	3.83	0.21	3.26	0.16	3.55	1.34	0.32	1.48	0.21	1.41	3
001-42	27	47	37	0.66	0.10	0.74	0.11	0.70	1.64	0.39	1.45	0.16	1.55	3

Note: Uranium concentrations converted to PCi/g from original reported ppm.
Analytical accuracy for uranium was +- 7.5%

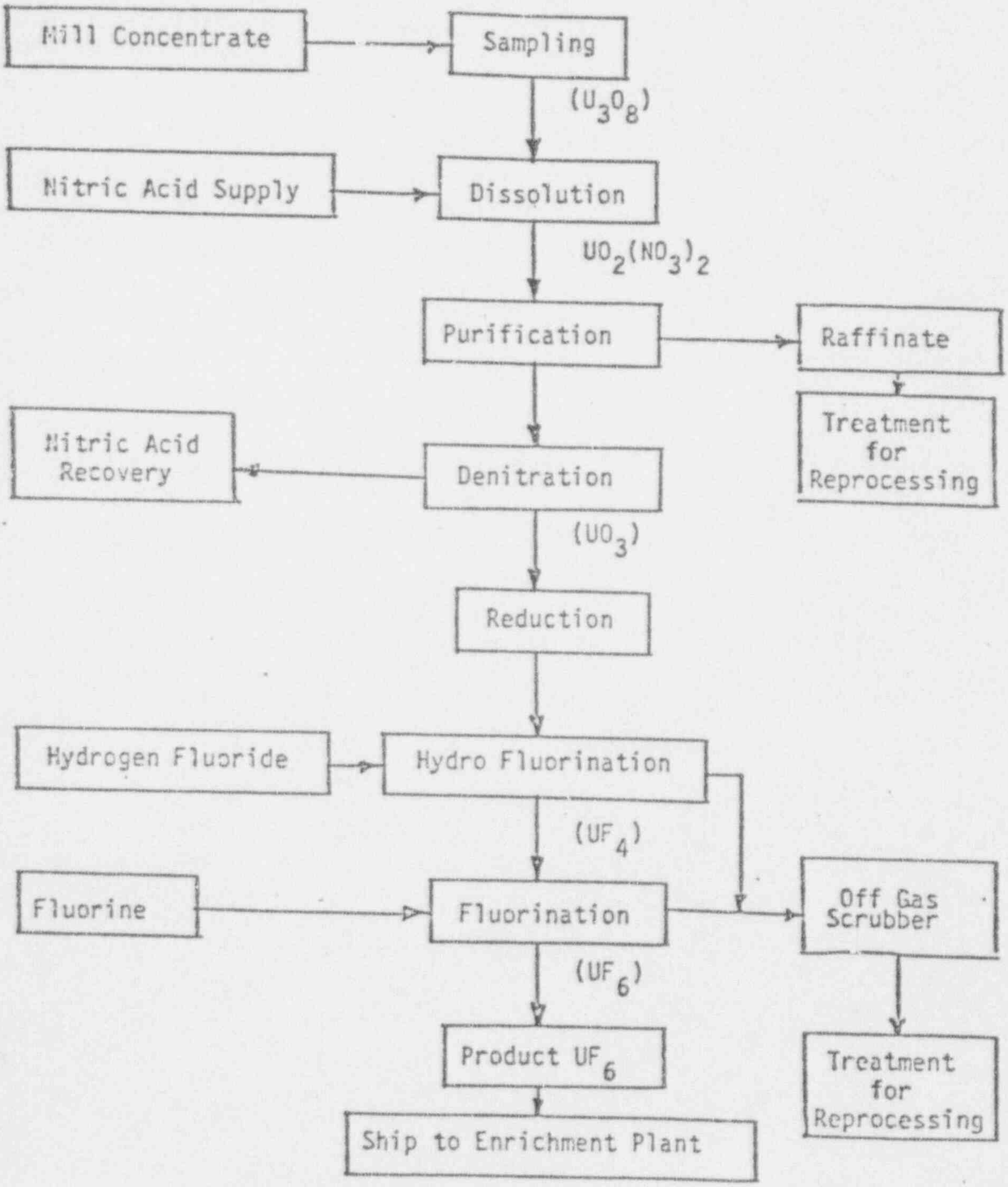
TABLE 2
SOIL/SEDIMENT SAMPLES
SEQUOYAH FUELS CORPORATION
OUTFALL DRAINAGE SURVEY

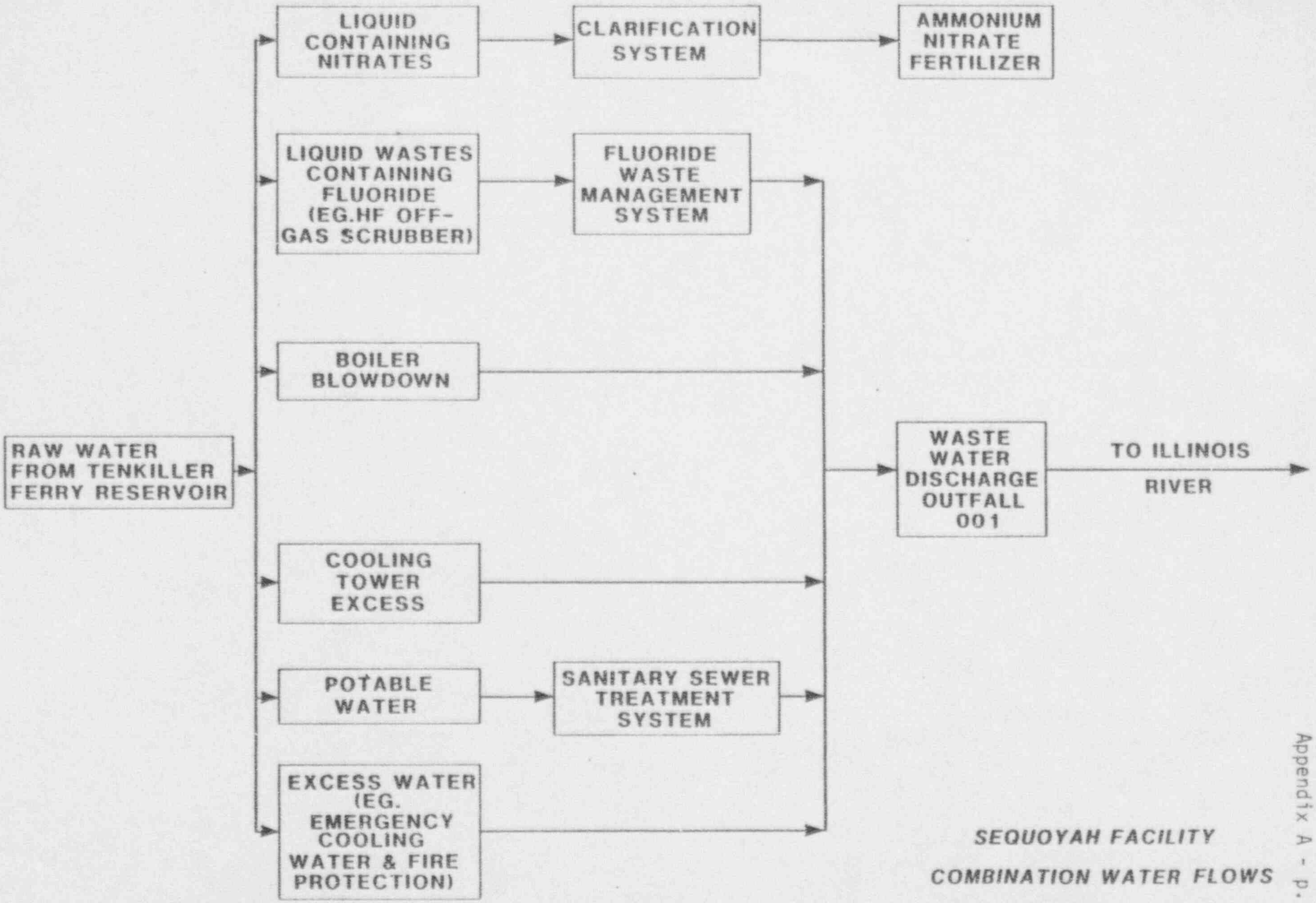
OUTFALL SAMPLE NO.	U (nat) (pCi/g)	Th 230 (pCi/g)	(+-)	Ra 226 (pCi/g)	(+-)	GAMMA (uR/hr
004A-00	3	0.69	0.05	1.56	0.16	3
004B-00	205	1.25	0.09	1.08	0.15	7
004A-01	13	1.44	0.11	1.90	0.34	5
004A-03	7	1.28	0.10	0.90	0.14	5
004A-06	6	0.62	0.05	1.14	0.14	5
005-00	159	49.00	3.68	2.22	0.38	15
005-03	170	73.00	5.48	1.30	0.16	9
005-06	277	354.00	26.55	2.40	0.34	10
005-09	505	106.00	7.95	1.60	0.32	10
007-00	35	3.54	0.27	1.07	0.14	52
006-00	118	6.86	0.51	1.30	0.14	25
007-01	17	1.85	0.14	1.08	0.15	25
007-03	40	2.95	0.22	1.37	0.14	7
007-06	105	2.52	0.19	1.46	0.24	5
007-09	104	16.20	1.22	1.41	0.15	3
007-12	74	2.47	0.19	1.27	0.17	2
UP-STRM	11	1.02	0.08	1.02	0.15	--
004-R	45	0.83	0.06	1.14	[illegible]	--
005-R	5	1.06	0.08	1.02	[illegible]	--
007-R	21	3.47	0.26	1.21	0.16	--
001-R	19	1.09	0.08	0.92	0.14	--
DN-STRM	5	1.51	0.11	1.34	0.15	--

Note: Uranium concentrations converted to pCi/g from original assay reported in ppm.
Analytical accuracy for uranium was +- 7.5%

SEQUOYAH FACILITY

CONVERSION OF MILL CONCENTRATE TO URANIUM HEXAFLUORIDE



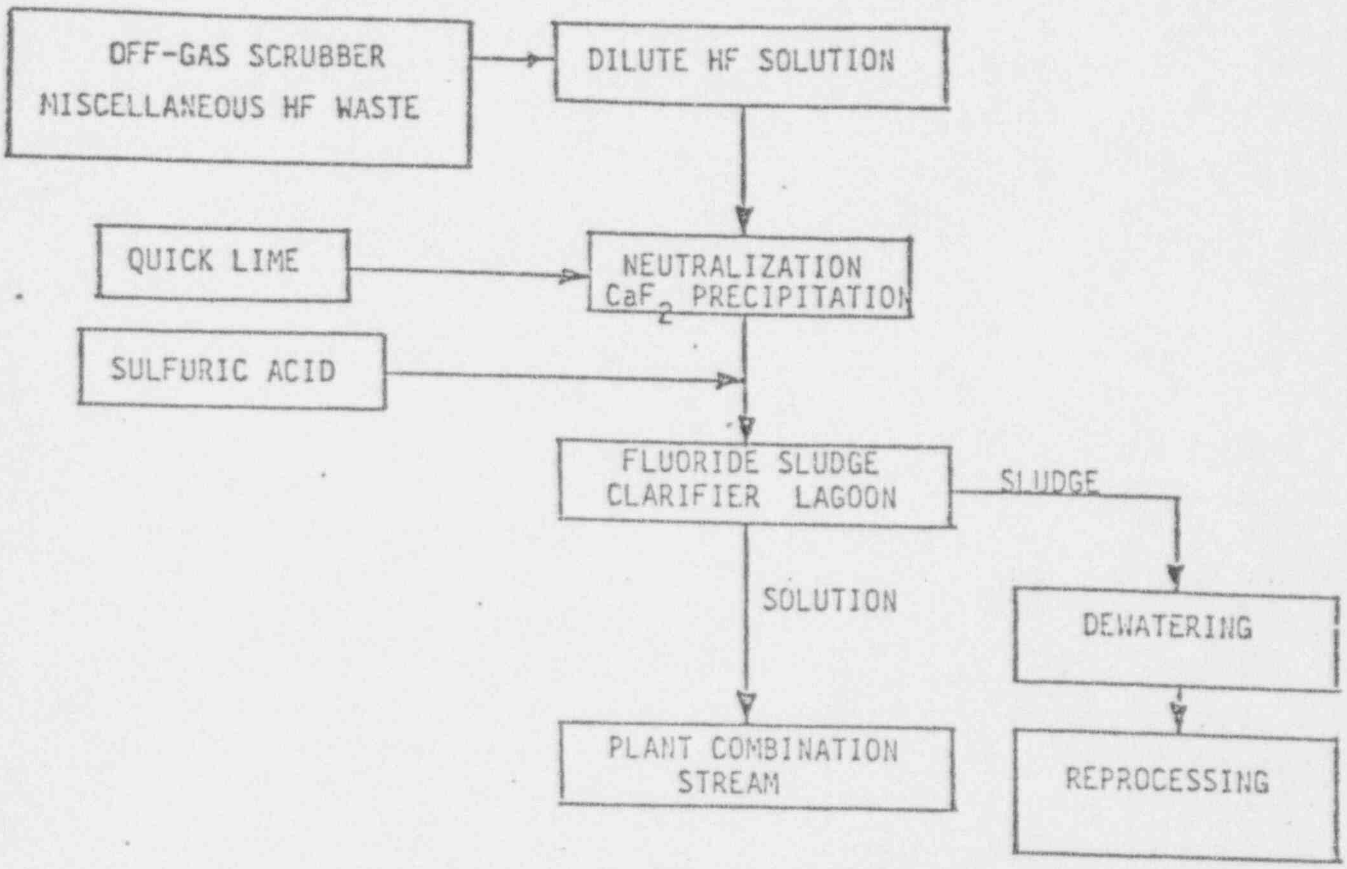


SEQUOYAH FACILITY

COMBINATION WATER FLOWS

SEQUOYAH FACILITY

FLUORIDE WASTE MANAGEMENT SYSTEM



APPENDIX B

Analytical Report for Corps of Engineers Soil, Sediment and Water Samples of Sequoyah Fuels Facility Outfalls - 1988

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

ANALYTICAL REPORT

884202

FOR

US ARMY CORPS OF ENG
DAVID COMBS
P.O. BOX 61
TULSA, OK 74121-0061

08/25/88

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

F I N A L   R E P O R T   D I S T R I B U T I O N
08/25/88

JOB NUMBER: 884202

COMPANY NAME	COMPANY MAILING ADDRESS	COMPANY CITY	STATE	COMPANY ZIP CODE
US ARMY CORPS OF ENG DAVID COMBS	P.O. BOX 61	TULSA	OK	74121-0061

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

L A B O R A T O R Y   T E S T S   R E S U L T S
08/25/88

JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 1 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:50 SAMPLE DATE: 07/08/88 SAMPLE TIME: 13:50
PROJECT: Sequoyah Fuels SAMPLE: 19879 SF-1-A0 6/30/88 001 STREAM, 25' REM:

SAMPLE NUMBER: 2 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:50 SAMPLE DATE: 07/08/88 SAMPLE TIME: 13:50
PROJECT: Sequoyah Fuels SAMPLE: 19880 SF-1-A1 6/30/88 001 BANK, RIGHT REM:

SAMPLE NUMBER: 3 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:50 SAMPLE DATE: 07/08/88 SAMPLE TIME: 13:50
PROJECT: Sequoyah Fuels SAMPLE: 19881 SF-1-A2 6/30/88 001 50', RIGHT REM:

SAMPLE NUMBER: 4 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:50 SAMPLE DATE: 07/08/88 SAMPLE TIME: 13:50
PROJECT: Sequoyah Fuels SAMPLE: 19882 SF-1-A3 6/30/88 001 100', RIGHT REM:

SAMPLE NUMBER: 5 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:50 SAMPLE DATE: 07/08/88 SAMPLE TIME: 13:50
PROJECT: Sequoyah Fuels SAMPLE: 19883 SF-1-B0 6/30/88 15:15 001 STREAM 200' REM:

SAMPLE NUMBER: 6 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19884 SF-1-B1 6/30/88 15:25 001 BANK RIGHT REM:

TEST DESCRIPTION	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	UNITS OF MEASURE
Uranium, natural	28	16	3.1	1.7	19	8.9	pCi/gm
Gross Alpha, total	54	31	14	14	19	19	pCi/gm
Gross Alpha, total, error, +/-	8.3	6.8	5.3	5.3	5.8	5.8	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.7	0.8	2.8	0.8	1.3	1.3	pCi/gm
Radium 226, total, error, +/-	0.5	0.3	0.6	0.3	0.4	0.4	pCi/gm
Radium 226, total, LLD	0.21	0.2	0.2	0.2	0.2	0.2	pCi/gm
Thorium 230, total	1.9	0.5	2	2.5	1.4	1.2	pCi/gm
Thorium 230, total, error, +/-	0.55	0.4	0.6	0.6	0.4	0.5	pCi/gm
Thorium 230, total, LLD	0.5	0.5	0.5	0.5	0.4	0.5	pCi/gm
Uranium (U), total	48	28	5.3	2.9	32	15	mg/kg

Western Atlas International
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CORE LABORATORIES

L A B O R A T O R Y   T E S T S   R E S U L T S
08/25/88

JOB NUMBER: 884202   CUSTOMER: US ARMY CORPS OF ENG   ATTN: DAVID COMBS

SAMPLE NUMBER: 7   DATE RECEIVED: 07/18/88   TIME RECEIVED: 13:55   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19885 SF-1-B2 6/30/88 001 50', RIGHT   REM:

SAMPLE NUMBER: 8   DATE RECEIVED: 07/18/88   TIME RECEIVED: 13:55   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19886 SF-1-B4 6/30/88 15:30 001 100' RIGHT   REM:

SAMPLE NUMBER: 9   DATE RECEIVED: 07/18/88   TIME RECEIVED: 13:55   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19887 SF-1-C0 6/30/88 15:00 001 STREAM 400'   REM:

SAMPLE NUMBER: 10   DATE RECEIVED: 07/18/88   TIME RECEIVED: 13:55   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19888 SF-1-C1 6/30/88 15:15 001 BANK RIGHT   REM:

SAMPLE NUMBER: 11   DATE RECEIVED: 07/18/88   TIME RECEIVED: 13:55   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19889 SF-1-C2 6/30/88 15:20 001 50' RIGHT   REM:

SAMPLE NUMBER: 12   DATE RECEIVED: 07/18/88   TIME RECEIVED: 13:55   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19890 SF-1-C3 6/30/88 15:30 001 100' RIGHT   REM:

TEST DESCRIPTION	SAMPLE 7	SAMPLE 8	SAMPLE 9	SAMPLE 10	SAMPLE 11	SAMPLE 12	UNITS OF MEASURE
Uranium, natural	19	8.3	19	14	21	38	pCi/gm
Gross Alpha, total	26	15	26	25	44	59	pCi/gm
Gross Alpha, total, error, +/-	6.3	5.5	6.4	6.2	7.6	8.6	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.6	2.9	1	1.1	1.7	2.7	pCi/gm
Radium 226, total, error, +/-	0.5	0.6	0.4	0.4	0.5	0.6	pCi/gm
Radium 226, total, LLD	0.2	0.2	0.2	0.2	0.2	0.2	pCi/gm
Thorium 230, total	1.1	5.5	1.4	1.7	1	3	pCi/gm
Thorium 230, total, error, +/-	0.4	0.8	0.5	0.6	0.4	0.6	pCi/gm
Thorium 230, total, LLD	0.5	0.5	0.4	0.5	0.5	0.5	pCi/gm
Uranium (U), total	33	14	33	23	36	64	mg/kg

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CORE LABORATORIES

LABORATORY TESTS RESULTS
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JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 13 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19891 SF-1-D0 6/30/88 13:50 001 STREAM 500' REM:

SAMPLE NUMBER: 14 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19892 SF-1-D1 6/30/88 13:50 001 50' LEFT REM:

SAMPLE NUMBER: 15 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19893 SF-1-D2 6/30/88 14:00 001 100' LEFT REM:

SAMPLE NUMBER: 16 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19894 SF-1-D3 6/30/88 14:00 001 140' LEFT REM:

SAMPLE NUMBER: 17 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19895 SF-1-E0 6/30/88 16:00 001 700' STREAM REM:

SAMPLE NUMBER: 18 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19896 SF-1-E1 6/30/88 16:10 001 30' RIGHT REM:

