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*The Comparative Uptake and
Interaction of Several Radionuclides
in the Trophic Levels Surrounding the
Los Alamos Meson Physics Facility
(LAMPF) Waste Water Ponds*

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ABSTRACT

A study was undertaken to examine the uptake, distribution, and interaction of five activation products (Co-57, Be-7, Cs-134, Rb-83, and Mn-54) within the biotic and abiotic components surrounding the waste treatment lagoons of the Los Alamos Meson Physics Facility (LAMPF). The study attempted to ascertain where, and what specific interactions were taking place among the isotopes and the biotic/abiotic components. A statistical approach, utilizing Multivariate Analysis of Variance (MANOVA), was conducted testing the radioisotopic concentrations by 1) the trophic levels (TROPLVL) in each position sampled on the grid, 2) where sampled on the grid (TRAN), 3) where sampled with-in each grid line (PLOT), and 4) the side with which sampled (SIDE). This provided both the dependent and independent variables that would be tested. The Null Hypothesis (Ho) tested the difference in the mean values of the isotopes within/between each of the four independent variables.

The Rb-83 statistic indicated an accumulation within the TRAN and PLOT variables within the sampled area. The Co-57 test statistic provided a value which indicated that accumulation of this isotope within TROPLVL was taking place. Mn-54 test values indicated that accumulation was also taking place at the higher trophic levels within the PLOT, TRAN, and SIDE positions. Cs-134 was found to accumulate to third level in this trophic level structure (TROPLVL - (vegetation), and then decrease from there. The Be-7 component provided no variance from known compartmental transfers.

Many factors, such as soil moisture, cation exchange capacity, percent organic matter, nutrient percent in the soil, and the interaction of the radioisotopes, are most probably the cause for the results with which have been found in this study.

INTRODUCTION

During the last three decades, the use and development of nuclear power reactors, linear accelerators, cyclotrons, and other systems associated with the "nuclear cycle" have increased dramatically. These systems have provided the scientific community with a significant amount of information and benefits, many that are only now beginning to be utilized. Unfortunately, along with positive comes negative; the problem of waste generated from these systems, radioactive waste in particular. What do we do with it? In the past, it seemed not to be a concern. There became an increased public awareness as to the placement of waste repositories and the handling of these wastes. With the increased interest of chemists and biologists (radiobiologists and ecologists) in the physical and biochemical behavior of such materials in the environment, and the passage of legislation, such as the National Environmental Policy Act in 1969 to regulate such activities, there has been a substantial increase in research and funding of projects associated with "radioactive" pollution (Bustad, 1960; Kitchings et al., 1976).

Interest in these pollutants arose as a result of the above ground nuclear testing programs of the early 50's and 60's. Approximately 200 isotopes of some 35 elements were identified from these tests (Reichle et al., 1970). Of these, a few of the fission products seemed to spark special interest. Among those were Cs-137, Sr-90, I-131, and H-3. These isotopes were of particular concern because of their relatively long half-life, abundance and availability in the environment as a direct result of the nuclear tests, and their toxicity and behavior in biological systems. As a result, these particular isotopes have become extremely well characterized and seem to be reasonably well understood within the scientific community.

As science, and its associated programs move forward, so does the problem involved with its wastes. Of more recent concern are those isotopes produced as a product of nuclear activation processes (as opposed to fission processes). These isotopes are most commonly produced when a neutron from a high energy source (such as a linear accelerator) "hits" a stable element, causing that element to take on an excited state, resulting in the emission of an energy of a characteristic wavelength. Examples of activation products include Co-57, Mn-54, Rb-83, and Be-7. These provide new sources of interest because a great number of these activation products are proving to be important in many of the biological systems associated with (and including) man (ie., carbon, zinc, and phosphorus). Because many of these isotopes rarely have been seen before, much less studied, their behavior in the environment is not well understood.

Our interest to study and understand the fate of these isotopes will provide us with the understanding of the uptake and turnover of radionuclides through the various biological processes occurring in organisms. Once these particular systems are better understood, the scientific community may develop better models for assessing the ecological consequences of radionuclides in nature. The response of biological systems (including man) to radioactivity may then be accurately and precisely predicted.

The study here has examined the uptake, distribution, and interaction of five activation products (Co-57, Be-7, Cs-134, Rb-83, and Mn-54) in abiotic and biotic ecosystem components surrounding the waste-water ponds of the Los Alamos Meson Physics Facility (LAMPF). A preliminary study conducted during the summer of 1981 provided sufficient information to initiate this study.