TEST DESCRIPTION	SAMPLE 13	SAMPLE 14	SAMPLE 15	SAMPLE 16	SAMPLE 17	SAMPLE 18	UNITS OF MEASURE
Uranium, natural	21	27	50	97	16	12	pCi/gm
Gross Alpha, total	33	35	96	108	23	25	pCi/gm
Gross Alpha, total, error, +/-	6.9	7.1	11	12	6.1	6.3	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.4	1.6	0.6	3.2	0.7	1.4	pCi/gm
Radium 226, total, error, +/-	0.4	0.5	0.3	0.6	0.3	0.4	pCi/gm
Radium 226, total, LLD	0.2	0.2	0.2	0.2	0.2	0.2	pCi/gm
Thorium 230, total	1.4	1.9	1.1	1.1	1.1	0.9	pCi/gm
Thorium 230, total, error, +/-	0.4	0.5	0.4	0.4	0.4	0.4	pCi/gm
Thorium 230, total, LLD	0.5	0.5	0.5	0.4	0.4	0.4	pCi/gm
Uranium (U), total	36	46	85	165	27	20	mg/kg

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JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 19 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19897 SF-1-E2 6/30/88 16:20 001 50' RIGHT REM:

SAMPLE NUMBER: 20 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19898 SF-1-F 6/30/88 14:00 001 500' REM:

SAMPLE NUMBER: 21 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19899 SF-1-G 6/30/88 16:00 001 700' REM:

SAMPLE NUMBER: 22 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19901 SF-S-01 7/1/88 13:00 GORE LANDING REM:

SAMPLE NUMBER: 23 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19902 SF-S-02 7/1/88 007 MOUTH REM:

SAMPLE NUMBER: 24 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19903 SF-S-03 7/1/88 005-007 REM:

TEST DESCRIPTION	SAMPLE 19	SAMPLE 20	SAMPLE 21	SAMPLE 22	SAMPLE 23	SAMPLE 24	UNITS OF MEASURE
Uranium, natural	32	26	19	1.4	1.1	1.4	pCi/gm
Gross Alpha, total	69	37	35	12	18	14	pCi/gm
Gross Alpha, total, error, +/-	9.1	7.2	7.1	5.1	5.7	5.4	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	2.7	1.3	1.2	0.7	1.2	0.9	pCi/gm
Radium 226, total, error, +/-	0.6	0.4	0.4	0.3	0.4	0.3	pCi/gm
Radium 226, total, LLD	0.2	0.2	0.2	0.2	0.2	0.2	pCi/gm
Thorium 230, total	3.8	1.4	2.3	0.4	1.8	1.2	pCi/gm
Thorium 230, total, error, +/-	0.6	0.5	0.5	0.4	0.5	0.4	pCi/gm
Thorium 230, total, LLD	0.4	0.5	0.4	0.5	0.5	0.4	pCi/gm
Uranium (U), total	54	44	32	2.4	1.8	2.4	mg/kg

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JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 25 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19904 SF-S-04 7/1/88 005A MOUTH REM:

SAMPLE NUMBER: 26 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19905 SF-S-05 7/1/88 10:30 005 MOUTH REM:

SAMPLE NUMBER: 27 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19906 SF-S-06 7/1/88 10:15 004 MOUTH REM:

SAMPLE NUMBER: 28 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19907 SF-S-07 7/1/88 10:00 001 MOUTH REM:

SAMPLE NUMBER: 29 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19908 SF-S-08 7/1/88 001 50', 45 REM:

SAMPLE NUMBER: 30 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19909 SF-S-09 7/1/88 001 50', 90 REM:

TEST DESCRIPTION	SAMPLE 25	SAMPLE 26	SAMPLE 27	SAMPLE 28	SAMPLE 29	SAMPLE 30	UNITS OF MEASURE
Uranium, natural	2	32	2.9	4.1	2.6	4.2	pCi/gm
Gross Alpha, total	17	139	21	9.6	4.8	11	pCi/gm
Gross Alpha, total, error, +/-	5.6	13	6	4.9	4.4	5	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.9	1	1.2	0.5	1.1	0.9	pCi/gm
Radium 226, total, error, +/-	0.5	0.3	0.4	0.3	0.4	0.3	pCi/gm
Radium 226, total, LLD	0.2	0.2	0.2	0.2	0.2	0.2	pCi/gm
Thorium 230, total	9.8	56	0.8	0.7	5	1	pCi/gm
Thorium 230, total, error, +/-	0.9	4.2	0.4	0.4	0.5	0.4	pCi/gm
Thorium 230, total, LLD	0.4	0.4	0.4	0.4	0.5	0.4	pCi/gm
Uranium (U), total	3.4	54	5	7	4.4	7.1	mg/kg

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JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 31 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19910 SF-S-10 7/1/88 11:35 001, 100', 90 REM:

SAMPLE NUMBER: 32 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19911 SF-S-11 7/1/88 11:45 001, 50', 45 REM:

SAMPLE NUMBER: 33 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19912 SF-S-12 7/1/88 11:50 001, 100', 45 REM:

SAMPLE NUMBER: 34 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19913 SF-S-13 7/1/88 11:55 001, 500' DOWN REM:

SAMPLE NUMBER: 35 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19914 SF-S-14 7/1/88 12:00 001, 1000' DOWN REM:

MPLE NUMBER: 36 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19916 SF-S-16 7/1/88 10:00 001 REM:

TEST DESCRIPTION	SAMPLE 31	SAMPLE 32	SAMPLE 33	SAMPLE 34	SAMPLE 35	SAMPLE 36	UNITS OF MEASURE
Uranium, natural	1.6	3.8	1.2	1.2	1.8	3.3	pCi/gm
Gross Alpha, total	2.1	5.2	0	4	5.3	14	pCi/gm
Gross Alpha, total, error, +/-	4.1	4.5	3.4	4.3	4.5	5.4	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	0.4	0.7	0.5	0.7	0.7	0.4	pCi/gm
Radium 226, total, error, +/-	0.2	0.3	0.2	0.3	0.3	0.2	pCi/gm
Radium 226, total, LLD	0.2	0.1	0.1	0.1	0.1	0.1	pCi/gm
Thorium 230, total	0.9	0.5	1	0.8	0.8	1	pCi/gm
Thorium 230, total, error, +/-	0.4	0.3	0.4	0.4	0.4	0.4	pCi/gm
Thorium 230, total, LLD	0.4	0.5	0.5	0.4	0.5	0.5	pCi/gm
Uranium (U), total	2.7	6.4	2.1	2	3.1	5.5	mg/kg

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JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 37 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19917 SF-R-01 7/1/88 13:55 REM:
JUNCTION I-40 & HWY 100

SAMPLE NUMBER: 38 DATE RECEIVED: 07/18/88 TIME RECEIVED: 13:55 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19918 SF-R-02 7/1/88 13:55 REM:
JUNCTION I-40 & HWY 100

SAMPLE NUMBER: 39 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19931 SF-5A-01 6/30/88 REM:
PROP. + 50

SAMPLE NUMBER: 40 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19932 SF-5A-02 6/30/88 11:10 REM:
50' RIGHT OF 01

SAMPLE NUMBER: 41 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19933 SF-5A-03 6/30/88 11:20 REM:
150' RIGHT OF 01

SAMPLE NUMBER: 42 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19934 SF-5A-04 6/30/88 11:25 REM:
300' RIGHT OF 01

TEST DESCRIPTION	SAMPLE 37	SAMPLE 38	SAMPLE 39	SAMPLE 40	SAMPLE 41	SAMPLE 42	UNITS OF MEASURE
Uranium, natural	1.2	1.1	6.5	6.5	9.4	2.1	pCi/gm
Gross Alpha, total	14	3.3	54	48	19	15	pCi/gm
Gross Alpha, total, error, +/-	5.4	4.3	8.3	7.9	5.8	5.4	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.1	2.2	1.1	0.9	1.1	0.5	pCi/gm
Radium 226, total, error, +/-	0.3	0.5	0.3	0.3	0.3	0.2	pCi/gm
Radium 226, total, LLD	0.1	0.1	0.1	0.1	0.1	0.1	pCi/gm
Thorium 230, total	3	1.1	1.1	3.3	0.6	0.2	pCi/gm
Thorium 230, total, error, +/-	0.5	0.3	0.4	0.7	0.4	0.3	pCi/gm
Thorium 230, total, LLD	0.4	0.3	0.4	0.5	0.5	0.4	pCi/gm
Uranium (U), total	2.1	1.8	11	11	16	3.6	mg/kg

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JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 43 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19935 SF-5A-05 6/30/88 11:35 REM:
PROP. + 150'

SAMPLE NUMBER: 44 DATE RECEIVED: 07/18/88 TIM' RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19936 SF-5A-06 6/30/88 11:45 REM:
50' LEFT OF 05

SAMPLE NUMBER: 45 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19937 SF-5A-07 6/30/88 11:45 REM:
150' LEFT OF 05

SAMPLE NUMBER: 46 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19938 SF-5A-08 6/30/88 11:50 REM:
300' LEFT OF 05

SAMPLE NUMBER: 47 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19939 SF-5A-09 6/30/88 12:00 REM:
SOIL, HIGHWATER

MPLE NUMBER: 48 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19940 SF-5-01 6/30/88 12:30 REM:
PROP. + 50'

TEST DESCRIPTION	SAMPLE 43	SAMPLE 44	SAMPLE 45	SAMPLE 46	SAMPLE 47	SAMPLE 48	UNITS OF MEASURE
Uranium, natural	2.8	7.4	4.8	6.8	83	7.9	pCi/gm
Gross Alpha, total	12	29	24	18	483	32	pCi/gm
Gross Alpha, total, error, +/-	5.2	6.6	6.2	5.7	37	6.8	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.7	1.3	1.5	0.5	2.9	1.2	pCi/gm
Radium 226, total, error, +/-	0.4	0.4	0.4	0.2	0.5	0.4	pCi/gm
Radium 226, total, LLD	0.1	0.1	0.1	0.1	0.1	0.1	pCi/gm
Thorium 230, total	2.5	0.8	0.9	0.6	159	1.1	pCi/gm
Thorium 230, total, error, +/-	0.5	0.4	0.3	0.3	14	0.4	pCi/gm
Thorium 230, total, LLD	0.4	0.5	0.4	0.4	0.5	0.5	pCi/gm
Uranium (U), total	4.8	13	8.1	12	140	14	mg/kg

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JOB NUMBER: 884202   CUSTOMER: US ARMY CORPS OF ENG   ATTN: DAVID COMBS

SAMPLE NUMBER: 49   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19941 SF-5-02 6/30/88 12:40 25' RIGHT OF 01   REM:

SAMPLE NUMBER: 50   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19942 SF-5-03 6/30/88 25' LEFT OF 01   REM:

SAMPLE NUMBER: 51   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19943 SF-5-04 6/30/88 PROP. + 80'   REM:

SAMPLE NUMBER: 52   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19944 SF-5-05 6/30/88 25' LEFT OF 04   REM:

SAMPLE NUMBER: 53   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19945 SF-5-06 6/30/88 25' RIGHT OF 04   REM:

SAMPLE NUMBER: 54   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19946 SF-5-07 6/30/88 13:00 SED. BASE/DITCH   REM:

TEST DESCRIPTION	SAMPLE 49	SAMPLE 50	SAMPLE 51	SAMPLE 52	SAMPLE 53	SAMPLE 54	UNITS OF MEASURE
Uranium, natural	4.2	5.6	18	254	4.1	289	pCi/gm
Gross Alpha, total	29	35	55	551	40	578	pCi/gm
Gross Alpha, total, error, +/-	6.6	7	8.3	44	7.4	49	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.4	1.4	1.9	2.7	1.8	3.3	pCi/gm
Radium 226, total, error, +/-	0.4	0.4	0.4	0.5	0.4	0.6	pCi/gm
Radium 226, total, LLD	0.1	0.1	0.1	0.1	0.1	0.1	pCi/gm
Thorium 230, total	1.6	1.4	2.7	101	2	97	pCi/gm
Thorium 230, total, error, +/-	0.4	0.4	0.5	10	0.4	11	pCi/gm
Thorium 230, total, LLD	0.4	0.3	0.3	0.3	0.3	0.3	pCi/gm
Uranium (U), total	7.1	9.1	30	430	6.9	490	mg/kg

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08/25/88

JOB NUMBER: 884202   CUSTOMER: US ARMY CORPS OF ENG   ATTN: DAVID COMBS

SAMPLE NUMBER: 55   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19947 SF-4-01 6/30/88 12:15 PROP. + 20'   REM:

SAMPLE NUMBER: 56   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19948 SF-4-02 6/30/88 12:25 PROP. + 50'   REM:

SAMPLE NUMBER: 57   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19949 SF-4-03 6/30/88 12:30 25' LEFT OF 04   REM:

SAMPLE NUMBER: 58   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19950 SF-4-04 6/30/88 12:30 PROP. + 100   REM:

SAMPLE NUMBER: 59   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19951 SF-4-05 6/30/88 12:35 25' RIGHT OF 02   REM:

SAMPLE NUMBER: 60   DATE RECEIVED: 07/18/88   TIME RECEIVED: 19:31   SAMPLE DATE: 07/07/88   SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels   SAMPLE: 19952 SF-07-01 6/30/88 13:30 PROP. + 40'   REM:

TEST DESCRIPTION	SAMPLE 55	SAMPLE 56	SAMPLE 57	SAMPLE 58	SAMPLE 59	SAMPLE 60	UNITS OF MEASURE
Uranium, natural	1.1	1.2	2.2	2.2	3.3	46	pCi/gm
Gross Alpha, total	18	9.3	8.8	18	10	72	pCi/gm
Gross Alpha, total, error, +/-	5.7	4.9	4.8	5.7	5	9.3	pCi/gm
Gross Alpha, total, LLD	2.1	2.1	2.1	2.1	2.1	2.1	pCi/gm
Radium 226, total	1.5	1.4	1.8	2.1	1.7	1.7	pCi/gm
Radium 226, total, error, +/-	0.4	0.4	0.4	0.5	0.4	0.4	pCi/gm
Radium 226, total, LLD	0.1	0.1	0.1	0.1	0.1	0.1	pCi/gm
Thorium 230, total	2.3	0.1	1.5	1.7	1.8	5.1	pCi/gm
Thorium 230, total, error, +/-	0.5	0.3	0.4	0.4	0.4	0.6	pCi/gm
Thorium 230, total, LLD	0.3	0.5	0.3	0.2	0.2	0.2	pCi/gm
Uranium (U), total	1.8	2.1	3.8	3.7	5.5	78	mg/kg

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L A B O R A T O R Y   T E S T S   R E S U L T S
08/25/88

JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

SAMPLE NUMBER: 61 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19953 SF-07-02 6/30/88 13:30 25' RIGHT OF 01 REM:

SAMPLE NUMBER: 62 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: Sequoyah Fuels SAMPLE: 19954 SF-07-03 6/30/88 13:30 25' LEFT OF 01 REM:

SAMPLE NUMBER: 63 DATE RECEIVED: 07/18/88 TIME RECEIVED: 19:31 SAMPLE DATE: 07/07/88 SAMPLE TIME: 13:55
PROJECT: SAMPLE: REM:

SAMPLE NUMBER: 64

SAMPLE NUMBER: 65

SAMPLE NUMBER: 66

TEST DESCRIPTION	SAMPLE 61	SAMPLE 62	SAMPLE 63	SAMPLE 64	SAMPLE 65	SAMPLE 66	UNITS OF MEASURE
Uranium, natural	2.7	3.6					pCi/gm
Gross Alpha, total	22	15					pCi/gm
Gross Alpha, total, error, +/-	6	5.4					pCi/gm
Gross Alpha, total, LLD	2.1	2.1					pCi/gm
Radium 226, total	1.2	2.9					pCi/gm
Radium 226, total, error, +/-	0.4	0.5					pCi/gm
Radium 226, total, LLD	0.1	0.1					pCi/gm
Thorium 230, total	1.2	1.8					pCi/gm
Thorium 230, total, error, +/-	0.3	0.3					pCi/gm
Thorium 230, total, LLD	0.2	0.2					pCi/gm
Uranium (U), total	4.5	6.1					mg/kg

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QUALITY ASSURANCE REPORT
08/25/88

JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

Q.A. TYPE	Q.A. ID	BLANK VALUE	STANDARD VALUE	ANALYZED VALUE	BACKGROUND VALUE	SPIKE TRUE VALUE	SPIKE MEASURED VALUE	DUPLICATE SAMPLE ANALYSIS	DUPLICATE ANALYSIS	% RECOVERY	% RELATIVE ERROR
Q.A. NUMBER:880168 08/18/88 14:36				Uranium, natural							TECHNICIAN:DF
DUPLICATE	884202-10							13.6	13.6		0.00
DUPLICATE	884202-22							1.4	1.7		19.35
DUPLICATE	884202-28							4.1	3.5		15.79
DUPLICATE	884202-34							1.2	1.2		0.00
DUPLICATE	884202-46							6.8	4.9		32.48
DUPLICATE	884202-60							46	40		13.9
Q.A. NUMBER:880169 08/18/88 15:07				Uranium (U), total							TECHNICIAN:DF
DUPLICATE	884202-10							23	23		0.0
DUPLICATE	884202-22							2.4	2.8		15.3
JPLICATE	884202-34							2	2		0.0
DUPLICATE	884202-46							12	8.25		37.0
DUPLICATE	884202-60							78	68		13.7
Q.A. NUMBER:880197 08/22/88 13:14				Gross Alpha, total							TECHNICIAN:DF
DUPLICATE	884202-15							96	83		14.5
DUPLICATE	884202-45							24	22		8.70
Q.A. NUMBER:880198 08/22/88 13:24				Gross Alpha, total, error, +/-							TECHNICIAN:DF
DUPLICATE	884202-15							11	10		9.52
DUPLICATE	884202-45							6.2	6		3.28
Q.A. NUMBER:880199 08/22/88 13:28				Gross Alpha, total, LLD							TECHNICIAN:DF
DUPLICATE	884202-15							2.1	2.1		0.00
DUPLICATE	884202-45							2.1	2.1		0.00
Q.A. NUMBER:880294 08/24/88 17:21				Radium 226, total							TECHNICIAN:DF
SPIKE	884202-16				3.2	23.8	24.5			89.50	
SPIKE	884202-28				0.5	23.8	26.2			107.98	
IKE	884202-39				1.1	23.8	23.2			92.86	

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CORE LABORATORIES

QUALITY ASSURANCE REPORT
08/25/88

JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

Q.A. TYPE	Q.A. ID	BLANK VALUE	STANDARD VALUE	ANALYZED VALUE	BACKGROUND VALUE	SPIKE TRUE VALUE	SPIKE MEASURED VALUE	DUPLICATE SAMPLE ANALYSIS	DUPLICATE ANALYSIS	% RECOVERY	% RELATIVE ERROR
Q.A. NUMBER:880294 08/24/88 17:21					Radium 226, total						TECHNICIAN:DF
SPIKE	884202-54				3.3	23.8	20			70.17	
DUPLICATE	884202-10							1.1	1.2		8.70
DUPLICATE	884202-22							0.7	0.8		13.33
DUPLICATE	884202-34							0.7	0.5		33.33
DUPLICATE	884202-46							0.5	0.8		46.15
Q.A. NUMBER:880296 08/24/88 17:34					Radium 226, total, error, +/-						TECHNICIAN:DF
DUPLICATE	884202-10							0.4	0.4		0.0
DUPLICATE	884202-22							0.3	0.3		0.0
DUPLICATE	884202-34							0.3	0.2		40.0
DUPLICATE	884202-46							0.2	0.3		40.0
Q.A. NUMBER:880297 08/24/88 17:38					Radium 226, total, LLD						TECHNICIAN:DF
DUPLICATE	884202-10							0.2	0.2		0.0
DUPLICATE	884202-22							0.2	0.2		0.0
DUPLICATE	884202-34							0.1	0.1		0.0
DUPLICATE	884202-46							0.1	0.1		0.00
Q.A. NUMBER:880315 08/25/88 11:12					Thorium 230, total						TECHNICIAN:MJH
STANDARD	884202-1		6.9	6.7						97.10	
STANDARD	884202-2		6.9	6.5						94.20	
STANDARD	884202-3		6.9	7.2						104.35	
STANDARD	884202-4		6.9	6.9						100.00	
STANDARD	884202-5		6.9	7.1						102.90	
STANDARD	884202-6		6.9	7.2						104.35	
SPIKE	884202-16				1.1	6.9	7.8			97.10	
SPIKE	884202-28				0.7	6.9	7.9			104.35	
SPIKE	884202-39				1	6.9	7.6			95.65	

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QUALITY ASSURANCE REPORT
08/25/88

JOB NUMBER: 884202 CUSTOMER: US ARMY CORPS OF ENG ATTN: DAVID COMBS

Q.A. TYPE	Q.A. ID	BLANK VALUE	STANDARD VALUE	ANALYZED VALUE	BACKGROUND VALUE	SPIKE TRUE VALUE	SPIKE MEASURED VALUE	DUPLICATE SAMPLE ANALYSIS	DUPLICATE ANALYSIS	% RECOVERY	% RELATIVE ERROR
Q.A. NUMBER:880315 08/25/88 11:12					Thorium 230, total						TECHNICIAN:MJH
SPIKE	884202-54				97	6.9	104			101.45	
DUPLICATE	884202-10							1.7	2.2		25.64
DUPLICATE	884202-22							0.4	0.6		40.00
DUPLICATE	884202-34							0.8	0.5		46.15
DUPLICATE	884202-46							0.6	1		50.00
DUPLICATE	884202-60							5.1	5.7		11.1
Q.A. NUMBER:880316 08/25/88 11:35					Thorium 230, total, error, +/-						TECHNICIAN:MJ
Q.A. NUMBER:880317 08/25/88 11:40					Thorium 230, total, LLD						TECHNICIAN:MJ
.A. NUMBER:880318 08/25/88 11:47					Thorium 230, total, LLD						TECHNICIAN:MJ

SWLO

Southwest Laboratory of Oklahoma

CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP3006.53

DATE: 08-31-88

SUBJECT: SAMPLES FOR RADIOACTIVITY (URANIUM & THORIUM)

SAMPLE MATRIX: WATERS
SWLO # 19900,19915,19919-19930
DATE SUBMITTED: 07-08-88
CLIENT I.D.'S: AS LISTED BELOW

CLIENT I.D.'S	URANIUM NATURAL (pCi/L)	URANIUM TOTAL (mg/L)	Th 230 TOTAL (pCi/l)	Th 230 ERROR(+/-) (pCi/l)	Th 230 TTL.LLD (pCi/l)
SF-1-H 6/30 14:00 001 EQUIPMENT BLANK	<0.2	<0.001	0.2	0.4	0.4
SF-S-15 7/1 10:00 EQUIPMENT BLANK	1.18	0.001	4.2	0.5	0.5
SF-1-00 6/30 16:00 TRIP BLANK	N/A	N/A	N/A	N/A	N/A
SF-W-01 6/29 09:30 GORE LANDING	0.59	0.001	0.1	0.4	0.4
SF-W-02 6/29 09:30 GORE LANDING	<0.2	<0.001	0.1	0.4	0.4
SF-W-03 6/29 10:00 ILLINOIS RIVER MOUTH	4.72	0.0067	0.3	0.3	0.3
SF-W-04 6/29 10:00 ILLINOIS RIVER MOUTH	5.3	0.008	1.1	0.4	0.4
SF-W-05 6/29 10:10 ARK RIVER UPSTREAM	2.95	0.004	0.1	0.4	0.4
SF-W-06 6/29 10:10 ARK RIVER UPSTREAM	2.36	0.003	0.2	0.4	0.4

CONTINUED........

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Southwest Laboratory of Oklahoma

CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP3006.53a

DATE: 08-31-88

SUBJECT: SAMPLES FOR URANIUM & THORIUM

PAGE: TWO

SAMPLE MATRIX: WATERS
SWLO # 19900,19915,19919-19930
DATE SUBMITTED: 07-08-88
CLIENT I.D.'S: AS LISTED BELOW

CLIENT I.D.'S	URANIUM NATURAL (pCi/L)	URANIUM TOTAL (mg/L)	Th 230 TOTAL (pCi/l)	Th 230 ERROR(+/-) (pCi/l)	Th 230 TTL.LLD (pCi/l)
SF-W-07 6/29 10:20 ARK RIVER DOWNSTREAM	0.59	0.001	0.5	0.4	0.4
SF-W-08 6/29 10:20 ARK RIVER DOWNSTREAM	1.48	0.003	1.5	0.4	0.4
SF-W-09 6/29 001 STREAM	554.6	0.797	0.7	0.4	0.4
SF-W-10 6/29 001 STREAM	548.7	0.789	0.6	0.3	0.3
SF-W-11 6/29 10:00 EQUIPMENT BLANK	<0.2	<0.001	0.6	0.5	0.5

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REPORT: SAP3006.54

DATE: 08-31-88

SUBJECT: SAMPLES FOR GROSS ALPHA (RADIOACTIVITY)

SAMPLE MATRIX: WATERS
SWLO # 19900,19915,19919-19930
DATE SUBMITTED: 07-08-88
CLIENT I.D.'S: AS LISTED BELOW

CLIENT I.D.'S	GROSS ALPHA TOTAL (pCi/l)	GROSS ALPHA ERROR(+/-) (pCi/l)	GROSS ALPHA TTL.LLD (pCi/l)
SF-1-H 6/30 14:00 001 EQUIPMENT BLANK	-0-	0.6	1.4
SF-S-15 7/1 10:00 EQUIPMENT BLANK	-0-	0.7	1.6
SF-1-00 6/30 16:00 TRIP BLANK	-0-	N/A	N/A
SF-W-01 6/29 09:30 GORE LANDING	-0-	1.4	1.4
SF-W-02 6/29 09:30 GORE LANDING	-0-	1.1	1.4
SF-W-03 6/29 10:00 ILLINOIS RIVER MOUTH	3.7	3.7	2.0
SF-W-04 6/29 10:00 ILLINOIS RIVER MOUTH	2.8	7.5	5.4
SF-W-05 6/29 10:10 ARK RIVER UPSTREAM	-0-	10.0	7.8
SF-W-06 6/29 10:10 ARK RIVER UPSTREAM	3.1	11.0	7.8

CONTINUED........

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CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP3006.54a

DATE: 08-31-88

SUBJECT: SAMPLES FOR GROSS ALPHA

PAGE: TWO

SAMPLE MATRIX: WATERS
SWLO # 19900,19915,19919-19930
DATE SUBMITTED: 07-08-88
CLIENT I.D.'S: AS LISTED BELOW

CLIENT I.D.'S	GROSS ALPHA TOTAL (pCi/l)	GROSS ALPHA ERROR(+/-) (pCi/l)	GROSS ALPHA TTL.LLD (pCi/l)
SF-W-07 6/29 10:20 ARK RIVER DOWNSTREAM	29.0	14.0	7.8
SF-W-08 6/29 10:20 ARK RIVER DOWNSTREAM	-0-	8.1	4.9
SF-W-09 6/29 001 STREAM	459.0	40.0	1.4
SF-W-10 6/29 001 STREAM	359.0	35.0	1.4
SF-W-11 6/29 10:00 EQUIPMENT BLANK	-0-	0.6	1.4

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POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP3006.55

DATE: 08-31-88

SUBJECT: SAMPLES FOR RADIUM 226 (RADIOACTIVITY)

SAMPLE MATRIX: WATERS
SWLO # 19900,19915,19919-19930
DATE SUBMITTED: 07-08-88
CLIENT I.D.'S: AS LISTED BELOW

CLIENT I.D.'S	RADIUM 226 TOTAL (pCi/l)	RADIUM 226 ERROR(+/-) (pCi/l)	RADIUM 226 TTL.LLD (pCi/l)
SF-1-H 6/30 14:00 001 EQUIPMENT BLANK	0.1	0.1	0.1
SF-S-15 7/1 10:00 EQUIPMENT BLANK	-0-	0.1	0.1
SF-1-00 6/30 16:00 TRIP BLANK	N/A	N/A	N/A
SF-W-01 6/29 09:30 GORE LANDING	0.1	0.1	0.1
SF-W-02 6/29 09:30 GORE LANDING	0.1	0.1	0.1
SF-W-03 6/29 10:00 ILLINOIS RIVER MOUTH	0.1	0.1	0.1
SF-W-04 6/29 10:00 ILLINOIS RIVER MOUTH	0.1	0.1	0.1
SF-W-05 6/29 10:10 ARK RIVER UPSTREAM	0.1	0.1	0.1
SF-W-06 6/29 10:10 ARK RIVER UPSTREAM	0.1	0.1	0.1

CONTINUED........

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CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP3006.55a

DATE: 08-31-88

SUBJECT: SAMPLES FOR RADIUM 226

PAGE: TWO

SAMPLE MATRIX: WATERS
SWLO # 19900,19915,19919-19930
DATE SUBMITTED: 07-08-88
CLIENT I.D.'S: AS LISTED BELOW

CLIENT I.D.'S	RADIUM 226 TOTAL (pCi/l)	RADIUM 226 ERROR(+/-) (pCi/l)	RADIUM 226 TTL.LLD (pCi/l)
SF-W-07 6/29 10:20 ARK RIVER DOWNSTREAM	0.1	0.1	0.1
SF-W-08 6/29 10:20 ARK RIVER DOWNSTREAM	0.1	0.1	0.1
SF-W-09 6/29 001 STREAM	0.1	0.1	0.1
SF-W-10 6/29 001 STREAM	0.1	0.1	0.1
SF-W-11 6/29 10:00 EQUIPMENT BLANK	0.1	0.1	0.1

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CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP3006.52

DATE: 08-31-88

SUBJECT: SAMPLES FOR ANALYSIS

SAMPLE MATRIX: SOILS
SWLO # 19931 - 19954
DATE SUBMITTED: 07-08-88
METHOD REFERENCE: STANDARD METHODS, 16TH EDITION

CLIENT I.D.'S	NITRATES (mg/Kg) Ref: 418C	MOLYBDENUM (mg/Kg) Ref: 303C
SF-5A-01 6/30/88 PROP. + 50	30.2	<15.0
SF-5A-02 6/30 11:10 50' RIGHT OF 01	19.9	<15.0
SF-5A-03 6/30 11:20 150' RIGHT OF 01	18.3	<15.0
SF-5A-04 6/30 11:25 300' RIGHT OF 01	13.1	<15.0
SF-5A-05 6/30 11:35 PROP + 150	16.9	<15.0
SF-5A-06 6/30 11:45 50' LEFT OF 05	14.5	<15.0
SF-5A-07 6/30 11:45 150' LEFT OF 05	16.9	<15.0
SF-5A-08 6/30 11:50 300' LEFT OF 05	11.5	<15.0
SF-5A-09 6/30 12:00 SOIL HIGHWATER	49.9	<15.0
SF-5-01 6/30 12:30 PROP + 50	42.8	<15.0

CONTINUED........

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Southwest Laboratory of Oklahoma

CLIENT: U.S. ARMY CORP OF ENGINEERS
SUBJECT: SAMPLES FOR ANALYSIS

REPORT: SAP3006.52a
PAGE : TWO.

SAMPLE MATRIX: SOILS
SWLO # 19931 - 19954
DATE SUBMITTED: 07-08-88
METHOD REFERENCE: STANDARD METHODS, 16TH EDITION

CLIENT I.D.'S	NITRATES (mg/Kg) Ref: 418C	MOLYBDENUM (mg/Kg) Ref: 303C
SF-5-02 6/30 12:40 25' RIGHT OF 01	4.0	<15.0
SF-5-03 6/30 12:40 25' LEFT OF 01	3.0	<15.0
SF-5-04 6/30 PROP. + 80'	9.5	<15.0
SF-5-05 6/30 25' LEFT OF 04	23.0	<15.0
SF-5-06 6/30 25' RIGHT OF 04	5.5	<15.0
SF-5-07 6/30 13:00 SEDIMENT BASE/DITCH	4.3	<15.0
SF-4-01 6/30 12:15 PROP. + 20'	11.5	<15.0
SF-4-02 6/30 12:25 PROP. + 50'	11.9	<15.0
SF-4-03 6/30 12:30 25' LEFT OF 4	24.0	<15.0
SF-4-04 6/30 12:30 PROP + 100	15.5	<15.0
SF-4-05 6/30 12:35 25' RIGHT OF 2	37.0	<15.0
SF-07-01 6/30 13:30 PROP. + 40	11.0	<15.0
SF-07-02 6/30 13:30 25' RIGHT OF 01	3.0	<15.0
SF-07-03 6/30 13:30 25' LEFT OF 01	4.5	<15.0

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APPENDIX C

Analytical Report of Corps of Engineers

Soil, Sediment and Water Samples of

Sequoyah Fuels Facility Outfall 001 - 1987

Sequoyah Fuels

CCI Stream

Appendix C - p. 1

Southwest Laboratory of Oklahoma

CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAF1006.7-C

DATE: 01-28-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT, CORRECTED

SWLO # 10868
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #1 12/3 10:45 FEDERAL PROP LINE 0'

PARAMETER	RESULTS	
URANIUM, NATURAL	16.5	pCi/gm
GROSS ALPHA, TOTAL	5.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	4.4	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	31.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.0	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	2.5	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	5.0	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	1.7	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.1	pCi/gm
RADIUM 228, TOTAL, LLD	1.6	pCi/gm
FLUORIDE (F), TOTAL	6.7	mg/kg
URANIUM (U), TOTAL	24.0	mg/kg

Southwest Laboratory of Oklahoma

BY Robert Nabors

Southwest Laboratory of Oklahoma

CLIENT: U.S. ARMY CORP OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121
ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAP1006.18-C

DATE: 01-28-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT, CORRECTED

SWLO # 10879
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC A 12/3 10:30 WATER AT 0'

PARAMETER	RESULTS	
URANIUM, NATURAL	289.0	pCi/L
GROSS ALPHA, TOTAL	125.0	pCi/L
GROSS ALPHA, TOTAL, ERROR, +/-	6.2	pCi/L
GROSS ALPHA, TOTAL, LLD	1.0	pCi/L
GROSS BETA, TOTAL	11.0	pCi/L
GROSS BETA, TOTAL, ERROR, +/-	2.9	pCi/L
GROSS BETA, TOTAL, LLD	1.0	pCi/L
RADIUM 226, TOTAL	0.2	pCi/L
RADIUM 226, TOTAL, ERROR, +/-	0.1	pCi/L
RADIUM 226, TOTAL, LLD	0.2	pCi/L
RADIUM 228, TOTAL	1.1	pCi/L
RADIUM 228, TOTAL, ERROR, +/-	0.8	pCi/L
RADIUM 228, TOTAL, LLD	1.2	pCi/L
FLUORIDE (F), TOTAL	300.0	ug/L
URANIUM (U), TOTAL	415.0	ug/L

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REPORT: SAP1006.7
DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10868
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #1 12/3 10:45 FEDERAL PROP LINE 0

PARAMETER	RESULTS	
URANIUM, NATURAL	16.5	pCi/gm
GROSS ALPHA, TOTAL	5.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	4.4	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	31.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.0	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	2.5	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	5.0	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	1.7	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.1	pCi/gm
RADIUM 228, TOTAL, LLD	1.6	pCi/gm
FLUORIDE (F), TOTAL	6.7	mg/kg
URANIUM (U), TOTAL	13.5	mg/kg

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REPORT: SAP1006.D
DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10869
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #2 12/3 14:45 STREAM AT 50'

PARAMETER	RESULTS	
URANIUM, NATURAL	19.4	pCi/gm
GROSS ALPHA, TOTAL	21.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	5.9	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	32.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.1	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	1.3	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	2.7	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.2	pCi/gm
RADIUM 228, TOTAL, LLD	1.6	pCi/gm
FLUORIDE (F), TOTAL	2.1	mg/kg
URANIUM (U), TOTAL	27.9	mg/kg

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REPORT: SAF1006.9
DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10870
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC36 #3 12/3 10:45 STREAM AT 100'

PARAMETER	RESULTS	
URANIUM, NATURAL	12.9	pCi/gm
GROSS ALPHA, TOTAL	11.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	5.1	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	28.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.0	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	1.6	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	0.6	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.1	pCi/gm
RADIUM 228, TOTAL, LLD	1.7	pCi/gm
FLUORIDE (F), TOTAL	6.2	mg/kg
URANIUM (U), TOTAL	18.5	mg/kg

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REPORT: SAF1006.10

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10871
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #4 12/3 12:45 STREAM AT 150'

PARAMETER	RESULTS	
URANIUM, NATURAL	21.2	pCi/gm
GROSS ALPHA, TOTAL	23.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	6.1	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	24.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	4.7	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	1.5	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	2.1	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.2	pCi/gm
RADIUM 228, TOTAL, LLD	1.7	pCi/gm
FLUORIDE (F), TOTAL	2.4	mg/kg
URANIUM (U), TOTAL	30.5	mg/kg

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REPORT: SAP1006.11

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10872
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #4A 12/3 10:45 BANK (RIGHT) AT 150'

PARAMETER	RESULTS	
URANIUM, NATURAL	18.8	pCi/gm
GROSS ALPHA, TOTAL	28.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	6.5	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	31.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.0	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	3.1	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.6	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	1.6	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.2	pCi/gm
RADIUM 228, TOTAL, LLD	1.8	pCi/gm
FLUORIDE (F), TOTAL	1.4	mg/kg
URANIUM (U), TOTAL	27.1	mg/kg

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REPORT: SAP1006.12

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10873
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #5 12/3 12:45 STREAM AT 200'

PARAMETER	RESULTS	
URANIUM, NATURAL	14.1	pCi/gm
GROSS ALPHA, TOTAL	38.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	7.2	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	39.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.4	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	2.0	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	2.1	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.2	pCi/gm
RADIUM 228, TOTAL, LLD	1.7	pCi/gm
FLUORIDE (F), TOTAL	3.7	mg/kg
URANIUM (U), TOTAL	20.3	mg/kg

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REPORT: SAP1006.13

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10874
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #6 12/3 10:45 BANK (BACKWATER) AT 200

PARAMETER	RESULTS	
URANIUM, NATURAL	17.7	pCi/gm
GROSS ALPHA, TOTAL	22.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	6.0	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	34.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.2	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	2.3	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	2.0	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.3	pCi/gm
RADIUM 228, TOTAL, LLD	1.9	pCi/gm
FLUORIDE (F), TOTAL	4.8	mg/kg
URANIUM (U), TOTAL	25.4	mg/kg

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REPORT: SAP1006.14

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10875
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #7 12/3 10:45 STREAM AT 250'

PARAMETER	RESULTS	
URANIUM, NATURAL	29.5	pCi/gm
GROSS ALPHA, TOTAL	28.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	6.5	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	38.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.4	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	3.1	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.6	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	1.8	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.4	pCi/gm
RADIUM 228, TOTAL, LLD	2.0	pCi/gm
FLUORIDE (F), TOTAL	2.1	mg/kg
URANIUM (U), TOTAL	42.4	mg/kg

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ATTN: DAVID COMBS, ENVIRONMENTAL DIV.