Figure 1 suggests the appearance of how the trophic level exchange might be defined around the ponds and the overflow stream. The primary goal of this study was to determine the quantity and distribution of the radionuclides produced, with

a statistical investigation into the bioenvironmental pathways and their interactions. Final measures that might be undertaken at the ponds and overflow stream concerning proactive action to decrease, or eliminate the possibility of "external" contamination is also discussed.

Essentially, the study attempted to answer two questions. First, and more important, was the question concerning the direction in which the radionuclides were travelling. In what amounts, where, and what were the specific interactions among the isotope/matrices and isotope/isotope components.? The other concern addressed the question of the whether or not any abiotic/biotic systems in and around the ponds (streams) could act as a biological sink for any of the radionuclides produced as a result of the Los Alamos Meson Physics Facility operations. The study addresses these questions while providing suggestions on future studies for the waste-water ponds and outflow stream.

Figure 1. Predicted Pathway of Contaminants Around the Waste-Water Ponds

LITERATURE REVIEW

COBALT

Cobalt, with its strong propensity for variation, solubility and tendency to form complexes within varying matrices (Bate and Leddicotte, 1961) can provide a variety of concentrations in the environment.

In the aqueous environment, Vanderploeg et al. (1975) suggested that soluble cobalt in eutrophic conditions was less likely to be available than soluble cobalt in oligotrophic or mesotrophic environments. This was a result of the tendency of cobalt to chelate, or form other associations with the dissolved organic matter. If this is true, then there should exist a strong tendency for extensive accumulation rates in eutrophic bodies of water. This has been shown by Norris (1958), where concentration factors of plankton from water after 6 weeks was found to be 100,000 times the original concentration. Similar results showing cobalt accumulation in water can be found in studies by Lowman (1961), Reichle et al. (1970), Harvey (1970), Copeland and Ayers (1972), Polikarpov (1966), Rice (1961), Lerman (1972), and Davis et al. (1958).

The role of cobalt in terrestrial ecosystems is equally varied. After the fraction of cobalt is removed by varying complexing stages in the trophic level exchange routes, there still remains a significant portion available to the other components in the ecosystem.

Much of the future transfer will depend to a great extent on the condition of the soil. Since it is the medium in which the liquid phase will travel before being exposed to the next trophic level, this particular medium can drastically alter the way in which cobalt will be transferred. This transfer can depend on such soil properties as pH, soil moisture, clay content, percent organics in the

soil, solubility, valence state, concentration, and whether there is a steady state interaction present (Eisenbud, 1973; Garner, 1972; Lerman, 1972). These factors affect how long cobalt remains in the immediate environment, and the extent to which the next trophic level will be exposed. Eisenbud (1973) believed the greatest factor affecting penetration into the soil was the elemental valence. He believed that a divalent cation will be bound more tightly than monovalent cations. Other factors also affecting uptake were found by Broseus (1970). He found that in areas having high soil moisture and abundant soil potassium, the Co-60 introduced by fallout was more readily available than otherwise noted in foliar uptake analysis. Eisenbud (1973) noted that cation exchange capacities also alter the uptake in soils. Soils with high cation exchange capacities ($CEC > 100 \text{ meq}/100\text{g}$) will "hold" an element significantly longer than those sandy soils possessing CEC values as low as $10 \text{ meq}/100 \text{ g}$.

Cobalt is a micronutrient that, in minute amounts, is important for the normal metabolism of most living organisms. It has been found to aid in the accumulation of chlorophyll in the leaves of some higher plants (Solovera and Makorova, 1961). Because foliar absorption is an important transfer process of cobalt (Garner, 1972; Russel, 1965; Gifford and Pack, 1966), the direct absorption of cobalt (as a fallout product) could improve the physiological well-being of the plants that require it.

Menzel (1965) has described cobalt as an element that is "not concentrated" in the uptake between soils and plants. He described cobalt as an element that after the addition to the soil, is neither more or less concentrated in the plant than in the soil. He suggests that cobalt is either more strongly adsorbed on soil materials, or has a less soluble hydroxide. Similar results examining the transfer of cobalt were seen in the analysis of the Sedan thermonuclear cratering

event (Romney et al., 1967). In a study conducted by Nishita et al. (1966), he found that they could detect cobalt in the soil, but not in plant material. Menzel (1965) concluded that the concentration factor for cobalt in the soil-plant regime was 0.1 to 10. Results in the previous studies indicate that differences in the chemical state of the element or soil type can be the cause of the variations in the cobalt levels. These differences were noted in a study examining the cobalt concentrations in aquatic vascular plants and floating leaf species (Vanderploeg et al., 1975).