REPORT: SAF1006.15

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10876
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #8 12/3 11:15 BANK (LEFT + RIGHT) AT 250'

PARAMETER	RESULTS	
URANIUM, NATURAL	27.1	pCi/gm
GROSS ALPHA, TOTAL	47.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	7.8	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	35.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.3	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	1.6	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	2.6	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.3	pCi/gm
RADIUM 228, TOTAL, LLD	1.8	pCi/gm
FLUORIDE (F), TOTAL	8.0	mg/kg
URANIUM (U), TOTAL	39.0	mg/kg

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BY Robert Harris

Encl 4

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REPORT: SAP1006.16

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10877
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #9 12/3 STREAM HALFWAY TO MOUTH

PARAMETER	RESULTS	
URANIUM, NATURAL	21.2	pCi/gm
GROSS ALPHA, TOTAL	36.0	pCi/gm
GROSS ALPHA, TOTAL, ERROR +/-	7.1	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	35.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	5.3	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	1.4	pCi/gm
RADIUM 226, TOTAL, ERROR +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	0.7	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.1	pCi/gm
RADIUM 228, TOTAL, LLD	1.6	pCi/gm
FLUORIDE (F), TOTAL	3.3	mg/kg
URANIUM (U), TOTAL	30.5	mg/kg

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REPORT: SAP1006.17

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10878
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC86 #10 12/3 12:30 REFERENCE SOIL

PARAMETER	RESULTS	
URANIUM, NATURAL	5.9	pCi/gm
GROSS ALPHA, TOTAL	8.2	pCi/gm
GROSS ALPHA, TOTAL, ERROR, +/-	4.8	pCi/gm
GROSS ALPHA, TOTAL, LLD	2.0	pCi/gm
GROSS BETA, TOTAL	17.0	pCi/gm
GROSS BETA, TOTAL, ERROR, +/-	4.3	pCi/gm
GROSS BETA, TOTAL, LLD	1.6	pCi/gm
RADIUM 226, TOTAL	2.7	pCi/gm
RADIUM 226, TOTAL, ERROR, +/-	0.5	pCi/gm
RADIUM 226, TOTAL, LLD	0.5	pCi/gm
RADIUM 228, TOTAL	1.5	pCi/gm
RADIUM 228, TOTAL, ERROR, +/-	1.1	pCi/gm
RADIUM 228, TOTAL, LLD	1.6	pCi/gm
FLUORIDE (F), TOTAL	<1.0	mg/kg
URANIUM (U), TOTAL	8.4	mg/kg

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REPORT: SAF1006.1[illegible]

DATE: 01-23-87

SUBJECT: SAMPLE FOR ANALYSIS, SEQUOYA FUELS PERMIT PROJECT

SWLO # 10879
DATE SUBMITTED: 12-10-86
CLIENT I.D.: SFC A 12/3 10:30 WATER AT 0'

PARAMETER	RESULTS		
URANIUM, NATURAL	289.0	~~pCi/gm~~	pCi/l
GROSS ALPHA, TOTAL	125.0	~~pCi/gm~~	pCi/l
GROSS ALPHA, TOTAL, ERROR, +/-	6.2	~~pCi/gm~~	
GROSS ALPHA, TOTAL, LLD	1.0	~~pCi/gm~~	
GROSS BETA, TOTAL	11.0	~~pCi/gm~~	
GROSS BETA, TOTAL, ERROR, +/-	2.5	~~pCi/gm~~	
GROSS BETA, TOTAL, LLD	1.0	~~pCi/gm~~	
RADIUM 226, TOTAL	0.2	~~pCi/gm~~	
RADIUM 226, TOTAL, ERROR, +/-	0.1	~~pCi/gm~~	
RADIUM 226, TOTAL, LLD	0.2	~~pCi/gm~~	
RADIUM 228, TOTAL	1.1	~~pCi/gm~~	
RADIUM 228, TOTAL, ERROR, +/-	0.8	~~pCi/gm~~	
RADIUM 228, TOTAL, LLD	1.2	~~pCi/gm~~	pCi/l
FLUORIDE (F), TOTAL	300.0	~~mg/kg~~	ug/l
URANIUM (U), TOTAL	415.0	~~mg/kg~~	ug/l

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CHAIN OF CUSTODY RECORD

PROJ. NO.	PROJECT NAME												
	Sequoyah Fuels Permit												
SAMPLERS: (Signature)	D. Combs, S. Nolen, J. Harris												
STA. NO.	DATE	TIME	COMP	GRAB	STATION LOCATION	NO. OF CONTAINERS	Gross Alpha	Uranium (uCi)	Uranium (U) ug/g	Radium 226 (pCi)	Radium 228 (pCi)	Fluoride (ug/g or ug/l)	REMARKS
FC86 #1	12/3	1045		✓	Federal Prop line 0'	1	✓	✓	✓	✓	✓	✓	
#2	12/3	1045	✓		Stream at 50'	1	✓	✓	✓	✓	✓	✓	
#3	12/3	1045	✓		Stream at 100'	1	✓	✓	✓	✓	✓	✓	Homogenate all
#4	12/3	1045	✓		Stream at 150'	1	✓	✓	✓	✓	✓	✓	soil/sediment
#4A	12/3	1045	✓		Bank (Right) at 150'	1	✓	✓	✓	✓	✓	✓	samples prior to
#5	12/3	1045	✓		Stream at 200'	1	✓	✓	✓	✓	✓	✓	sample analyses
#6	12/3	1045	✓		Bank (Backwater) at 200'	1	✓	✓	✓	✓	✓	✓	
#7	12/3	1045	✓		Stream at 250'	1	✓	✓	✓	✓	✓	✓	
#8	12/3	1115	✓		Bank (Left + Right) at 250'	1	✓	✓	✓	✓	✓	✓	
#9	12/3	—	✓		Stream halfway to mouth	1	✓	✓	✓	✓	✓	✓	
#10	12/2	1230		✓	Reference Soil	1	✓	✓	✓	✓	✓	✓	(Core Sampling)
SFC A	12/3	1030		✓	Water at 0'	4	✓	✓	✓	✓	✓	✓	4 liters for one analyses

Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
David M. Combs	12/9/86 1400	P. Northam	P. Northam	12/11/86 10am	David Demarest via UPS 12/15 3:00
Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Relinquished by: (Signature)	Date / Time	Received for Laboratory by: (Signature)	Date / Time	Remarks	

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

TOXICITY MONITORING IN ROBERT S. KERR LAKE - 1989

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTER OF ENVIRONMENTAL SCIENCE

By

THAD HUMMEL WOODWARD

Norman, Oklahoma

1991

TOXICITY MONITORING IN ROBERT S. KERR LAKE - 1989

A THESIS

APPROVED FOR THE SCHOOL OF CIVIL ENGINEERING AND

ENVIRONMENTAL SCIENCE

By

____

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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Dr. James Robertson and Dr. Robert C. Knox, for their guidance, understanding and endless patience. I would also like to thank Dr. Larry McKee for taking the time to serve as a committee member.

Special thanks go to Jerry J. Black for introducing me to this field and spending many hours teaching me what it was all about.

I would also like to thank Scott Hargrave, Diane Evans, Patti Koutahi, and Joe Highfil for their much needed help. Thanks also to Lin Lau for all her long hours of work on the computer and in the lab.

And of course, I would like to thank my tortured typist, Dawn Flick, for her patience and hard work above and beyond the call of duty.

I would like to dedicate this to Mom and Dad, thank you for making this possible.

Abstract

This study was conducted to assess the acute and chronic toxicity of effluent from a uranium hexaflouride manufacturing plant. Standard EPA methods were used in the testing of the effluent from the plant. During collection of the first sample, observations were made as to the lack of animal and insect life. Later sample collection dates showed contrary conditions with abundant fish and insect life. The toxicity tests for the effluent were negative. Chemical analyses revealed only nitrate and nitrite to be in excess of drinking water standards. Suggestions were made for future monitoring and methods of study for this site.

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CHAPTER I

INTRODUCTION

The Sequoyah Fuels Plant manufactures uranium hexaflouride for nuclear power plant use. The refining process involved results in several toxic byproducts which are of concern. The wastewater effluent streams from the plant empty into Robert S. Kerr Lake which is used for recreation, water supply and irrigation.

The Army Corps of Engineers is in charge of managing the waters around the plant and enforcing standards. In order to ensure proper decision making, they felt a current bioassay was needed. In addition the Sequoyah Fuels Plant has been the focus of several studies ranging from chemical analysis and toxicity studies to radioisotope assays. One of these conducted by the University of Oklahoma involved the determination of radioactivity in the main effluent stream of the plant (Skierkowski et al., unpublished). Although the water was within limits the researchers involved found data that lead them to the conclusion that a bioassay was indicated.

The first objective of this research is to determine whether or not the effluent streams of the Sequoyah Fuels Plant are in violation of any Federal, State or local water standards. If violations are discovered, the determination of the severity of the contamination and potential harm would be the next objective. The tasks involved in reaching the objectives of this research are to:

1. Perform on-site observations of effluent streams.
2. Perform acute and chronic toxicity testing of effluent streams at various sites to determine whether they contain toxic levels of the elements of concern.
3. Perform chemical analyses on the effluent streams to quantify the amounts of chemicals present.
4. Analyze results of the testing mentioned in parts 1 through 4.
5. Make suggestions based upon the results of the analysis.

The methods to be used are all standard EPA procedures using laboratory quality EPA equipment. Any exceptions to the procedures will be noted in the methods section.

CHAPTER II

LITERATURE REVIEW

A number of the different processes that occur inside the Sequoyah Fuels Plant are not known. Two of these processes are the production of the uranium hexafluoride and the operation of a wastewater treatment plant. There are many other processes that occur within the plant, affecting the effluent of the plant. Therefore, numerous substances were reviewed in the literature search.

This chapter will be divided into two sections, the first covering *Daphnia magna* and the second, *Pimephales promelas*.

Section I. *Daphnia magna*:

A. *Historical*.

The use of *Daphnia magna* (*D. magna*) as a test organism in acute and chronic tests is well established (Canton and Adema, 1978). There has been much time spent examining the best methods and parameters for toxicity testing using *D. magna*. Adema (1978) studied these procedures extensively and made the following conclusions:

1. If no food is supplied, the duration of toxicity test with D. magna should not exceed 48 hrs.

2. If the test compound is a slow-acting poison, a constant LC_{50} may not be reached before the lapse of 10-14 days, during which the daphnids should be supplied with sufficient food and will therefore grow during the experiment.

3. Adult daphnids may be less sensitive to certain toxicants or may react more slowly than young ones.

4. Acute toxicity tests should be carried out with one day old daphnids, without food and with a maximum test duration of 48 hrs. Chronic toxicity tests with mortality as the criterion should be started with one day old daphnids, that are fed normally, with a maximum test duration of at least two weeks.

5. The temperature of the medium should not exceed 20° C. Since rate of growth and reproduction increases with temperature (within limits), a relatively high temperature is recommended for chronic tests with reproduction as the criterion. If the only criterion is mortality, slight temperature fluctuations do not greatly influence the results. A temperature of 18-20°C is quite suitable for acute as well as for chronic tests.

6. The composition and pH of the medium should allow the animals to develop normally. No difficulties are encountered in this respect in the testing of known compounds in standard media. However, if the compounds to be tested are in dilute aqueous solution (e.g. wastewater), care should be taken to keep the concentration of essential elements and the pH of the medium within suitable limits.

7. In view of their small size, a number of 25 daphnids per testing vessel will seldom give rise to problems of handling. This number is sufficient for reliable results to be obtained. If, however, the number of daphnids per testing vessel is limited to 10, the resulting LC_{50} values will be approximately correct.

8. A frequent source of error is lack of oxygen in the test medium, particularly in the closed and non-aerated systems needed for the testing of volatile compounds. The set-up of the test (ratio of number of daphnids to volume of medium, aeration or no aeration, replacement scheme) should be so chosen that lack of oxygen is not likely to occur. The oxygen concentration in all testing vessels must be measured frequently. Continuous-flow systems offer little economical advantage, because the gain in time is insignificant compared with the time needed for counting the daphnids, as well as other criteria.

9. The duration of chronic tests in which reproduction, growth, and mortality is quantitatively measured, should be at least three weeks.

10. In general, reproduction is a sensitive criterion. (Adema, 1978).

Most of these initial conclusions are still recognized today as evidenced by the testing procedures utilized by the Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 1985). One main difference is the number of organisms per replicate. The EPA requires 10 organisms per container with replicates; whereas Adema (1978) suggests 25. The EPA method is also more explicit as to the media composition used in the toxicity testing procedures.

Results obtained using D. magna as the test organism are reproducible (Canton and Adema, 1978). The use of daphnids and fish is supported by Kenega and Moolenaar (1979) as organisms sufficiently sensitive to be indicators of toxicity. Canton and Adema (1978) also found that LC_{50} values differing by a factor of 2 could be regarded as normal in tests performed at different times. A more recent study supports the use of toxicity tests using daphnia over chemical analyses alone (Thomas et al., 1985).

The physiology and development of daphnids has also been highly studied. The different aspects of their life cycle have been extensively researched (Carvalho and Hughes, 1983; Doma, 1979) including their respiratory response to pH changes (Alibone and Fair, 1981; France, 1982) and their digestive response to pH changes (Gophen and Gold, 1981).

Applications of the acute toxicity test using daphnids were studied and five types were suggested by the European Inland Fisheries Advisory Commission (EIFAC) of the Food and Agriculture Organization of the United Nations (EIFAC). These five types are:

1. Screening tests - To determine the acute toxicity of chemicals or products under standard conditions. In this way acute toxicities of different chemicals can be compared under identical conditions and, therefore, the substances may be placed in broad categories of toxicity.

2. Tests to establish water quality criteria - These tests are designed not only to assess hazards, but to enable water quality objectives to be prepared.

3. Effluent monitoring tests - Effluents are frequently complex mixtures of chemicals which

are difficult to analyze. Therefore biological testing of aqueous effluents has advantages when compared with chemical testing. Acute toxicity tests with daphnids have shown to be feasible for monitoring these discharges to assess effluent quality.

4. Legal tests - Where quality standards for effluents have been established, closely defined reproducible procedures are necessary to meet the test requirements and to establish in a court of law acceptable evidence of failure to comply with the (daphnids, fish) toxicity standard. For these tests daphnids are recommended as useful test organisms.

5. River monitoring tests - In order to decrease hazards for water users from incidental high-level pollution of rivers, biological monitoring systems have been developed...As daphnids require a water quality within rather narrow limits, these organisms are unsuited for monitoring river water. (Leeuwangh, 1978)

There are several advantages for using daphnids for toxicity tests as mentioned in the literature. The following is a summarized form of the combined opinions

1. Daphnids can be cultured with relative ease (Berge, 1978; Leeuwangh, 1978).
2. Individuals are genetically identical through the process of parthenogenesis (Leeuwangh, 1978).
3. The size of the daphnids allows for higher numbers of organisms used and, therefore, increases statistical accuracy (Leeuwangh, 1978).
4. Daphnids have been found to be a very sensitive test organism (Adema, 1978; Canton and Adema,

1978; Kenaga and Moolenaar, 1979; Leeuwangh, 1978).

5. The short life span of the daphnids allows chronic second and third generation studies to be performed (Adema, 1978; Canton and Adema, 1978; Kenaga and Moolenaar, 1979; Leeuwangh, 1978).
6. The effects of chemicals on food uptake, growth efficiency, respiration and enzyme activities can be measured (Leeuwangh, 1978; Kersting, 1978; France, 1982).
7. Results of toxicity testing using daphnids have been found to be reproducible (Leeuwangh, 1978; Canton and Adema, 1978; Adema 1978).
8. Several representatives of the daphnids are important species indigenous to our surface water. The consequence of daphnids dwindling from an ecosystem may be the eventual elimination of one or more other species in the food web of fishes as well (Leeuwangh, 1978).

B. Application

The previous section presented the use of *D. magna* as a test organism in toxicity testing. This section will discuss several applications of the acute test with the daphnid.

1. General

A study has been done to correlate the toxicity results of tests using daphnids and fish (Khangarot and Ray, 1987). The authors compared the results of tests using D. magna and Salmo gairdneri (rainbow trout) and found there was a statistical correlation between the EC_{50} for the trout and the daphnid. The authors also suggest the importance of hardness in toxicity testing since softer water allows more toxicity.

Kaiser (1979) performed a study on the correlation and prediction of metals toxicity. The author developed an equation for the prediction of toxicity of an ion by studying published data on the toxicity of metal ions. The author compared the toxicity results with ion specific physico-chemical parameters expressed in the equation.

Maki (1979) also conducted a comparison study on the correlation between D. magna and Pimephales promelas. The author cited the problems involved with the higher costs and longer time requirements for chronic fish testing as major obstacles for research. Maki (1979) found that in a comparison of eight detergent components, seven metals, four PCB isomers, fifteen pesticides, and chlorine, the combined regressions of their results were significantly correlated. This indicated that the short term daphnid test has significant predictive value for longer term fish toxicity data. The author further stated that these results demonstrate aquatic safety data developed for the protection of one trophic level may similarly extend to include representatives of a higher level.

Cooper and Stout (1983) also studied the accuracy of bioassays using fathead minnows (*Pimephales promelas*), largemouth bass, smallmouth bass, damselfly, amphipod, and the waterflea (*D.magna*). They made the following conclusions:

1) The acute toxicity tests with fathead minnows, largemouth bass, smallmouth bass, damselflies, and amphipods produced estimated survivorship rates of exposure to p-cresol which were consistent with the results of the field experiments.

2) The community parameters, both structural(evenness and diversity) and functional(community metabolism and leaf pack degradation), indicated the same type of ecological impacts on macroinvertebrates as did the single species analyses.

3) The pulsed exposure produced slightly more impacts than continuous 48 hr exposure with a comparable "ppm x days" integral.

2. Metals

i. Cadmium

Cadmium contamination was studied by Maleug, et al., (1984) and it was concluded that *D. magna* was a useful, sensitive laboratory bioassay organism for conducting acute metal toxicity tests. In general, they found that numbers of organism, biomass, species diversity, and dominant types of organisms correlated well with metal content and acute laboratory toxicity. The research involved sediment contamination of cadmium, copper, chromium mercury, nickel, and zinc.

Cadmium was also the contaminating metal in a study done by the EPA on metal sediment contamination of water and slurries. Schuytema, et al., (1984) found that the sediment sorbed cadmium contributed negligibly to D. magna mortality. The authors suggested further work in the toxicity testing of sediments.

Griffiths (1980) studied the effects of low level cadmium poisoning to D. magna and found the daphnid may make a useful indicator of low levels of cadmium pollution in the field. The research focused upon the effects of cadmium upon the gut diverticulum of the daphnid. When exposed to cadmium, the basal and lateral cell membranes, and also the mitochondria and microvilli, had formations of calcium granules.

The effect of cadmium on the alpha-aminolevulinic acid dehydratase (ALA-D) activity of D. magna was studied by Berglind (1986). It was found that cadmium by itself enhanced the activity of ALA-D, but in the presence of lead it was a powerful inhibitor. In the presence of zinc, the cadmium effect was neutralized.

ii. Copper

Numerous studies have documented that elevated concentrations of copper and/or zinc in aquatic environments, resulting from man's activities, could have detrimental impacts on biological communities (Hodson, et al., 1979; Forstner and Wittmann, 1983). Hardy, et al., (1983) outlined the variables they found to be most important in controlling the fate of metals and their resultant toxicity in aquatic ecosystems in order of decreasing importance as follows:

1. pH
2. hardness
3. alkalinity
4. adsorption
5. partitioning on surfaces
   a. air-water
   b. suspended particles
   c. sediments

Hardy, et al., (1983) also found that increasing pH and alkalinity afforded protection for *D. magna* against the toxic effects of brass powder. In addition, they discussed the suggestion by many researchers that the free copper ion, and at least some of the hydroxoide species, are toxic and the copper carbonate species are nontoxic. Zn^{++} was also suggested to be toxic while zinc carbonate species were nontoxic.

D. magna was found to be the most sensitive species in a comparison sediment toxicity bioassay using *Chironomus* *tentans*, *Hyalella azteca*, and *Gammarus lacustris* (Cairns, et al., 1984). Cairns et al., (1984) also found that most of the copper in the sediments remained there unless disturbed either chemically or physically. The authors suggested that when studying the effects of sediment bound copper or other toxicants, it is best to sample at the water sediment interface.

Malueg et al., (1984) studied the toxicity of several sites known to have metal toxicity. These metals were cadmium, chromium, copper, mercury, nickel, and zinc. The authors made the following conclusions relative to the research on the Robert S. Kerr Lake:

1. Daphnia and Hexagenia, when used together in the recirculating apparatus, were useful sensitive laboratory bioassay organisms for conducting acute metal toxicity sediment tests, the Daphnia being the most sensitive.

2. Elevated metal levels were present in sediment and bioassay test water where significant organism mortality occurred.

3. In general, numbers of organisms, biomass, species diversity, and dominant types of organisms correlated with metal content and acute laboratory toxicity.

As several of the metals studied by Malueg are possible contaminants in the Sequoyah Fuels effluent stream, the validation of Daphnia as a sensitive test organism by Malueg is extremely important in the selection of Daphnia magna as a test organism.

It was found that 0.56 mg/L of copper and greater caused 100% mortality with D. magna (Khangarot, et al., 1986). Khangarot et al., (1986) studied the effects of amino acids on the toxicity of copper and found that a 4.7 to 27 fold decrease in toxicity occurred when amino acids were added. The authors found the amino acids formed a complex with the copper to become a sort of "anti-pollutant."

iii. Manganese

^{54}Mn is an activation product, formed from stable ^{55}Mn and ^{54}Fe in the presence of high energy neutrons (Kwasnik et al., 1978). Kwasnik et al., (1978) studied the bioaccumulation of manganese in three species: Protococcoidal chlorella, D. magna, and Pimephales promelas. They found that accumulation of manganese decreases with ascent up a theoretical aquatic food chain when water is the only source of contamination.

iv. Selenium

Selenium toxicity to D. magna was compared to that for Hyalella azteca and Pimephales promelas. It was found that the daphnid was more sensitive initially (48 hours), but in chronic tests the amphipod was more sensitive (Halter, et al., 1980). These results demonstrate the appropriateness of daphnids for acute tests.

v. Uranium

The LC_{50} for uranium in an acute test using *D. magna* was found to range between 5.34 and 7.62 mg/L (Poston, et al., 1983). The authors also found a correlation between carbonate hardness and toxicity as noted below:

> ...Because uranyl ion has a high affinity for CO_3^{-2}, the relationship between hardness and toxicity may be more appropriately expressed as a function of carbonate alkalinity. At a pH of 7.9 to 8.0, bicarbonate and carbonate ions predominate. Consequently, the relationship between hardness and toxicity can be expressed as a function of bicarbonate and carbonate concentration by the regression equation:
>
> $LC_{50} = 19.491 + 19.830 \ln [HCO_3^{-1} = CO_3^{-2}]$ (1)
>
> When expressed as a function of hardness, the equation is:
>
> $LC_{50} = -159.777 + 39.322 \ln CaCO_3$ mg/L EDTA (2) hardness

Poston, et al. (1985) made the following conclusions from their research:

1. Uranium was acutely toxic at 6 mg/L in mildly alkaline water systems.
2. The toxicity of uranium was moderated by alkalinity or hardness.
3. Reproduction in experimental populations of *D. magna* may be suppressed at uranium concentrations as low as 0.5 mg/L.
4. Although the toxicity of uranium VI relative to other trace metals was low, the potential for release of toxic levels into natural bodies of water was a concern that required site specific hazard assessment.