Reichle et al. (1970) found that cobalt progressively decreased in concentration through invertebrate food chains. Elemental concentrations of the invertebrates generally averaged half that of the plants after two trophic exchanges. Cobalt was found to have a relatively slow biological turnover in both terrestrial and aquatic invertebrate organism, contributing to a high bioaccumulation factor.

In aquatic vertebrate organisms, Vanderploeg et al. (1975) found that the bioaccumulation of cobalt in fish was very low. In terrestrial systems, the concentration factors were also very low. Cobalt is found to be poorly assimilated by mammalian species (Kitchings et al., 1976). Abrunina (1963a) found the retention and distribution of oral doses in the rat and domestic rabbit to be highest in the liver (Figure 2). This was followed by the kidneys, pancreas, and suprarenals. The skeletal muscles, nervous system, bones, skin, and fat exhibited lower specific activities. The conclusion was that 17-30 percent of the administered dose was absorbed into the intestine. The remaining cobalt was excreted in approximately one week.

Abrunina (1963b) examined cobalt accumulation in rats and rabbits after a series of daily oral doses. The concentration in the body could be found at a maximum level in 1-2 days after the initial administration. After

FRACTION OF Co^{60} IN THE URINE AND FECES
AFTER SINGLE ORAL DOSE (ABRUNINA, 1963)

Figure 2. Cobalt Assimilation in Rats and Rabbits

termination of dose administration, excretion fell to negligible levels within one week. Abrunina believed that the excretion rates were dependent upon the speed at which absorption took place and the percentage absorbed, as well as the duration that the cobalt remained in the gastrointestinal tract. Abrunina concluded that cobalt assimilation was dependent upon an entire series of physicochemical and physiological factors.

Halford et al. (1979) initiated a study that examined the body burdens and accumulation rates of a variety of isotopes in a group of mallard ducks inhabiting a radioactive waste disposal pond. Overall concentrations were highest in the gut, followed by feathers, liver, and muscle. Muscle tissue was found to have substantially lower concentrations than any other tissue. After termination of dosage, nearly all the mallards showed a rapid drop in fecal concentrations from days 1 through 10. The initial rapid decline in fecal concentrations suggested rapid elimination from the gut, as well as other tissues into the gut. They found the most dramatic feces decline with cobalt-58 and cobalt-60. These particular radionuclides had the highest initial gut concentrations because they were poorly assimilated. This rapid decline in fecal activities suggested a relatively short biological half-life.

In another study by Halford et al. (1981) concerning mallards, it was found that cobalt was highly concentrated in the liver as compared to tissues other than the gut. Total muscle concentration accounted for only 13% of the total activity. Cobalt was also found in the feathers, but levels found here were believed to be caused by the direct adsorption of radionuclides from the pond water. Again, the conclusion was that cobalt was rapidly eliminated, with little absorption into the mallard's system. They also suggested that the elimination of cobalt proceeded at an even faster pace during the migration period of the mallards, when the metabolic and physiological processes were at their

peak. Willard (1960) found that the heart and lung had the highest concentration of cobalt in several small mammalian species trapped from a waste-disposal seep area.

BERYLLIUM

Beryllium has a strong tendency to form insoluble species in aqueous solutions at a pH of 7. Because of this, natural environmental waters rarely contain beryllium in any significant concentration levels. Consequently, analysis for beryllium in environmental waters is made only infrequently, and the current literature is deficient in such data. In highly acidic or basic waste streams where beryllium is actively dumped, concentrations may reach greater levels than in neutral waters (Fairhall, 1960).

Romney and Childress (1965) found that beryllium-7 is strongly adsorbed by test soils containing extremely high fractions of bentonite. They found that Be-7 taken up by bentonite is not replaced by magnesium, barium, or calcium, even though these elements are found in high concentrations. Beryllium is known to be held tightly in the soil matrix. It easily complexes with various other compounds in solution. This implies that very little can be transferred across the food chain. In aquatic systems, it was found to concentrate in magnesium-deficient Chlorella pyrenoidosa at extremely high pH values (Hoagland, 1952). These results were difficult to interpret because others had found beryllium to be highly toxic to other life forms (Romney and Childress, 1965; Dubois et al., 1949; Romney et al., 1961). Hoagland (1952) found toxicity to be a problem in specific aquatic organisms only when the pH was extremely high and the organisms were manganese deficient. Fairhall (1960) found that beryllium was extremely toxic to algae when the pH was below 7, regardless of the magnesium levels in the organism. In typical

situations where the pH was normal, magnesium and other metal concentrations were normal, beryllium inhibited the growth of aquatic microorganisms.

The literature concerning the transport of beryllium from soils to plants is limited. Results showed both the beneficial and detrimental effects. Maze and Maze (1939) found that small amounts of a beryllium salt added to a nutrient solution had slightly beneficial actions upon the growth of corn in a liquid medium. They found on several occasions what seemed to be growth stimulation in bean seedlings from low levels of beryllium in the soil and nutrient solution. Hoagland (1952) studied the effects of beryllium when added to the soil of tomatoes. He found an increase in growth of the young plants when the pH was high (>9) and the magnesium concentration was low. Typically however, beryllium is known for its inhibitory action upon growing plants. Whether the addition of beryllium leads to severe root damage, darkening of the leaves, or stunted growth, it is considered harmful for plant growth.

In a study by Romney and Childress (1965) concerning the uptake of beryllium-7 in various plants (beans, barley, sunflowers, and tomato plants), they found that over 95% of the radioactivity was found in the roots of each species. Very little beryllium-7 was translocated to the foliage as compared to the roots. The leaves of the bean and barley plants showed higher levels of beryllium-7 than did the stems. The beryllium content was lowest in the fruit tissue. Oustrin et al. (1967) found that in maize supplemented with beryllium sulfate, the highest concentration of beryllium was found in the reproductive apparatus. Bingham and Stencek (1972) reported that 46% of beryllium-7 applied to the leaves was absorbed, and, of that amount, 4% was transported out of the leaves, presumably through the phloem. They found the mobility of this element to be similar to that of the other alkaline earth elements. Nikonova (1971)

considered pine, birch, aspen, and willow as the best indicators for vegetative accumulation of soil beryllium.

Beryllium concentration factors for the soil-plant regime vary. Menzel (1965) found that beryllium was concentrated by a factor of 0.1 to 1.0. He considered this element slightly excluded in normal metabolic uptake because of the possible chelation or fixation in the soil matrix. Drury et al. (1978) found no data suggesting that beryllium was actively eliminated from living plant material. They suggested that beryllium was being strongly concentrated in some parts of the plant.

Beryllium can adversely affect other physiological and morphological systems in plants. Romney and Childress (1965) found that increased levels of beryllium in nutrient solutions progressively increased the plant uptake of phosphorous, while decreasing plant uptake of calcium. In some studies, magnesium uptake was found to be reduced by high levels of beryllium. This effect, however, was found to be more apparent in the root tissue than in the foliage. Plant uptake of iron, manganese, potassium, and sodium was not influenced to any extent by the beryllium treatments. Other studies by Romney and Childress have shown that beryllium has effectively displaced calcium, magnesium, and strontium from the various absorption sites, allowing for differential uptake.

How beryllium affects upper trophic levels depends upon the organism involved. In aquatic vertebrates, the uptake varies with the concentration of beryllium in the surrounding water, length of exposure, and the hardness of the water. Hard-water levels were found to increase the antagonism of calcium to beryllium (Slonim, 1973), while soft water allowed beryllium to penetrate the vital organs more easily. Highest concentrations of beryllium were found in the gastrointestinal tract, followed by the kidneys and ovaries (Slonim and Damm, 1972).

Avian population studies concerning beryllium distribution are very limited. This is probably due to the lack of beryllium (stable or radioactive) in the natural environment. One study by Baker et al. (1976) found no beryllium in the liver, muscle, or brain tissue of seven species of waterfowl sampled in New York state.

In mammals, few studies have been conducted involving the uptake, distribution, and interaction within the body's systems. Mullen et al. (1972) investigated the uptake and distribution of beryllium-7 in dairy cattle. The results indicated that the liver, kidney, and skeleton were sites of greatest concentration. They found that beryllium-7 was rapidly excreted in the feces, urine, and milk within the first 83 hours. Feces contained over 90% of the excreted beryllium, while milk contained less than 0.002%.