3. Non-Metals

i. Wastewater Disinfectants

Ward and DeGraeve (1978) published a study on the topic of toxicity of wastewater disinfectants. The authors focused their study on chlorinated, chlorobrominated, and ozonated effluents. The chlorinated effluent exhibited the greatest potential for residual toxicity to aquatic life of the three; however, the residual bromine chloride proved to have the potential to be harmful to aquatic life when present in sufficient concentration. The relatively reduced stability and longevity of bromine chloride in comparison to chlorine contributed to its reduced potential for lethal effects on aquatic life. Ozone was found to be the least toxic of the three and the authors attributed this partly to the rapid dissipation of ozone.

ii. Chlorobenzenes

Bobra et al. (1985) studied the correlation or statistical interdependence between concentrations of chlorobenzenes that cause a defined toxic endpoint, and a physical-chemical property such as octanol/water partition coefficient (K_{ow}) or aqueous solubility (C). In their case the researchers found the toxic effects were nonspecific in nature and the concentration at which fifty percent of the sample demonstrated effects of the chlorobenzenes (EC_{50}) was controlled primarily by octonol/water partitioning.

iii. <u>Polychlorinated Biphenyl (PCB) Replacement Products</u>

Herman Sanders et al. (1985) conducted laboratory studies to determine the acute or chronic toxicity of seven potential PCB replacement products. These seven products were six phosphate esters and one water-glycol mixture. The organisms used were the alga <u>Selenastrum capricornutum</u>, the daphnid <u>D. magna</u>, the midge <u>Chironomus plumosus</u>, and the amphipod <u>Gammarus pseudolimnaeus</u>. The authors concluded that the least potential environmental hazard was presented by the water-glycol mixture followed by the phosphate esters and PCB's. They also found that the risk from phosphate esters to the environment was significantly less than that of PCB's.

iv. <u>Fluorides</u>

Fieser, et al. (1986) studied the critical concentrations of fluorides using <u>D. magna</u>. They found a simple exponential relationship between the toxicity of fluorides and temperature in hard water which they attributed to increased physiological processes and, thus, increased uptake of the fluoride. The study also revealed that increases in fluoride content up to 65 mg/L stimulate egg production by amounts up to about 150% of that of the control. It also demonstrated that increasing flucride concentrations reduced the hatchabiliity rate continuously with a sharp decrease around 34 mg/L.

v. Dithiocarbamates

Van Leeuwen, et al. (1978) conducted a study into the toxicity of dithiocarbamates to the guppy *Poecilla reticulata*, the water flea *D. magna*, the Green alga *Chlorella pyrenoidosa*, and the bacterium *Photobacterium phosphoreum*. They concluded that dithiocarbamates are cytotoxic substances and, therefore, must be regarded as broad spectrum biocides.

Section II. *Pimethales promelas*:

A. General

Maki (1979) performed a comparison study between the toxicity responses of the fathead minnow (*Pimephales promelas*) and the water flea (*D. magna*). See the discussion in Section I, B.

B. Metals

1. Chromium

Pickering (1980) conducted a study focused on the chronic effects of hexavalent chromium on *Pimephales* *promelas*. In this study, the following results were observed:

1) Survival was affected only at the high test concentration of 3.95 mg/L

2) All chromium concentrations, including the lowest tested (.018 mg/L), retarded the early growth of the first generation fish, but this effect was only temporary.

3) Growth of second generation fish was not affected at concentrations of 1.0 mg/L or lower.

4) Reproduction and hatchability of eggs were not affected at any chromium concentration tested. (Pickering, 1980)

2. Metals Avoidance

Hartwell et al., (1987), conducted a laboratory study on the avoidance behavior of fathead minnows over a nine month period. The metals used in the study were copper, chromium, arsenic, and selenium which were mixed together at ratios of 1.0:.54:1.85:.38, respectively. The authors reported that unexposed fish avoided very low concentrations of the (0.29 mg/l total metals) blend. Exposed fish preferred elevated concentrations equal to three times the holding exposure concentration after three months of exposure and mildly avoided concentrations five times the holding exposure concentration after six months of exposure. The authors also found the fish were not responsive to concentrations approaching ten times the holding exposure level after nine months of exposure.

Activity was not found to be affected by the long term exposure or test exposure. Hartwell et al. (1976) conducted a second test which was a field validation of the results obtained in the first test. The authors found the response of fish acclimated to the metals blend for three months in the field was in marked contrast to that of laboratory acclimated fish. They also found that fish in the laboratory avoided lower concentrations of metals than did fish in the field tests. They concluded that predicted responses, based on short term laboratory exposure, may be erroneous. Depending upon unexposed laboratory fish would be in closer agreement, but would likely overestimate the responsiveness of fish to metals pollution in the wild.

3. Heavy Metal Tolerance

Benson and Birge (1985) conducted a study comparing two different natural fathead populations in their response to metals. The authors concluded from the data produced that the results justify the conclusion that fathead minnows developed increased tolerance to cadmium and copper following prolonged sublethal exposure to these metals; and that this metal-induced tolerance was not sustained once organisms are removed from toxicant stress. They also found tolerance induction was, in part, attributed to increased production of metallothionein, a protein which selectively binds and deactivates cadmium, copper, and certain other metals.

C. Non-Metals

1. Wastewater Disinfectants

Ward and DeGraeve (1978b) studied the toxicity of several wastewater disinfectants on *Pimephales promelas*. From the results of their study they concluded the following:

1) The lowest total residual chlorine concentration that had a lethal effect on fathead minnows was .165 mg/L in 25% effluent.

2) The test animals in this study exhibited a greater tolerance to residual chlorine than those in a similar study with domestic wastewater treated by the activated sludge process. The reason for this greater tolerance was not known.

3) Dechlorination with sulfur dioxide eliminated the lethal effects associated with chlorinated effluent.

4) None of the effluent treatments tested were observed to have any negative effect on the growth or reproduction of fathead minnows. (Ward and DeGraeve, 1978b)

2. Fluoride

Smith, et al., (1985) conducted a study on the acute toxicity of the fluoride ion on *Gasterosteus aculeatus*, *Pimephales promelas*, and juvenile *Salmo gairdneri*. Their results suggested fluoride may not be as acutely toxic to fish as certain earlier studies concluded. The authors discussed the problems associated with the determination and classification of fluoride as a toxicant and concluded that the available data suggested a uniform consensus about the maximum safe level of fluoride ion for fish in natural waters of varying hardness has not yet been achieved.

3. Pentachlorophenol

Two amphipods, *Gammarus pseudolimnaeus* and *Crangonyx pseudogracilis*, and fathead minnows were used in a study to observe the effects of varying pH on the toxicity of pentachlorophenol (PCP). Acute exposures with all three species showed PCP toxicity was decreased with increased test pH (Spehar, et al., 1985). In addition, chronic PCP toxicity and bioaccumulation were similarly decreased when pH values were increased. The authors attributed the decrease in chronic PCP toxicity to the reduction in PCP accumulation as a direct result of the increased ionization of PCP at higher pH values. The authors then used this conclusion to state that the ionized form of the PCP was less toxic per unit concentration than was the un-ionized form. They also concluded from the results that chronic, as well as acute toxicity, may be caused by both forms of PCP when significant concentrations are present in solution.

4. Multi-Species Testing

Phipps and Holcombe (1985) developed a method to simultaneously determine 96 hour LC_{50} values for seven freshwater species in a single flow-through test. They tested the following compounds and compared the results with single species toxicity results:

1) pentachlorophenol
2) 2-chloroethanol
3) 2,4-pentanedione
4) hexachloroethane
5) alpha-bromo-2',5'-dimethoxyacetophenone
6) benzaldehyde
7) 1,3-dichloro-4,6-dinitro-benzene
8) dursban
9) sevin
10) cadmium chloride

The authors found the LC_{50} values obtained from their test methods usually were within 20% of those determined with single species methods.

5. Inhibitory Effects on Acetylcholinesterase

Olson and Christensen (1980) conducted a study into the inhibition of acetylcholinesterase (AChE) by several water pollutants. They found a highly inhibitory effect with several carbamates, one organo-oxy-phosphate, the arsenite ion, and certain other heavy metal ions. The authors also found intermediate effects from the arsenate ion, other metal cations, organometals, certain neuroactive agents, organophosphates, and one organochloride pesticide.

The authors came up with a rank order of transition metal inhibiting effects as follows:

$$Cu^{2+} > Au^{3+} > Pd^{2+} > Cd^{2+} > Pd^{4+} > Ag^{1+} > Au^{1+} > Hg^{2+} > Sn^{2+} > Pt^{4+}.$$

6. Ammonia

Arthur, et al. (1987) conducted a test into the toxicity of ammonia to fourteen species, including five species of fish. The authors ranked the fish from the highest sensitivity to the lowest as: Rainbow Trout > Walleye > Channel Catfish > White Sucker > Fathead Minnows.

7. Synthetic Detergents

A study into the toxic effects of synthetic detergents on several species including fathead minnows was done by Abel (1974). The author concluded that the most important environmental factors influencing toxicity were the type of detergent, its molecular configuration, and the dissolved oxygen concentration. The author also listed species, age and life stage of fish, and acclimation as important biotic factors. The author found that exposure to low levels of detergents prior to, or simultaneously with, exposure to some other poisons, notably pesticides, lowered resistance to these poisons.

8. Synthetic Polyelectrolytes

Biesinger and Stokes (1986) performed a study into the acute toxicity of several polyelectrolytes on *D. magna*, *Pimephales promelas*, *Gammarus pseudolimnaeus*, and *Paratanytarsus parthenogeneticus*. They found that the nonanionic and anionic polyelectrolytes tested were not acutely toxic at 100 mg/L to the four species studied with the exception of one experimental anionic polymer. The authors also found that of the fifteen cationic polyelectrolytes tested, only two were not toxic at 100 mg/L.

CHAPTER III

METHODS

I. Test Methods for 48-hour Acute Toxicity Static Testing

The procedures used were taken directly from the EPA publication entitled "Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms" (Third Edition, 1985). A short summary of these methods follows.

A. Collection and Transport of Samples

Samples for the 48-hour acute toxicity static test were collected on June 8, 1989. Samples were collected at the three test sites in plastic one-gallon jugs. The jugs were held beneath the surface of the water and allowed to freely fill while avoiding excess turbulence. Once the jugs were filled, they were capped under water to prevent the trapping of air bubbles. Following collection, the samples were placed in ice chests and iced for transport to the University of Oklahoma. Upon arrival at the

University, the samples were transferred to a refrigerator and stored at 5°C.

B. Preparation of Test Solution

Several hours prior to the beginning of the test the samples were removed from the refrigerator and allowed to equilibrate to test temperature. Test dilutions were prepared using a dilution factor of 0.5. This dilution factor was chosen for its greater precision and coverage. The resulting effluent percentages were 100, 50, 25, 12.5, and 6.25 percent. Test solutions were prepared in 4.0 ounce Qor pak bottles. A total solution volume of 50 milliliters (ml) was used. Solutions were prepared using the above mentioned dilution factor. The combination of the dilution factor with the initial volume used, resulted in effluent volumes of 50 ml, 25 ml, 12.5 ml, 6.25 ml, and 3.12 ml, with corresponding volumes of reconstituted water to provide a total volume of 50 ml. Each replicate had a control of 0.0 percent effluent or 100 percent reconstituted water.

Reference toxicants of zinc chloride were prepared using the previously discussed dilution factors and solution volume. Two concentrations of zinc chloride were prepared in order to accurately determine the sensitivity of the test organisms. Zinc chloride concentrations of 0.7 mg/l and 0.05 mg/l were used.

After checking the temperature and dissolved oxygen level, 24-hour neonates were randomly placed in each test vessel. Upon completion of this step, the test vessels containing the test solution and the organisms were placed in the environmental chamber.

C. Environmental Conditions

The environmental chamber was maintained at 20 ± 2℃. The photoperiod of the chamber was set on a cycle of a 16 hour light cycle which was divided into two four hour periods of incandescent lighting and one eight hour period of florescent lighting. One period of incandescent lighting preceded the 8 hour period of florescent lighting followed by the second 4 hour incandescent period.

D. Observations

Two hours after the initiation of the test, the test organisms were examined to ensure that the organisms survived handling and that the toxicity of the solution was not too great. This examination was repeated at 6, 8, 12, 24, and 48 hours. The overall effect observed was immobilization or no movement of body or appendages upon gentle prodding. At each observation period immobilization numbers were collected and analyzed for toxicity. Throughout the duration of the test, the test organisms were not fed. Dissolved oxygen measurements showed that aeration was not needed.

II. Test Methods for 7-Day Chronic Static Renewal Embryo-Larval Survival and Teratogenicity Test-

The procedures and methods used were taken directly from the latest edition of the EPA document entitled "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms," (1985). A short summary of these methods follows. Table 1 summarizes the procedures and conditions for *D. magna* acute toxicity testing.

A. Collection and Transport of Samples

Samples for the 7-day chronic test were collected on July 17, 20, and 22, 1989. Samples were collected at site numbers one and four in one-gallon plastic jugs. The jugs were held beneath the surface of the water and allowed to freely fill while avoiding excess turbulence. Once the jugs were filled, they were capped under water to prevent the trapping of air bubbles. Following collection, the samples were placed in ice chests and iced for transport to the University of Oklahoma. Upon arrival at the University, the samples were transferred to a refrigerator and stored at 5C, until their use.

B. Preparation of Test Solution

Prior to the test, moderately hard reconstituted water was prepared for use as dilution water. The reconstituted water was prepared following EPA standatds (EPA, 1985).

Several hours prior to the preparation of the solution, the samples were removed from the refrigerator and allowed to equilibrate to the test temperature. Test dilutions were prepared using a dilution factor of 0.5. This dilution factor was chosen for its greater precision and coverage. The resulting effluent percentages were 100, 50, 25, 12.5, and 6.25 percent.

Test solutions were prepared in 500 ml Corning 7201-D Pyrex bowls. A total solution volume of 250 ml was used. Solutions were prepared according to the above dilution factors. The combination of the dilution factor and initial volume resulted in effluent volumes of 250 ml, 125 ml, 62.5 ml, 31.25 ml, and 15.63 mls with corresponding volumes of reconstituted water to provide a total solution volume of 250 ml. This procedure was repeated to produce three replicates for both sites. Each replicate had a control of 0.0 percent effluent or 100 percent reconstituted water.

Reference toxicants of zinc chloride were prepared using the previously discussed dilution factors and solution volume. Zinc chloride concentrations of 0.7 mg/l and 0.05 mg/l were used.

After initially measuring water quality parameters including temperature, dissolved oxygen, pH, conductivity, hardness, and alkalinity, the test embryos were gently agitated and mixed in large containers so that eggs from different spawns were evenly distributed according to EPA specifications. After random placement of the embryos in the test chambers, the test chambers were placed in the environmental chamber.

C. Environmental Conditions

The environment chamber was maintained at 25 ± 2 °C. The photoperiod of the chamber was a cycle of sixteen hours of light and eight hours of darkness. The light period consisted of four hours of incandescent lighting followed by eight hours of florescent lighting and ending with another four hour incandescent lighting period.

D. Observations

Twenty-four hours after the initiation of the test the embryos were examined for hatching and death. The indicator of death used for the unhatched embryos was the appearance of fungal growth on the egg casing. The embryos were examined every 24 hours for a period of seven days. After hatching, the fry were checked for survival and teratogenicity. Immobilization was used as an indicator for death. Curvature of the spine, enlarged gas bladders, and difficulty in swimming were used as indications of teratogenicity.

New test solutions were prepared daily using the above mentioned methods. These solutions were also analyzed for temperature, dissolved oxygen, pH, conductivity, hardness and alkalinity. New sample water was used to replenish the test bowls in accordance with EPA standards.

Throughout the duration of the test the fry were not fed. Also, based on dissolved oxygen measurements it was determined that aeration was not needed.

TABLE 1: RECOMMENDED TEST CONDITIONS FOR DAPHNIDS (DAPHNIA PULEX[a] AND D. MAGNA)

1.	Temperature (°C):	20 ± 2°C
2.	Light quality:	Ambient laboratory illumination
3.	Light intensity:	50-100 footcandles (ftc)[b] (ambient laboratory levels)
4.	Photoperiod:	8-16 h light/24 h
5.	Size of test vessel:	100 mL beaker
6.	Volume of test solution:	50 mL
7.	Age of test animals:	1-24 h (neonates)
8.	No. animals per test vessel:	10
9.	No. of replicate test vessels per concentration:	2
10.	Total no. organisms per concentration:	20
11.	Feeding regime:	Feeding not required during first 48 h. For longer tests, feed every other day beginning on the third day (Appendix A).
12.	Aeration:	None, unless DO concentration falls below 40% of saturation, at which time start gentle, single-bubble, aeration.
13.	Dilution water:	Receiving water or other surface water, ground water, or synthetic water: hard water for *Daphnia magna*; moderately hard or soft water for *D. pulex*
14.	Test duration:	Screening test - 24 h (Static Tests) Definitive test - 48 h (Static tests)
15.	Effect measured:	Mortality - no movement of body or appendages on gentle prodding (LC50)

[a] Use of *D. pulex* is preferred.
[b] ft c = foot candles.

TABLE 2: SUMMARY OF RECOMMENDED EFFLUENT TOXICITY TEST CONDITIONS FOR THE FATHEAD MINNOW (PIMEPHALES PROMELAS) EMBRYO-LARVAL SURVIVAL AND TERATOGENICITY TEST

1. Test type:	Static renewal
2. Temperature:	25 ± 1°C
3. Light quality:	Ambient laboratory illumination
4. Light intensity:	10-20 uE/m^2/s or 50-100 ft-c (ambient laboratory levels)
5. Photoperiod:	16 h light, 8 h dark
6. Test chamber size:	150-400 mL
7. Test solution volume:	70-200 mL
8. Renewal of test concentration:	Daily
9. Age of test organisms:	Less than 36-h old embryos
10. No. embryos per test chamber:	15 (minimum of 10)
11. No. Replicate test chambers per concentration:	4 (minimum of 3)
12. No. Embryos per concentration:	60 (minimum of 30)
13. Feeding regime:	Feeding not required
14. Aeration:	None unless DO falls below 40% saturation
15. Dilution water:	Moderately hard synthetic water is prepared using MILLIPORE MILLI-Q® or equivalent deionized water and reagent grade chemicals or 20% DMW (see Section 7). The hardness of the test solutions must equal or exceed 25 mg/L ($CaCO_3$) to ensure hatching.
16. Effluent test concentrations:	5 and a control
17. Dilution factor:[a]	Approximately 0.3 or 0.5

[a] Surface water test samples are used as collected (undiluted).

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This section will discuss the data obtained from the site visits, the chemical analysis of the water samples and the results of the acute and chronic toxicity tests. The information from the site visits includes general qualitative observations that may have had an influence on the test results and quantitative results using various probes and meters. The sites mentioned in the text following refer to the locations demonstrated on Figure 1. In addition, there is also a stream profile (Figure 2) and a calculation of volume and flow (Table 3). The chemical analysis was performed by the Oklahoma State Department of Health.