Crowley et al. (1949) studied the distribution of beryllium-7 in the rat after oral uptake. They found that adsorption of Be-7 occurred in the digestive tract after oral administration. On the basis of the amount of beryllium taken in, it was estimated that if any absorption took place, it was less than 0.2% of the total administered dose.

In a study concerning rats and beryllium injections (Scott et al., 1950), the authors noted the difference in uptake of radioberyllium with the addition of a chemical carrier. They found that the excretion of beryllium-7 with the carrier was twice as great as without. The greatest elimination occurred in the first day after administration. They concluded that beryllium-7 was found to adsorb to the walls of the gastrointestinal tract to a significant degree. Many of the differences seen were a result of low solubility of beryllium at the pH of the normal body fluids. The difference in elimination rates result from the carrier allowing a more rapid mobilization of the element from the liver, spleen, and bone marrow, with even slower movement from the bone.

Beryllium in animals can interact and antagonize other chemical systems in the body. DuBois et al. (1949) were concerned with the effects of beryllium on calcium and magnesium, two chemical congeners. They suggested that beryllium might interfere with the biological functions of calcium and magnesium. Preliminary investigations showed how beryllium acted on adenosine triphosphatase activity, which is important for the activity of all biological tissues. Other results demonstrated the pronounced inhibitory action of beryllium on magnesium-activated phosphatases. This inhibition probably resulted from the competition with magnesium and calcium for the same site on the enzyme with which they interacted. The results show that beryllium interferes with biological reactions in which magnesium and calcium participate. Magnesium-activated reactions appear to be more sensitive to beryllium than calcium-activated reactions.

RUBIDIUM

Literature involving the uptake, assimilation, or concentration of rubidium in aquatic ecosystems is limited. One study showed that algae accumulated rubidium from the surrounding environment (Scott and Hayward, 1954.) Reichle et al. (1970) found that rubidium (a potassium analogue) concentrated in aquatic animals from the surrounding water.

Rubidium transfer from the aqueous medium to the soil-plant regime has been studied by Fried et al. (1959). They found that the rubidium concentration in the plant was in direct relation to the rubidium/potassium ratio in the substrate. If the concentration varied in either element, the ratio taken up in the plant would also change. Chemically, since potassium and rubidium are elements that are competitive for the same sites on the roots, the added potassium could reduce the rubidium uptake.

In a study concerning the competitive uptake of rubidium and other elements on plants, and how those amounts of exchangeable potassium affected these rates, Menzel (1954) found that uptake was proportional to the concentration in the substrate. The analysis showed that rubidium uptake was more closely related to the available potassium content of the soil rather than the exchangeable potassium (bound versus unbound). Uptake of rubidium in plants is inversely proportional to the available soil potassium.

Rubidium transfer between soil and plants was significant. Menzel (1965) found that rubidium was concentrated from 10 to 1,000 times from soil to plants. This may have resulted from plant tissues acting as ion exchangers, exhibiting selectivity or preference for rubidium over sodium. He found highly concentrated regions in the cell nuclei and rapidly dividing plant tissue (tips of roots, root stems, and root branches).

Menzel and Heald (1955) conducted a study to determine the distribution of alkali metals in plants grown in a variety of nutrient solutions. Rubidium concentrated in the flowers, young leaves, and roots. They found that rubidium and potassium were absorbed by many different plants (millet, oats, sweet clover, and sunflowers) at 0.85 times their concentrations in the nutrient medium.

Because rubidium is an analogue of potassium, its relevance in the physiological systems of animals has long been recognized. Clark (1922) showed that rubidium could be substituted for potassium in the regular maintenance of the physiological activity of various isolated organs. Relman et al. (1957) demonstrated that more than half of the muscle potassium was replaced by rubidium when rubidium was fed together with potassium in young rats. Their results suggest that alkali metals accumulate in the muscle cells in the decreasing order of preference of potassium, rubidium, and cesium.

In a study involving the retention and excretion of rubidium, Richmond (1958) found that the muscle, skin, liver, and gastrointestinal tract had the highest concentrations of rubidium. The muscle mass contained almost two-thirds of the entire body activity, while only four percent remained in the skeletal mass. The testes, brain, and plasma contained peak rubidium concentrations sometime between 1 and 5 days, while other tissues reached their maximum concentration within the first 24 hours after administration. Rubidium found in the muscle was found to be completely absorbed (98-100%) from the gastrointestinal tract. Similar results were found by Hamilton (1948) and Reichle et al. (1970).

Kilpatrick et al. (1956) found rubidium to be concentrated in the liver, kidney, intestine, heart and spleen, while lower concentrations were observed in the brain, bone, and urine. This follows previous results found by Reichle et al. (1970) showing the distribution of short biological half-life isotopes in soft tissues.

Rubidium concentrations in mammals are not static but dependent upon several variables. Mraz and Patrick (1957a) found that diet played an important part in the retention and excretion of rubidium in rats. If no suitable medium (food) was present in the gut to absorb or remove rubidium via the gastrointestinal tract, it would then be reabsorbed by the body and passed either to the kidneys or recycled through the body, eventually reaching the gut again.

While Mraz and Patrick (1957b) suggested the importance of rubidium in the concentration of dietary potassium, Relman et al. (1957) found that the muscle tissues accumulated rubidium in concentrations ranging from 20 to 60 percent higher than potassium. Follis (1943) concluded that the role of rubidium in the normal physiological processes is not yet clear.

CESIUM

Cesium belongs to the alkali metals group. Its actions in several physiological processes are grossly analogous to potassium and calcium metabolism (Finston and Kinsley, 1961). In solution, cesium, like all alkali metals, exists primarily as a free ion and does not form inorganic complexes. Because it is strongly adsorbed by suspended particulates, especially clays, these materials may remove the element from the surrounding solution to varying degrees. In freshwater ecosystems, the fraction of cesium in water in the suspended phase is found to range between 19 and 92 percent, while this value appears to be correlated with the concentration of suspended solids (Vanderploeg et al. 1975). The food web accumulates cesium from both the aqueous medium (or substrate) and particulates and bottom sediments. Filter feeders are known to accumulate cesium adsorbed to particulate matter, while benthic invertebrates obtain cesium fixed to ingested bottom sediments. Trout were found to accumulate cesium adsorbed to clay particles. Absorption efficiencies from ingested clay vary with the clay type: 8% for illite, 65% for kaolinite, and 85% for montmorillonite (Eyman and Kitchings, 1974).

Cesium cycles can be altered by seasonal cycles as well as by clay fractions. Alberts et al. (1979) found cesium concentrations closely followed the annual cycle of thermal stratification of a variety of ponds, indicating that intense anoxic conditions may have been a central factor in cesium cycling. They concluded that the cesium concentrations in the water column were coincident with the dissolution of ferric oxides. The cesium was returned to the sediments when mixing introduced oxygen into the water column, which they believed caused reprecipitation of the hydrated ferric oxides, which in turn carried the complexed cesium back to the sediment.

Algae accumulate cesium from the soluble phase. Williams and Swanson

(1958) found that in ponds with high levels of dissolved cesium, two species of algae (Euglena sp. and Chlorella sp.) bioaccumulated cesium to levels of 96 and 47%, respectively. Algae also have a great affinity for cesium even when dead. The authors concluded that the structural components that persist in dead chlorella will adsorb cesium from very dilute solutions.

King (1964) was interested in aquatic transfer among benthic invertebrates and found that variation in cesium concentrations had no apparent effect upon the uptake of cesium by Chlamydomonas, while Daphnia pulex concentrations varied greatly. Vanderploeg et al. (1975) found that in aquatic systems, absorption efficiencies of cesium from food were high. If potassium levels within the predators and prey were equal, the cesium bioaccumulation factor increased by a factor of three with each successive trophic level. Gertz (1973), Williams (1970), and Watts and Harvey (1963) are other studies concerned with aquatic cesium concentrations.

Cesium was readily absorbed in all four soils that Essington et al. (1981) tested. The high degree of sorption and the known positive charge of Cs-137 ions strongly suggest that cation exchange is the principal mechanism for retention of cesium in the soil. Other reactions, such as precipitation cannot be discounted, although precipitation is not probable in view of the high degree of solubility of common cesium salts. The presence of complexing ligands in the soil, such as organic chelating agents, should solubilize some part of the insoluble cesium fraction and thus complex the soluble radionuclides, creating nonsorbable species. In all soils, they found the degree of removal to range from 96 to 100 percent, with the most probable removal mechanism being primary cation exchange.