I. Site Observations-

A. Stream 001

6/8/89

Quantitative Observations-

The various physical and chemical parameters measured for this date were within expected ranges

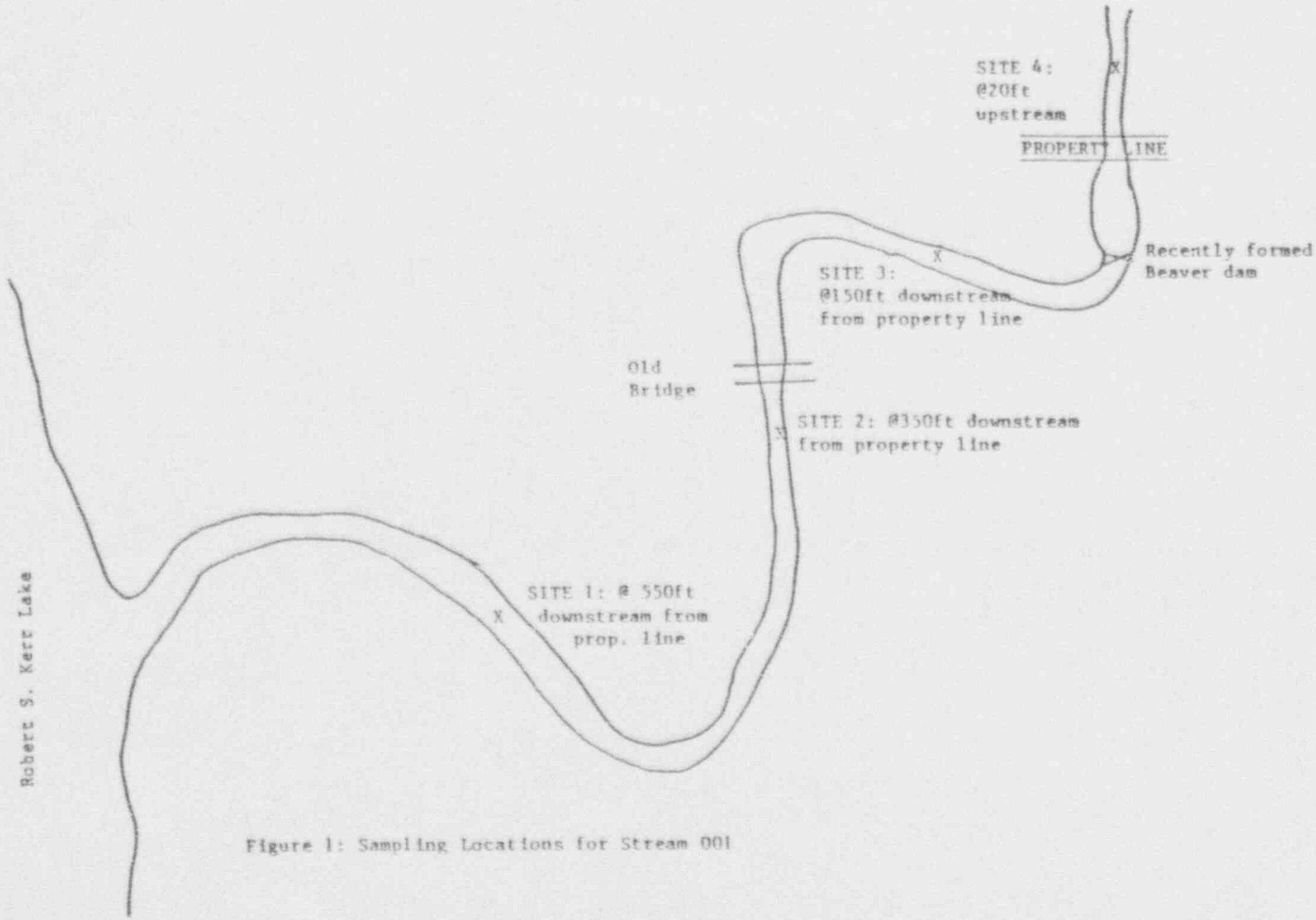

Figure 1: Sampling Locations for Stream 001

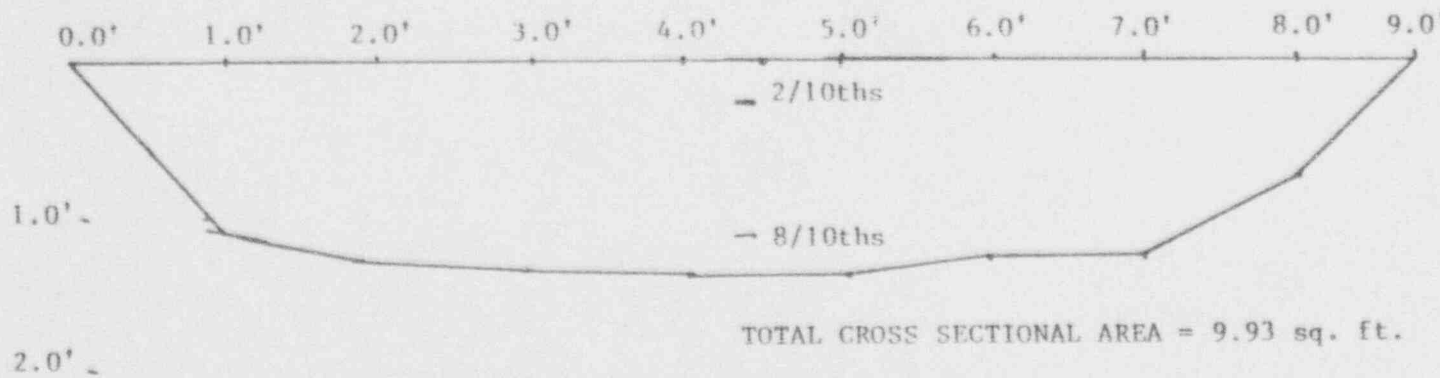

Figure 2: Cross Sectional View of Stream 001 at Site 2

Table 3

Stream Profile at Site 2 on 7/17/89

Width	8.8 ft
Width at center	4.4 ft
Cross-section area	9.93 ft3
Flow at 2/10's depth	0.6 ft/sec
Flow at 8/10's depth	0.6 ft/sec
Volume*	5.96 ft3

Distance from Bank	Depth
1 ft	1.10 ft
2 ft	1.30 ft
3 ft	1.35 ft
4 ft	1.40 ft
5 ft	1.40 ft
6 ft	1.30 ft
7 ft	1.30 ft
8 ft	0.80 ft

*derived using Q = V/A

except for the dissolved oxygen and the ambient temperature. These values were caused by a defective meter. The "percent shaded" observation was a subjective estimate of the shadedness of one site relative to the other. This data gave general information as to the amount of light penetrating the canopy (see Table 4).

Qualitative Observations-

For the first visit to the 001 stream (Table 4) there appeared to be "sub-normal" aquatic flora and fauna. The diversity in number and species of water bugs present at each site decreased from the mouth to site 4. This trend could indicate a preference of the waterbugs, but is not a conclusive indicator in and of itself.

The absence of any fish was a more telling observation as this stream would lend itself well to habitation by minnows and small fish. However, the lack of minnows or small fish in the stream was purely a non-scientific observation and could be due to any number of reasons.

Readily observable algae, insects and insect larvae appeared to be lacking in the stream and immediate bank area. Even after somewhat extensive

Table 4

Site Observations on 6/8/89

Quantitative Observations

Chemical Parameters	SITE 1	2	3	4
Time	12:37p	12:52p	1:08p	1:26p
Ambient Temp.	**	**	**	**
Water Temp. C	21.5	20.6	21.9	21.8
D.O. mg/L	**3.7	**4.0	**3.7	**3.2
pH	8.3	8.3	8.0	8.0
Conductivity mV	23.0	23.0	19.0	22.0
% shaded	~1%	~10%	~80%	~90%

Qualitative Observations:

- -**D.O. probe not functioning properly
- -Weather was sunny with a few clouds
- -Mild winds
- -4 species of water bugs observed at mouth of sstream
- -Only 1 species of water bug observed at Site 4
- -Periphyton observed at mouth of stream but no further upstream
- -No algae observed in stream
- -Silt plume observed entering Kerr Lake at mouth of stream
- -No minnows observed in stream
- -No insect larvae observed in stream or sediments
- -Beaver dam found @ 30-40 ft downstream of property line

searching, larvae could not be found. Again, these were interesting facts about the site, but they were not scientifically derived.

6/15/89

Quantitative Observations-

The physical and chemical parameters measured for this date were all within expected ranges and varied only slightly from the previous sampling data. The pH data varied a little more but this may be due to the fact that the original pH meter (Hydrolab) was discarded in favor of a new one (Orion Research). In any case, the variance was not enough to cause concern (see Table 5).

Qualitative Observations-

Recent rains increased the level of the stream and caused sediments and detritus to be suspended in the water. The main point of interest here was the appearance of another species of waterbug at the site closest to the plant.

7/17/89

Quantitative Observations-

The data from this visit were all within expected ranges. As shown in Table 6 the data for dissolved

Table 5

Site Observations on 6/15/89

Quantitative Observations

Chemical Parameters	SITE 1	2	3	4
Time	2:55p	3:01p	3:14p	3:25p
Ambient Temp. C	20.0	20.0	20.0	20.0
Water Temp. C	21.0	20.9	20.7	20.8
D.O. mg/L	**	**	**	**
pH	7.5	7.5	7.6	7.6
Conductivity mV	27.5	30.0	30.7	33.0
% shaded	~1%	~10%	~80%	~90%

Qualitative Observations:

- -D.O. probe inoperable
- -Weather was cloudy
- -Moderately strong breeze
- -Increased depth due to recent rains and subsequent water release from Lake Tenkiller
- -2 Species of water bugs observed at Site 4
- -Increased turbidity due to recent rains and runoff
- -Brown scum observed in stream, possibly an algae

Table 6

Site Observations on 7/17/89

Quantitative Observations

Chemical Parameters	SITE 1	2	3	4
Time	4:15p	4:39p	5:10p	5:32p
Ambient Temp. C	22.4	23.0	23.8	23.6
Water Temp. C	21.8	22.1	22.5	22.5
D.O. mg/L	7.8	7.7	7.8	7.6
pH	7.7	7.9	7.9	8.0
Conductivity mV	41.7	48.7	49.7	54.5
% shaded	~1%	~10%	~80%	~90%

Qualitative Observations:

-Thunderstorms and heavy rain up until 2:30 p.m.
-After 2:30 p.m. the rain stopped any by 4:00 p.m. the sky was partly cloudy.
-Heavy clay plume observed at mouth due to rain.

oxygen were finally obtained and were found to be within acceptable ranges. The temperature values were slightly higher than previous visits, but this was most probably due to the time of day.

Qualitative Observations-

There were extensive, severe thunderstorms in the area for the previous 24 hours before the sampling. On arrival to the boat launch the sky began to clear, and by the time the sampling was complete, the sky was only partly cloudy. The effect of the severe weather was increased levels of detritus and turbidity in the stream. As noted in Table 6, there was a heavy clay plume at the mouth of the stream.

7/20/89

Quantitative Observations-

The physical/chemical parameters for the stream on this date were all within expected ranges.

Qualitative Observations-

As Table 7 shows, there were no unusual observations of the site and site area.

Table 7

Site Observations on 7/20/89

Quantitative Observations

	SITE			
Chemical Parameters	1	2	3	4
Time	1:20p	1:43p	1:54p	2:11p
Ambient Temp. C	32.4	31.8	28.0	23.4
Water Temp. C	23.2	22.8	22.6	22.5
D.O. mg/L	8.1	8.0	7.8	7.9
pH	8.0	8.0	8.0	8.1
Conductivity mV	56.5	56.3	58.5	63.5
% shaded	~1%	~10%	~80%	~90%

Qualitative Observations:

- Partly cloudy.
- Moderate breeze.

7/22/89

Quantitative Observations-

The values for dissolved oxygen were a little higher for this date than for previous dates. One possibility for this difference is the lack of rain previous to sampling. As noted in Table 8, the water levels were the lowest observed.

Qualitative Observations-

The stream biota on this visit strongly contrasted that of the initial visit. The insect life was abundant and waterbugs at site 4 were as numerous and various as at site 1. Minnows were observed in the stream as far upstream as site 3. Spawning beds were also observed approximately fifty feet upstream of site 1. Bluegill were observed throughout the stream below site 3, possibly responsible for the spawning beds. Blue Heron tracks were also seen throughout the stream from site 1 to well above site 4.

Table 8

Site Observations on 7/22/89

Quantitative Observations

	SITE			
Chemical Parameters	1	2	3	4
Time	3:00p	3:09p	3:16p	3:30p
Ambient Temp. C	24.3	25.6	24.9	23.8
Water Temp. C	21.7	21.4	21.2	21.0
D.O. mg/L	8.4	8.7	8.6	8.9
pH	8.0	8.0	8.0	8.0
Conductivity mV	65.5	61.7	60.8	59.7
% shaded	~1%	~10%	~80%	~90%

Qualitative Observations:

- -Partly cloudy.
- -Water level lower than previous visits.
- -Increased presence of insects.
- -Bluegill observed in stream.
- -Spawning beds observed @ 50 ft. upstream of site. 1: possibly bluegill.
- -Minnows observed as far upstream as site 3.
- -Blue Heron tracks observed throughout stream downstream from site 2.

B. Stream 005 and 007

6/15/89

Quantitative Observations-

All of the physical and chemical parameters were within expected ranges for the sites (Table 9). As with Stream 001, the dissolved oxygen probe was not functional.

Qualitative Observations-

The observations for these sites did not vary significantly from those for Stream 001. The comments in Table 4, in general, also apply to Stream 005 and 007 (Table 9). One point of interest, a crayfish was observed and caught in the stream. Upon further observation and examination, the crayfish appeared to be in a healthy condition. He was observed in the laboratory for a period of 1 month and exhibited no unexpected attributes.

7/17/89

Quantitative Observations-

The physical and chemical parameters for Stream 005 and 007 were within the expected ranges (Table 10).

Table 9

Site Observations for Streams 005 and 007 on 6/15/89

Quantitative Observations

Chemical Parameters	STREAM 005	007
Time	1:08p	1:48p
Ambient Temp. C	20.0	18.9
Water Temp. C	19.5	19.2
D.O. mg/L	**	**
pH	6.4	7.7
Conductivity mV	39.0	34.7
% shaded	~98%	~98%

Qualitative Observations:

-Partly cloudy.
-Moderatley strong breeze.
-Crayfish observed and caught.
-Further comments located on site observations for Stream 001 sites.

Table 10

Site Observations for Streams 005 and 007 on 7/17/89

Quantitative Observations

Chemical Parameters	STREAM 005	007
Time	2:30p	3:45p
Ambient Temp. C	22.2	21.7
Water Temp. C	22.5	22.5
D.O. mg/L	7.8	7.6
pH	7.9	7.5
Conductivity mV	49.5	22.5
% shaded	~98%	~98%

Qualitative Observations:

-Thunderstorms and heavy rain.
-Rain stopped around 2:30p.m.
-Further comments located on site observations for Stream 001 sites.

Qualitative Observations-

See comments for Stream 001 on 7/17/89.

II. Chemical Analysis

A. Hardness

The hardness for sites 1 and 4 for Stream 001 fell between 52 and 68 mg/l $CaCO_3$ except for site 1 on 7/20/89. On this date the hardness was 116 mg/l as $CaCO_3$ for site 1. As Table 11 shows, the increase in hardness was due to an increase in calcium hardness while the magnesium hardness was approximately the same for all sampling dates. The reason for this was unknown. To ensure accuracy, a second titration was done to confirm hardness. The hardness values for the $ZnCl_2$ spikes were also within acceptable ranges.

B. Alkalinity

The total alkalinity for the sampling sites and the $ZnCl_2$ spikes ranged from 80 to 110 mg/l $CaCO_3$ (Table 12). The phenolpthalein alkalinity was 10 mg/l $CaCO_3$ for all dates and sampling sites, except for site 1 on 7/17/89 (Table 12).

C. Other Parameters

Table 13 shows the various chemical parameters analyzed at each sampling site. Of these, only the

Table 11

Hardness Data for Sites 1, 4, and Spike Solutions

Hardness in mg/l CaCO3						
Site	Date	ml EDTA	Ca++ Hardness	Mg++ Hardness	ml EDTA	Total Hardness
1	7/17	1.90	38	14	2.60	52
1	7/20	5.20	104	12	5.80	116
1	7/22	2.20	44	16	3.00	60
4	7/17	2.20	44	24	3.40	68
4	7/20	2.20	44	20	3.20	64
4	7/22	2.10	42	10	2.60	52
S-1	-	1.10	22	26	2.40	48
S-2	-	1.00	20	26	2.30	46

Table 12

Alkalinity Data for Sites 1, 4, and Spike Solutions

Alkalinity in mg/l $CaCO_3$					
Site	Date	ml H_2SO_4	Phenolpthalein Alkalinity	ml H_2SO_4	Total Alkalinity
1	7/17	1.0	20	4.0	80
1	7/20	0.5	10	5.0	100
1	7/22	0.5	10	5.0	100
4	7/17	0.5	10	5.0	100
4	7/20	0.5	10	5.5	110
4	7/22	0.5	10	5.5	110
S-1	-	0.5	10	4.0	80
S-2	-	0.5	10	4.5	90

Table 13

Results of Chemical Analyses

6/15/89

Site	Total PO4	Organ. PO4	NH3	TKN	NO2 NO3	F1-	SO4	C1-
1	.053	.013	xx	xx	.8	.61	21	10
4	.090	.057	xx	xx	.8	.62	<20	<10
005	.130	.030	xx	xx	9.3*	.42	74	<10
007	.098	.018	xx	xx	3.6	.25	23	<10

7/17/89

Site	Total PO4	Organ. PO4	NH3	TKN	NO2 NO3	F1-	SO4	C1-
1	.152	.011	.688	2.552	5.8	.47	35	<10
4	.213	.213	.229	1.044	2.8	.91	35	<10
005	.444	.030	.344	2.784	20.8#	.95	49	<10
007	.343	.254	.229	1.508	4.0	.52	41	<10

All values in mg/L except for NH3, TKN, and NO2/NO3, which are in mg/l as N.
xx-data not available.
*-approaching limit #-in excess of limits.

Maximum Allowable Limits:

Nitrate/Nitrite as Nitrogen	10 mg/L
Flouride Total	4 mg/L
Chloride	250 mg/L
Sulfate	250 mg/L

nitrate/nitrite (as nitrogen) values were at or above permitted amounts. For Stream 005, the nitrate/nitrite value was 9.3 mg/L on 6/15/89 and 20.8 mg/L on 7/17/89. The Maximum Allowable Limit for this parameter is 10 mg/L and thus, the stream is near violation on the first date and is in clear violation in the second case.

III. Test Results

A. Chemical/Physical Parameters-

The chemical and physical parameter monitoring during the tests was done to ensure conditions were within the required ranges as established by the U.S. Environmental Protection Agency. The data in Appendix A show that there were .o instances where these ranges were violated, either for the *D. magna* or *Pimephales promelas*. The only parameter close to exceeding its given range was temperature for day five on the fathead minnow test. Even then, the temperature was within given ranges and did not affect the test.

B. Acute Toxicity -

The results of the *D. magna* acute bioassay did not show toxicity to any significant degree. The reference toxicants, however, demonstrated that the organisms were acutely sensitive to the spikes used. The control for site 1 had no deaths and the highest mortality was in the fifty percent dilution (Table 14). The results did not indicate a pattern of increasing toxicity with increased effluent strength.

The control for site 2 had one death which was nine percent of the test organisms in that dilution (Table 15). This was well within the twenty percent limit expressed by the EPA. The highest mortality for this site was twenty percent and this occurred at the fifty percent dilution level. As in the case of site 1, there are no significant trends in the limited toxicity demonstrated by the daphnids.

The control for site 4 demonstrated no toxicity whereas the highest toxicity, seventeen percent mortality, was found at the 6.25 percent dilution level (Table 16). There were no apparent trends in the result for this site.

The control for Spike 1 had no deaths whereas all of the dilutions for this reference toxicant demonstrated one hundred percent mortality (Table 17). For this reason, Spike 2 was started. Spike 2 was initiated eight hours after the beginning of the test. The test organisms appeared to be far more sensitive that had been thought. There was a

Table 14

Daphnia Survival Data for Site 1

Daphnia Condition	HOUR 6	15	24	48	sum
Control					
Live	10	10	10	10	
Dead	0	0	0	0	0
Mortality %	0	0	0	0	0
6.25%					
Live	31	31	31	30	
Dead	0	0	0	1	1
Mortality %	0	0	0	3	3
12.5%					
Live	30	30	30	27	
Dead	0	0	0	3	3
Mortality %	0	0	0	10	10
25%					
Live	30	30	30	30	
Dead	0	0	0	0	0
Mortality %	0	0	0	0	0
50%					
Live	30	29	29	25	
Dead	0	1	0	5	6
Mortality %	0	3	0	17	20
100%					
Live	30	30	30	29	
Dead	0	0	0	1	1
Mortality %	0	0	0	3	3

Table 17

Daphnia Survival Data for Spike 1

Daphnia Condition	HOUR 6	15	24	48	sum
Control					
Live	10	10	10	10	
Dead	0	0	0	0	0
Mortality %	0	0	0	0	0
6.25%					
Live	7	1	0	0	
Dead	3	9	10	10	10
Mortality %	30	90	100	100	100
12.5%					
Live	1	0	0	0	
Dead	9	10	10	10	10
Mortality %	90	100	100	100	100
25%					
Live	0	0	0	0	
Dead	10	10	10	10	10
Mortality %	100	100	100	100	100
50%					
Live	0	0	0	0	
Dead	10	10	10	10	10
Mortality %	100	100	100	100	100
100%					
Live	0	0	0	0	
Dead	10	10	10	10	10
Mortality %	100	100	100	100	100

Table 18

Daphnia Survival Data for Spike 2

Daphnia Condition	HOUR 6	15	24	48	sum
Control					
Live	**	5	5	4	
Dead	**	0	0	1	1
Mortality %	**	0	0	20	20
6.25%					
Live	**	5	5	5	
Dead	**	0	0	0	0
Mortality %	**	0	0	0	0
12.5%					
Live	**	5	5	0	
Dead	**	0	0	5	5
Mortality %	**	0	0	100	100
25%					
Live	**	4	4	0	
Dead	**	1	0	5	5
Mortality %	**	20	0	100	100
50%					
Live	**	0	0	0	
Dead	**	5	0	0	5
Mortality %	**	100	0	0	100
100%					
Live	**	0	0	0	
Dead	**	5	0	0	5
Mortality %	**	100	0	0	100

Table 19

Data Summary for Fathead Minnow Survival and Teratogenicity, Site 1

	0%	6.25%	12.5%	25%	50%	100%
Dead*	2	4	0	2	6	3
Terata	2	6	3	2	6	1
Total** mortality	4	10	3	4	12	4
Total mortality %	13	32	10	13	39	12
Terata %	7	19	10	7	19	3
Hatch %	97	94	94	97	81	88

Note: *dead embryos and larvae
**dead and deformed organisms

The control for site 4 had twenty percent mortality rate with a ninety seven percent hatch rate (Table 20). Although the mortality rates for this site were generally higher than the other site, there was still no correlation between the rates and the dilutions.

Spike 1 had two dilutions with one hundred percent mortality, twenty five and one hundred percent dilution as shown in Table 21. The control had a twenty percent mortality rate with one hundred percent hatch rate. The one hundred percent dilution did not have a single minnow hatch.

Spike 2 had only one dilution, the one hundred percent dilution, with one hundred percent mortality, (Table 22). This dilution also had no minnows hatch. The other dilutions and the control, however, had one hundred percent hatch rates.

Table 20

Data Summary for Fathead Minnow Survival and Teratogenicity, Site 4

	0%	6.25%	12.5%	25%	50%	100%
Dead*	1	5	1	4	1	7
Terata	5	2	12	13	4	1
Total** mortality	6	7	13	17	5	8
Total mortality %	20	24	43	57	17	27
Terata %	17	7	40	43	13	3
Hatch %	97	86	97	83	93	93

Note: *dead embryos and larvae
**dead and deformed organisms

Table 21

Data Summary for Fathead Minnow Survival and Teratogenicity for Spike 1 (0.7 mg/L ZnCl)

	0%	6.25%	12.5%	25%	50%	100%
Dead*	2	3	0	9	5	10
Terata	0	0	3	1	0	0
Total** mortality	2	3	3	10	5	10
Total mortality %	20	30	30	100	50	100
Terata %	0	0	30	10	0	0
Hatch %	100	91	100	80	70	0

Note: *dead embryos and larvae
**dead and deformed organisms

Table 22

Data Summary for Fathead Minnow Survival and Teratogenicity for Spike 2 (0.5 mg/L ZnCl)

	0%	6.25%	12.5%	25%	50%	100%
Dead*	0	7	7	3	3	10
Terata	1	1	0	2	3	0
Total** mortality	1	8	7	5	6	10
Total mortality %	10	80	70	50	60	100
Terata %	10	10	0	20	30	0
Hatch %	100	100	100	100	100	0

Note: *dead embryos and larvae
**dead and deformed organisms

CHAPTER V

CONCLUSIONS

The results of both the acute and chronic toxicity tests indicate that the sites investigated in this study are not toxic. However, several points related to site characteristics need to be discussed.

The first site visit qualitative observations were completely opposite of those from the last visit in terms of ecological conditions and stream biota. On the first visit, the stream revealed little or no insect or animal life in and around the stream. The insects that did inhabit the stream decreased as one traveled closer to the source of the wastewater discharge.

The last site visit yielded completely different observations. Not only did the insect life seem far more abundant, fish and minnows were also observed throughout the lower one third of the study area. There were what appeared to be spawning beds for bluegill in the stream. In addition, there were tracks in the stream bed that were possibly due to a Blue Heron, as many of these birds were observed in and around the site area. The number of tracks in the stream bed could indicate successful feeding.

The reason for these differences in qualitative observations is difficult to discern since the number of site visits were limited and the events preceding the first visit were unknown. It is also difficult to conclude that the observations made were the norm for the same reasons. In addition, the visits were made at different times of the day and there were no 24 hour background studies to determine daily cycles and variations. The lack of 24 hour data limits the conclusions by the possibility of toxic spikes occurring at times other than those when collections were made. The limited visits also could obscure toxic spikes in between collection days. For example, the qualitative observations of the stream improved over the course of this study which could indicate a toxic spike just previous to the first visit. If no other contamination occurred during the study, the violation would go undetected. Another possible explanation for the difference is the effect of a heavy rain on the biota. It is possible that if there was enough flushing of the stream it theoretically could have caused the conditions observed.

Other problems with the sampling methods involved the collection of the samples from the stream. The methods used in this study resulted in surface samples. The potential problem here is that the water at the sediment/water interface may have been more toxic and since it was never sampled, it would not be detected. Several of the articles concerning metal contamination reviewed in the literature search advised sediment/water interface sampling as the metals were bound to the sediments.

In order to correct the problems mentioned in the previous paragraph it would be advisable to change several of the methods used. A 24 hour chemical study should be conducted several times in order to obtain a good diurnal variation of physical/chemical parameters. These 24 hour studies should be done at least a week apart to ensure accuracy. Chemical analysis should be performed on weekly or bi-monthly basis to detect large changes in concentrations. At least one bioassay should be performed per month and more if it is indicated by one of the other monitored parameters. A method to obtain sediment/water interface samples should be devised and both the surface and the interface samples should be tested.

The adjusted methods would also improve the statistical accuracy of the results. The small samples in this study limit the ability to make broad conclusions as to the conditions of the effluent water. As the time and manpower involved in increasing the size of the samples is prohibitive, the increase in the number of tests run as well as the 24 hour study would increase the accuracy of the results and the strength of the conclusions. However, it should be noted that the results from the bioassays appear to be a good representation of the stream when it was sampled. The main point here is that the stream may not always be in this condition.

The results of the chemical analyses yielded no significant findings except that stream 005 had a nitrate problem (Table 13). However, since the toxicity tests were performed on stream 001, this information is ancillary and does not change the interpretation of the bioassays.

There were slightly higher mortality rates for site number four than for site number one in the chronic testing which could indicate possible sub-chronic toxicity. The trends in both tests did not indicate increasing toxicity with increasing effluent concentration which makes it difficult to accredit the mortality rates to the effluent.

In addition to the information obtained from this study, there was a radioisotope study performed on stream 001 by Skierkowsky et al. (unpublished). It was discovered that the levels of radioactivity were higher in the soils and sediments in and around the stream bed than in the aqueous wastewater effluent at some locations. Even though the effluent was within acceptable limits at the time of sampling, the level of radioactivity of the soil raised a question as to compliance of standards in the past. One of the authors of the research stated that it was their opinion that an extended study of the effluent stream was needed.

In conclusion, stream 001 was found to be non-toxic. However, further studies are strongly suggested with the changes in methods as noted earlier in this section.

REFERENCES

Abel, P.D., "Toxicity of Synthetic Detergents to Fish and Aquatic Invertebrates," Journal of Fish Biology, Vol. 6, pp. 279 - 298, 1974.

Adema, D.M.M., "Daphnia Magna as a Test Animal in Acute and Chronic Toxicity Tests," Hydrobiologia, Vol. 59.2, pp. 125 - 134, 1978.

Alibone, M.R. and Fair, P., "The Effects of Low pH on the respiration of Daphnia magna Straus," Hydrobiologia, Vol. 85, pp. 185 - 188, 1981.

Arthur, J.W., West, C.W., Allen, K.N., Hedtke, S.F., "Seasonal Toxicity of Ammonia to Five Fish and Nine Invertebrate Species," Bulletin of Environmental Contamination and Toxicology, Springer-Verlag New York Inc. Vol. 38, pp. 324 - 331, 1987.

Benson, W.H. and Birge, W.J., "Heavy Metal Tolerance and Metallothionein Induction in Fathead Minnows: Results from Field and Laboratory Investigations," Environmental Toxiciology and Chemistry, Vol. 4, pp. 209 - 217, 1985.

Biesinger, K, Stokes, G.N., "Effects of Synthetic Polyelectrolytes on Selected Aquatic Organisms," Journal WPCF, Vol. 58, No. 3, pp. 207 - 213, 1986.

Bobra, A., Shiu, W.Y., and Mackay, D., "Quantitative Structure - Activity Relationships for the Acute Toxicity of Chlorobenzenes to Daphnia magna," Environmental Toxicolocy and Chemistry, Vol. 4, pp. 297 - 305, 1985.

Cairns, M.A., Nebeker, A.V., Gakstatter, J.H., and Griffis, W.L., " Toxicity of Copper-Spiked Sediments to Freshwater Invertebrates," Environmental Toxicology and Chemistry, Vol. 3, pp. 435 - 445, 1984.

Carvalho, G.R. and Hughes, R.N., "The Effect of Food Availability, Female Culture-Density and Photoperiod on Ephippia Production in Daphnia magna Straus (Crustacea: Cladocera)," Freshwater Biology, Vol. 13, pp. 37 - 46, 1983.

Cooper, W.E., and Stout, R.J., "The Monticello Minnesota USA Experiment: A Case Study", Multispecies Toxicity Testing; Meeting, Blacksburg, VA., USA, May 15-18, 1983.

Doma, S. "Ephippia of Daphnia magna Straus - A Technique for Their Mass Production and Quick Revival," Hydrobiologia, Vol. 67, No. 2, pp. 183 - 188, 1979.

Fieser, A.H., Syukora, J.L., Kostalos, MS., Wu, Y.C., and Weyel, D.W., "Effect of Fluorides on Survival and Reproduction of Daphnia magna," Journal WPCF, Vol. 58, No. 1, pp. 82 - 86, 1986,

France, R.L., "Comment on Daphnia Respiration in Low pH Water," Hydrobiologia, Vol. 94, pp. 195 - 198, 1982.

Gale, W.F. and Buynak, G.L., "Fecundity and Spawning Frequency of the Fathead Minnow - A Fractional Spawner," Transactions of the American Fisheries, Vol. 111, pp. 35 - 40, 1982.

Ganton, J.H. and Adema. D.M.M., "Reproducibility of Short-Term and Reproduction Toxicity Experiments with Daphnia magna and Comparison of the Sensitivity of Daphnia magna with Daphnia pulex and Daphnia cululatta in Short-Term Experiments," Hydrobiologia, Vol. 59, No. 2, pp. 135 - 140, 1978.

Gophen, M. and Gold, B., "The Use of Inorganic Substances to Stimulate Gut Evacuation in Daphnia magna," Hydrobiologia, Vol. 80, pp. 43 - 45, 1981.

Griffiths, P.R.E., "Morphological and Ultrastructural Effects of Sublethal Cadmium Poisoning on Daphnia," Environmental Research, Vol. 22, pp. 277 -284, 1980.

Forstner U., Wittman G.T.W., "Metal Pollution in the Aquatic Environment," Springer-Verlag, New York, pp. 486, 1983.

Hardy, J.T., Crecelius, E.A., Cowan, C.E., and Wentsel, E.S., "Toxicity and Metal Speciation Relationships for *Daphnia magna* Exposed to Brass Powder, *Archives of Environmental Contamination and Toxicology*, Vol. 17, pp. 575 - 581, 1988.

Halter, M.T., Adams, W.J., and Johnson, H.E., "Selenium Toxicity to *Daphnia magna*, *Hyallela azteca*, and the Fathead Minnow in Hard Water," *Bulletin of Environmental Contamination and Toxicology*, Vol. 24, pp. 102 - 107, 1980.

Hartwell, I.S., Cherry, D.S., and Cairns, J.,Jr., "Avoidance Responses of Schooling Fathead Minnows (*Pimephales promelas*) to a Blend of Metals During a 9-Month Exposure," *Environmental Toxicology and, Chemistry*, Vol. 6, pp. 177 - 187, 1987.

Hartwell, I.S., Cherry, D.S. and Cairns, J., Jr., "Field Validation of Avoidance of Elevated Metals by Fathead Minnows (*Pimephales promelas*) Flowing In Situ Acclimation," *Environmental Toxicology and, Chemistry*, Vol. 6, pp. 189 - 200, 1987.

Hodson P.V., Borgmann U. and Shear H. "Toxicity of Copper to Aquatic Biota." In: Nriagu J.O. (ed) *Copper in the Environment*. Pt 2: Health Effects, John Wiley & Sons, New York, pp. 307-372, 1984.

Kaiser, K.L.E., "Correlation and Prediction of Metal Toxicity to Aquatic Biota," *Canadian Journal of Fisheries and Aquatic Science*, Vol. 37, pp. 211 - 218, 1980.

Kenage, E.E. and Moolenaar, R.J., "Fish and Daphnia Toxicity and Surrogates for Aquatic Vascular Plants and Algae," *American Chemical Society*, Vol. 13, No. 12, Dec. 1979.

Khangarot, B.S. and Rya, P.E., "Correlation Between Heavy Metal Acute Toxicity Values in *Daphnia magna* and Fish, "*Bulletin Environmental Contamination Toxicology*, Vol. 38, pp. 722 - 726, 1987.

Kwasnik, G.M., Vetter, R.J. and Atchison, G.J., "The Uptake of Manganese-54 by Green Algae (*Protococcoidal chlorella*), *Daphnia magna*, and Fathead Minnows (*Pimephales promelas*)," *Hydrobiologia*, Vol. 59, No. 3, pp. 181 - 185, 1978.

Leeuwangh, P., "Toxicity Tests with Daphnids: Its Application in the Management of Water Quality," Hydrobiologia, Vol. 59, No. 2, pp. 145 - 148, 1978.

Maki, A.W., "Correlations Between Daphnia magna and Fathead Minnow (Pimephales promelas) Chronic Toxicity Values for Several Classes of Test Substances," Journal of the Fisheries Research Board of Canada, Vol. 36, pp. 412 - 412, 1979.

Malueg, K.W., Schuytema, G.S., Gakstatter, J.H. and Krawczyk, D.F., "Toxicity of Sediments from Three Metal-Contaminated Areas," Environmental Toxicology and Chemistry, Vol. 3, pp. 279 - 291, 1984.

Olson, D.L. and Christensen, G.M., "Effects of Water Pollutants and Other Chemicals on Fish Acetylcholinesterase (in Vitro)," Environmental Research, Vol. 21, pp. 327 - 335, 1980.

Phipps, G.L. and Holcombe, G.W., "A Method for Aquatic Multiple Species Toxicant Testing: Acute Toxicity of 10 Chemicals to 5 Vertebrates and 2 Invertebrates," Environmental Pollution (Series A), Vol. 38, pp. 141 - 157, 1985.

Pickering, Q.H., "Chronic Toxicity of Hexavalent Chromium to the Fathead Minnow (Pimephales promelas)," Archives of Environmental Contamination Toxicology, Vol. 9, pp. 405 - 413, 1980.

Poston, T.M., Hanf, R.W., Jr., and Simmons, M.A., "Toxicity of Uranium to Daphnia magna," Water, Air, and Soil Pollution, Vol. 22, pp. 289 - 298, 1984.

Rabe, F.W. and Gibson, F., "The Effect of Macrophyte Removal on the Distribution of Selected Invertebrates in a Littoral Environment," Journal of Freshwater Ecology, Vol. 2, No. 4, pp. 359 - 371, April 1984.

Sanders, H.O., Hunn, J.B., Robinson-Wilson, E. and Mayer, F.L., Jr., "Toxicity of Seven Potential Polychlorinated Biphenyl Substitutes to Algae and Aquatic Invertebrates," Environmental Toxicology and Chemistry, Vol. 4, pp. 149 - 154, 1985.

Schuytema, G.S. et al., "Toxicity of Cadmium in Water and Sediment Slurries to Daphnia magna," Environmental Toxicology and Chemistry, Vol. 3, pp. 293 - 308, 1984.

Skierkowsky et al., Radiation Safety Office and School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, Oklahoma, "Evaluation of Sampling and Test Methodologies, Report of Levels of Radionuclides Present and Toxicity Testing of Sediments and Water from Robert S. Kerr Project Lands," December 1988, unpublished.

Ten Berge, W.F., "Breeding Daphnia magna," Hydrobiologia, Vol. 59, No. 2, pp. 121 - 123, 1978.

Tevlin, M.P., "An Improved Experimental Medium for Freshwater Toxicity Studies Using Daphnia magna," Water Research, Vol. 12, pp. 1027 - 1034, 1978.

Thomas, J.M. et al, 1985, Characterization of Chemical Waste Site Contamination and Determination of its Extent Using Bioassays, Environmental Toxicology and Chemistry, Vol. 5, pp. 487-501.

Ward, R.W., and DeGraeve, G.M., "Acute Residual Toxicity of Several Wastewater Disinfectants to Aquatic Life," Water Resources Bulletin, American Water Resources Association, Vol. 14, No. 3, June 1978.

Ward, R.W., Degraeve, G.M., "Residual Toxicity of Several Disinfectants in Domestic and Industrial Wastewaters," Journal of the Water Pollution Control Federation, pp. 2703 - 2722, December 1978.

United States Environmental Protection Agency, "Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms," (Third Edition), EPA/800/4-85/013, March 1985.

United States Environmental Protection Agency, "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms," EPA/800/4-85/014, December, 1985.

Van Leeuwen, et al., "Aquatic Toxicological Aspects of Dithiocarbamates and Related Compounds, I. Short-Term Toxicity Tests," Aquatic Toxicology, Vol. 7, pp. 145 - 164, 1985.

APPENDIX A

Chemical-Physical Parameter
Monitoring During Chronic Test

Table 1.1.1: Chemical Parameters for Site 1, Series 1

	1	2	3	4	5	6	7
Concentration	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Temperature	22.4	22.2	-	22.9	25.5	22.1	22.8
D.O.							
initial	7.0	7.4	7.3	7.1	7.5	7.8	7.0
final	7.3	7.6	7.1	6.9	7.7	7.1	7.3
Alkalinity	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Hardness	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Conductivity	-61.7	-72.5	-67.3	-43.0	-50.0	-35.0	-35.0

Table 1.1.2: Chemical Parameters for Site 1, Series 1

	1	2	3	4	5	6	7
Concentration	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Temperature	22.2	22.5	-	22.5	25.1	22.0	22.7
D.O.							
initial	7.2	7.4	7.3	7.2	7.5	7.8	7.3
final	7.3	7.4	6.8	7.0	7.9	7.2	7.3
Conductivity	-61.3	-65.3	-63.3	-57.0	-51.0	-45.0	-42.0

Table 1.1.3: Chemical Parameters for Site 1, Series 1

	1	2	3	4	5	6	7
Concentration	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Temperature	22.4	22.6	-	22.6	25.0	22.0	22.5
D.O.							
initial	7.2	7.5	7.2	7.2	7.2	7.8	7.3
final	7.3	7.4	7.1	7.1	7.5	7.1	7.4
7 pH							
initial	7.8	8.1	8.0	8.5	7.8	8.0	7.9
final	8.0	8.1	8.1	6.9	8.0	7.9	8.2
Conductivity	-61.7	-68.7	-62.7	-59.0	-48.0	-45.0	-43.0

Table 1.1.4: Chemical Parameters for Site 1, Series 1

	1	2	3	4	5	6	7
Concentration	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Temperature	22.4	22.6	-	22.6	24.8	22.6	22.7
D.O.							
initial	7.2	7.3	7.2	7.3	7.1	8.0	7.5
final	7.3	7.3	6.8	6.8	7.7	7.0	7.2
pH							
initial	7.9	8.0	8.0	8.3	7.9	8.3	7.9
final	8.1	8.2	8.2	6.9	8.0	8.2	8.1
Conductivity	-57.5	-60.3	-63.0	-44.0	-50.0	-52.7	-43.0

Table 1.1.5: Chemical Parameters for Site 1, Series 1

	1	2	3	4	5	6	7
Concentration	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Temperature	22.2	22.7	-	22.7	24.8	22.5	22.6
D.O.							
initial	7.1	7.4	7.1	7.1	7.2	8.1	7.5
final	7.2	7.1	7.1	6.9	7.8	7.2	7.2
pH							
initial	7.8	7.9	7.9	8.2	7.8	8.2	7.9
final	8.0	8.1	8.1	6.9	8.0	8.3	8.2
Conductivity	-55.0	-55.7	-60.3	-35.0	-47.0	-51.8	-45.0

Table 1.1.6: Chemical Parameters for Site 1, Series 1

	1	2	3	4	5	6	7
Concentration	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Temperature	22.7	23.0	-	22.7	25.4	22.5	22.7
D.O.							
initial	7.1	7.3	7.3	7.4	7.1	8.4	7.5
final	7.1	7.3	7.3	7.0	7.4	7.5	7.3
pH							
initial	7.8	7.7	8.0	8.0	7.7	8.3	7.9
final	7.9	8.1	8.2	8.1	8.0	8.1	8.2
Alkalinity	80.0	80.0	100.0	100.0	100.0	100.0	100.0
Hardness	52.0	52.0	116.0	116.0	60.0	60.0	60.0
Conductivity	-49.0	-43.0	-62.3	-31.0	-44.0	-52.2	-46.0

Table 1: Chemical Parameters for Site 1, Series 2

	1	2	3	4	5	6	7
Concentration	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Temperature	23.2	22.2	-	22.8	25.6	22.5	22.9
D.O.							
initial	7.1	7.6	7.4	7.3	7.5	7.8	7.4
final	7.5	8.0	6.9	6.9	7.5	7.3	7.6
pH							
initial	8.0	8.2	8.1	8.2	7.8	8.2	7.9
final	8.2	8.2	8.2	8.1	8.0	8.1	8.2
Alkalinity	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Hardness	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Conductivity	-61.0	-70.0	-67.3	-37.0	-49.0	-48.0	-43.0

Table 2: Chemical Parameters for Site 1, Series 2

	1	2	3	4	5	6	7
Concentration	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Temperature	22.7	22.1	-	22.5	25.2	22.5	22.7
D.O.							
initial	7.2	7.7	7.3	7.4	7.5	7.8	7.3
final	7.5	7.7	6.9	7.5	7.5	7.2	7.2
pH							
initial	7.8	8.2	8.0	8.3	7.9	8.3	7.9
final	8.1	8.2	8.1	6.9	8.1	8.1	8.1
Conductivity	-61.3	-69.7	-63.5	-43.0	-50.0	-50.6	-45.0

Table 3: Chemical Parameters for Site 1, Series 2

	1	2	3	4	5	6	7
Concentration	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Temperature	22.5	22.2	-	22.5	25.0	22.5	22.6
D.O.							
initial	7.1	7.4	7.2	7.2	7.0	7.8	7.1
final	7.4	7.4	6.9	6.8	7.6	7.2	7.2
pH							
initial	8.0	8.0	8.0	8.2	7.9	8.3	7.9
final	8.0	8.0	8.1	6.9	8.0	8.2	8.1
Conductivity	-61.3	-65.7	-63.3	-39.0	-53.0	-49.8	-45.0

Table 4: Chemical Parameters for Site 1, Series 2

	1	2	3	4	5	6	7
Concentration	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Temperature	22.3	22.5	-	22.5	24.8	22.6	22.5
D.O.							
initial	7.1	7.4	7.3	7.4	6.9	7.9	7.2
final	7.3	7.2	7.0	7.0	7.8	7.2	7.4
pH							
initial	8.0	8.0	8.0	8.1	7.9	8.2	7.9
final	8.0	8.1	8.1	6.9	8.0	7.9	8.2
Conductivity	-59.7	-64.3	-63.3	-34.0	-47.0	-49.9	-46.0

Table 5: Chemical Parameters for Site 1, Series 2

	1	2	3	4	5	6	7
Concentration	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Temperature	22.3	22.3	-	22.4	24.6	22.7	22.5
D.O.							
initial	7.1	7.6	7.3	7.1	7.0	8.1	7.4
final	-	7.7	6.7	6.9	7.7	7.0	7.4
pH							
initial	7.9	8.0	7.8	7.9	7.8	8.3	7.9
final	-	8.1	8.2	6.9	8.0	8.3	8.2
Conductivity	-54.5	-56.5	-58.5	-26.0	-45.0	-52.8	-46.0

Table 6: Chemical Parameters for Site 1, Series 2

	1	2	3	4	5	6	7
Concentration	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Temperature	22.0	22.8	-	22.4	24.9	22.5	22.6
D.O.							
initial	7.0	7.4	7.4	7.3	6.9	8.4	7.3
final	6.7	7.3	7.1	6.9	7.8	7.2	7.2
pH							
initial	7.8	7.8	8.0	8.0	7.8	8.3	7.9
final	7.8	7.9	8.2	6.9	8.2	8.3	8.2
Alkalinity	80.0	80.0	100.0	100.0	100.0	100.0	100.0
Hardness	52.0	52.0	116.0	116.0	60.0	60.0	60.0
Conductivity	-44.3	-46.3	-61.3	-27.0	-41.0	-53.9	-47.0

APPENDIX B

Raw Data for Chronic Test

Data Summary for Fathead Minnow Survival
And Teratogenicity, Site 1, Series 1

Dilution	0%	6.25%	12.5%	25%	50%	100%
Dead*	0	1	0	0	4	1
Terata	1	1	0	0	2	0
Total** Mortality	1	2	0	0	6	1
Total** Mortality %	10	18	0	0	55	9
Terata %	10	9	0	0	18	0
Hatch	100	100	100	100	64	91

Note: *-dead embryos and larvae
**-dead and deformed organisms

Data Summary for Fathead Minnow Survival
And Teratogenicity, Site 1, Series 2

Dilution	0%	6.25%	12.5%	25%	50%	100%
Dead*	1	2	0	1	1	1
Terata	1	5	2	0	3	0
Total** Mortality	2	7	2	1	4	1
Total** Mortality %	20	70	20	10	40	10
Terata %	10	50	20	0	30	0
Hatch	90	80	90	90	90	90

Note: *-dead embryos and larvae
**-dead and deformed organisms

Data Summary for Fathead Minnow Survival
And Teratogenicity, Site 1, Series 3

Dilution	0%	6.25%	12.5%	25%	50%	100%
Dead*	1	1	0	1	1	1
Terata	0	0	1	2	1	1
Total** Mortality	1	1	1	3	2	2
Total** Mortality %	10	10	10	30	20	18
Terata %	0	0	10	20	10	9
Hatch	100	100	100	100	90	91

Note: *-dead embryos and larvae
**-dead and deformed organisms

Data Summary for Fathead Minnow Survival
And Teratogenicity, Site 4, Series 1

Dilution	0%	6.25%	12.5%	25%	50%	100%
Dead*	0	0	0	0	1	2
Terata	2	2	9	10	1	1
Total** Mortality	2	2	9	10	2	3
Total** Mortality %	20	20	90	100	20	30
Terata %	20	20	90	100	10	10
Hatch	100	100	100	100	90	100

Note: *-dead embryos and larvae
**-dead and deformed organisms

Data Summary for Fathead Minnow Survival
And Teratogenicity, Site 4, Series 2

Dilution	0%	6.25%	12.5%	25%	50%	100%
Dead*	0	0	0	3	0	1
Terata	2	0	1	1	0	0
Total** Mortality	2	0	1	4	0	1
Total** Mortality %	20	0	10	40	0	10
Terata %	20	0	10	10	0	0
Hatch	100	100	100	70	100	100

Note: *-dead embryos and larvae
**-dead and deformed organisms

Data Summary for Fathead Minnow Survival
And Teratogenicity, Site 4, Series 3

Dilution	0%	6.25%	12.5%	25%	50%	100%
Dead*	1	5	1	1	0	4
Terata	1	0	2	2	3	0
Total** Mortality	2	5	3	3	3	4
Total** Mortality %	20	50	30	30	30	40
Terata %	10	0	20	20	30	0
Hatch	90	50	90	80	90	80

Note: *-dead embryos and larvae
**-dead and deformed organisms

Survival, Terata and Hatch Data for Site 1, Series 1

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	10	10	9	9	9	9	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	1	0	0	0	1
Hatch	0	2	8	10				10
6.25%								
Live	11	11	11	11	10	10	9	
Dead	0	0	0	0	1	1	0	1
Terata	0	0	0	0	0	0	1	1
Hatch	0	2	10	11				11
12.5%								
Live	10	10	10	10	10	10	10	
Dead	1	0	0	0	0	0	0	0
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	10					10
25%								
Live	10	10	10	10	10	10	10	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	10					10
50%								
Live	8	7	7	7	6	6	5	
Dead	3	1	0	0	0	0	0	4
Terata	0	0	0	0	1	0	1	2
Hatch	0	0	6	7	0			7
100%								
Live	11	11	11	10	10	10	10	
Dead	0	0	0	1	0	0	0	1
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	3	10				10

Survival, Terata and Hatch Data for Site 1, Series 2

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	9	9	9	8	8	8	8	
Dead	1	0	0	0	0	0	0	1
Terata	0	0	0	1	1	0	0	1
Hatch	0	1	8	9	9			9
6.25%								
Live	10	8	4	3	3	3	3	
Dead	0	2	0	0	0	0	0	2
Terata	0	0	4	1	1	0	0	5
Hatch	0	3	8					8
12.5%								
Live	10	10	9	9	9	9	8	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	1	0	0	0	1	2
Hatch	0	0	7	9				9
25%								
Live	10	10	9	9	9	9	9	
Dead	0	0	1	0	0	0	0	1
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	9					9
50%								
Live	9	9	8	7	6	6	6	
Dead	1	0	0	0	0	0	0	1
Terata	0	0	1	1	1	0	0	3
Hatch	0	0	8	9				9
100%								
Live	10	10	9	9	9	9	9	
Dead	0	0	1	0	0	0	0	1
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	8	9				9

Survival, Terata and Hatch Data for Site 1, Series 3

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	10	10	10	9	9	9	
Dead	0	0	0	0	1	0	0	1
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	10					10
6.25%								
Live	10	10	10	10	10	10	9	
Dead	0	0	0	0	0	0	1	1
Terata	0	0	0	0	0	0	0	0
Hatch	0	2	10					10
12.5%								
Live	10	10	10	10	10	10	9	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	0	0	1	1
Hatch	0	0	10					10
25%								
Live	10	10	9	9	7	7	7	
Dead	0	0	0	0	1	0	0	1
Terata	0	0	1	0	1	0	0	2
Hatch	0	0	10					10
50%								
Live	9	9	9	8	8	8	8	
Dead	1	0	0	0	0	0	0	1
Terata	0	0	0	1	0	0	0	1
Hatch	0	1	7	9				9
100%								
Live	11	10	10	9	9	9	9	
Dead	1	0	0	0	0	0	0	1
Terata	0	0	0	1	0	0	0	1
Hatch	0	0	7	10				10

Survival, Terata and Hatch Data for Site 4, Series 1

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	10	9	8	7	6	5	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	1	0	0	0	2
Hatch	0	3	10					10
6.25%								
Live	10	10	10	10	10	10	8	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	0	0	2	2
Hatch	0	0	6	9	10			10
12.5%								
Live	10	10	8	8	6	4	1	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	2	0	2	2	3	9
Hatch	0	3	10					10
25%								
Live	10	10	9	8	6	3	0	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	1	1	2	3	3	10
Hatch	0	0	10					10
50%								
Live	10	10	9	9	9	9	8	
Dead	0	0	1	0	0	0	0	1
Terata	0	0	0	0	0	0	1	1
Hatch	0	0	9					9
100%								
Live	10	10	10	10	8	8	7	
Dead	0	0	0	0	2	0	0	2
Terata	0	0	0	0	0	0	1	1
Hatch	0	1	10					10

Survival, Terata and Hatch Data for Site 4, Series 2

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	10	9	8	7	6	6	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	1	1	0	2
Hatch	0	0	10					10
6.25%								
Live	10	10	10	10	10	10	10	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	0	0	0	0
Hatch	0	1	7	10				10
12.5%								
Live	10	10	10	9	9	9	9	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	1	0	0	0	1
Hatch	0	3	10					10
25%								
Live	10	9	7	7	7	6	6	
Dead	0	1	2	0	0	0	0	3
Terata	0	0	0	0	0	1	0	1
Hatch	0	4	7					7
50%								
Live	10	10	10	10	10	10	10	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	0	0	0	0
Hatch	0	2	10					10
100%								
Live	10	10	10	10	9	9	9	
Dead	0	0	0	0	1	0	0	1
Terata	0	0	0	0	0	0	0	0
Hatch	0	10						10

Survival, Terata and Hatch Data for Site 4, Series 3

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	9	9	9	8	8	8	
Dead	0	1	0	0	0	0	0	1
Terata	0	0	0	0	1	0	0	1
Hatch	0	0	0	9				9
6.25%								
Live	9	9	5	5	5	5	4	
Dead	0	0	4	0	0	0	1	5
Terata	0	0	0	0	0	0	0	0
Hatch	0	3	3	3	5			5
12.5%								
Live	10	10	7	7	7	7	7	
Dead	0	0	1	0	0	0	0	1
Terata	0	0	2	0	0	0	0	2
Hatch	0	1	9					9
25%								
Live	10	10	8	8	7	7	7	
Dead	0	0	0	0	1	0	0	1
Terata	0	0	2	0	0	0	0	2
Hatch	0	1	8					8
50%								
Live	10	10	9	9	7	7	7	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	1	0	2	0	0	3
Hatch	0	2	9					9
100%								
Live	9	9	8	7	6	6	6	
Dead	1	0	1	1	1	0	0	4
Terata	0	0	0	0	0	0	0	0
Hatch	0	0	8					8

Survival, Terata and Hatch Data for Spike 1

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	10	10	10	10	8	8	
Dead	0	0	0	0	0	2	0	2
Terata	0	0	0	0	0	0	0	0
Hatch	0	3	10					10
6.25%								
Live	11	10	10	10	10	10	8	
Dead	0	1	0	0	0	0	2	3
Terata	0	0	0	0	0	0	0	0
Hatch	0	3	9	10				10
12.5%								
Live	10	10	8	8	7	7	7	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	2	0	1	0	0	3
Hatch	0	2	9	10				10
25%								
Live	9	8	8	7	0	**	**	
Dead	1	1	0	0	8	**	**	9
Terata	0	0	0	1	0	**	**	1
Hatch	0	1	7	8				8
50%								
Live	10	9	7	7	5	5	5	
Dead	0	1	2	0	2	0	0	5
Terata	0	0	0	0	0	0	0	0
Hatch	0	2	7					7
100%								
Live	0	**	**	**	**	**	**	
Dead	10	**	**	**	**	**	**	10
Terata	0	**	**	**	**	**	**	0
Hatch	0							0

Survival, Terata and Hatch Data for Spike 2

Embryo Condition	DAY 1	2	3	4	5	6	7	Sum
Control								
Live	10	10	10	10	9	9	9	
Dead	0	0	0	0	0	0	0	0
Terata	0	0	0	0	1	0	0	1
Hatch	0	4	9	9	10			10
6.25%								
Live	10	10	10	10	9	4	2	
Dead	0	0	0	0	0	5	2	7
Terata	0	0	0	0	1	0	0	1
Hatch	0	3	6	10				10
12.5%								
Live	10	10	10	10	10	5	3	
Dead	0	0	0	0	0	5	2	7
Terata	0	0	0	0	0	0	0	0
Hatch	0	4	10					10
25%								
Live	10	10	10	9	8	6	5	
Dead	0	0	0	1	0	2	0	3
Terata	0	0	0	0	1	0	1	2
Hatch	0	3	10					10
50%								
Live	10	10	10	10	8	5	4	
Dead	0	0	0	0	0	3	0	3
Terata	0	0	0	0	2	0	1	3
Hatch	0	4	10					10
100%								
Live	9	0	**	**	**	**	**	
Dead	1	9	**	**	**	**	**	10
Terata	0	0	**	**	**	**	**	0
Hatch	0	0						0

APPENDIX C

Daphnia Raw Data

Daphnia Survival Data for Site 1, Series 1

Daphnia Condition	HOUR 6	15	24	48
Control				
Live	10	10	10	10
Dead	0	0	0	0
6.25%				
Live	11	11	11	11
Dead	0	0	0	0
12.5%				
Live	10	10	10	9
Dead	0	0	0	1
25%				
Live	10	10	10	10
Dead	0	0	0	0
50%				
Live	10	10	10	10
Dead	0	0	0	0
100%				
Live	10	10	10	10
Dead	0	0	0	0

Daphnia Survival Data for Site 1, Series 2

Daphnia Condition	HOUR 6	15	24	48
6.25%				
Live	10	10	10	10
Dead	0	0	0	0
12.5%				
Live	10	10	10	8
Dead	0	0	0	2
25%				
Live	10	10	10	10
Dead	0	0	0	0
50%				
Live	10	10	10	9
Dead	0	0	0	1
100%				
Live	10	10	10	10
Dead	0	0	0	0

Daphnia Survival Data for Site 1, Series 3

Daphnia Condition	HOUR 6	15	24	48
6.25%				
Live	10	10	10	9
Dead	0	0	0	1
12.5%				
Live	10	10	10	10
Dead	0	0	0	0
25%				
Live	10	10	10	10
Dead	0	0	0	0
50%				
Live	10	9	9	5
Dead	1	0	0	4
100%				
Live	10	10	10	9
Dead	0	0	0	1

Daphnia Survival Data for Site 2, Series 1

Daphnia Condition	HOUR 6	15	24	48
Control				
Live	11	11	11	10
Dead	0	0	0	1
6.25%				
Live	10	10	10	10
Dead	0	0	0	0
12.5%				
Live	8	8	8	8
Dead	0	0	0	0
25%				
Live	11	11	11	11
Dead	0	0	0	4
50%				
Live	10	10	10	9
Dead	0	0	0	1
100%				
Live	10	10	10	10
Dead	0	0	0	0

Daphnia Survival Data for Site 2, Series 2

Daphnia Condition	HOUR 6	15	24	48
6.25%				
Live	10	10	10	10
Dead	0	0	0	0
12.5%				
Live	9	9	9	9
Dead	0	0	0	0
25%				
Live	10	8	10	8
Dead	0	0	0	2
50%				
Live	10	10	10	9
Dead	0	0	0	1
100%				
Live	10	10	10	9
Dead	0	0	0	1

Daphnia Survival Data for Site 2, Series 3

Daphnia Condition	HOUR 6	15	24	48
6.25%				
Live	10	10	10	10
Dead	0	0	0	0
12.5%				
Live	10	10	9	8
Dead	0	0	1	2
25%				
Live	10	10	10	8
Dead	0	0	0	2
50%				
Live	10	10	10	10
Dead	0	0	0	0
100%				
Live	10	10	10	9
Dead	0	0	0	1

Daphnia Survival Data for Site 4, Series 1

Daphnia Condition	HOUR 6	15	24	48
Control				
Live	10	10	10	10
Dead	0	0	0	0
6.25%				
Live	10	10	10	10
Dead	0	0	0	0
12.5%				
Live	10	10	10	9
Dead	0	0	0	1
25%				
Live	11	11	10	10
Dead	0	0	1	0
50%				
Live	10	10	10	9
Dead	0	0	0	1
100%				
Live	10	10	10	10
Dead	0	0	0	0

Daphnia Survival Data for Site 4, Series 2

Daphnia Condition	HOUR 6	15	24	48
6.25%				
Live	10	10	10	9
Dead	0	0	0	1
12.5%				
Live	10	10	10	10
Dead	0	0	0	0
25%				
Live	10	10	10	8
Dead	0	0	0	2
50%				
Live	10	10	10	10
Dead	0	0	0	0
100%				
Live	10	10	10	10
Dead	0	0	0	0

Daphnia Survival Data for Site 4, Series 3

Daphnia Condition	HOUR 6	15	24	48
6.25%				
Live	10	10	10	6
Dead	0	0	0	4
12.5%				
Live	10	10	10	9
Dead	0	0	0	1
25%				
Live	10	10	10	10
Dead	0	0	0	0
50%				
Live	10	10	10	10
Dead	0	0	0	0
100%				
Live	10	10	10	10
Dead	0	0	0	0

Daphnia Survival Data for Spike 1

Daphnia Condition	HOUR 6	15	24	48
Control				
Live	10	10	10	10
Dead	0	0	0	0
6.25%				
Live	7	1	0	0
Dead	3	9	10	10
12.5%				
Live	1	0	0	0
Dead	9	10	10	10
25%				
Live	0	0	0	0
Dead	10	10	10	10
50%				
Live	0	0	0	0
Dead	10	10	10	10
100%				
Live	0	0	0	0
Dead	10	10	10	10

Daphnia Survival Data for Spike 2

Daphnia Condition	HOUR 6	15	24	48
Control				
Live	**	5	5	4
Dead	**	0	0	1
6.25%				
Live	**	5	5	5
Dead	**	0	0	0
12.5%				
Live	**	5	5	0
Dead	**	0	0	5
25%				
Live	**	4	4	0
Dead	**	1	1	5
50%				
Live	**	0	0	0
Dead	**	5	5	5
100%				
Live	**	0	0	0
Dead	**	5	5	5

Parameter
Monitoring During Chronic Test