The variability of cesium sorption by different soils was demonstrated in a study by Spitsyn et al. (1958). They compared the adsorption charact-

eristics of several soils, and found that sand removed 50 percent of the available cesium, while sandy loams and clays effectively removed 90 percent. Other factors also affect cesium availability. Amphlett and McDonald (1956) found that soil exchange capacity for cesium is constant above a pH of 3.5, while it decreases rapidly below this value. Evans (1958) reported that cesium in highly acidic wastes is quickly fixed in the soil.

Vegetative cesium uptake can be altered by the strong sorptive forces between cesium ions and the soil particles (Dunham, 1958). Since only a small fraction of soil-adsorbed cesium is available to the plants, there can be a discrimination among the cesium transfer from soil to plant. Cummings et al. (1969) found that soils with low cation exchange capacities (CEC) allowed a greater transfer of cesium to plants. Fredricksson et al. (1958) also found that cesium uptake could be significantly increased by the addition of a stable cesium carrier to the soil. Magnesium concentrations in the top six inches, the pH, various morphological variations within plants, the length of time the radioisotopes were in the soil matrix, and the age of the plant (Shanks and DeSelm, 1961; Arthur, 1982, and Cline, 1981) are also important factors in cesium uptake.

Distribution of cesium within the plant varies with the species. If cesium is available during the active reproductive stage, it becomes concentrated in the leaves and flowers (Neels et al., 1953, Auerbach and Crossley, 1958), while smaller amounts are found in the seeds (Davis, 1961). Trace amounts of cesium are also readily assimilated through direct foliar absorption. Middleton (1958) demonstrated that when soluble carrier-free cesium was sprayed on various species of plants, it entered the veins and readily moved to other parts of the plant. Other investigators have noted the speed at which cesium is translocated within the plant (Klechkovsky and Gulyakin, 1958).

Cesium cycling in white-oak forests was studied by Witherspoon (1961). He found that translocation of cesium in the trees was very rapid, with about one third of the original activity reaching the leaves. During the summer, an average of 63 percent reduction in leaf radiocesium content was observed. Of this decrease, it was estimated that 13 percent was leached out by rain, 50 percent returned to the woody tissue, and 37 percent was left in the leaves to fall as litter during the winter. Similar results have been found by Adriano et al. (1981).

Arthropods have proven to be an important indicator of radiocesium contamination (Crossley and Howden, 1961). The authors found cesium concentrations in the arthropods of 70% of the host plant. Cesium concentrations in predacious insects were equivalent to the herbivorous species.

Willard (1960) examined passerine birds in association with a waste disposal area. He found significant amounts of contamination within the species inhabiting the area nearest the disposal area. Brisbin et al. (1982) investigated coots utilizing waste disposal ponds, and found radiocesium contamination. Brisbin et al. (1972) studied the varying degrees of contamination in waterfowl inhabiting a reactor cooling pond. They suggested that variables such as body weight and age, body condition (fatty deposits), and sex can vary the level of contamination.

In a study of contamination in waterfowl inhabiting a radioactive waste area, Halford et al. (1982) found the radiocesium activity received by the waterfowl to be quite varied. From the several species sampled, cesium was found to be readily absorbed from the gut into the muscle. Species with the maximum internal concentrations were the American coot. It is suggested that the higher levels of radiocesium are directly related to the fact that the coot is a diving bird, one that is readily exposed to the sediments. Halford et al.

(1980) suggested in an earlier study of these same ponds that cesium elimination in the mallard was a direct function of the body weight or metabolic rate. They believed that the biological pathways followed by radiocesium could be comparable to other bird species because biological elimination is a basic metabolic process associated with the mineral nutrition of the organism (Reichle et al., 1970).

Orally administered cesium, like potassium, is readily absorbed. One hundred percent absorption of orally administered cesium in rats was reported by Hamilton (1947). When administered orally, cesium is initially and rapidly concentrated in the blood. It soon thereafter leaves the blood and accumulates in other tissues, or is excreted (Davis, 1961).

Relman (1956) found that cesium-134 is mainly concentrated in the muscle of the rat, although it is to some extent distributed throughout all tissues, including bone. Other investigators have reported that muscle is the largest storehouse for radiocesium (Hood and Comar, 1953; Ballou and Thompson, 1957). Richmond (1958) found muscle, skin, gastrointestinal tract, intestinal tract, and liver to be the sites of greatest cesium concentrations immediately after oral administration. The muscle mass contained about 80 percent of the total body burden at 5, 12, and 20 days after administration. Ballou and Thompson (1957) reported that 90 percent of the cesium body burden was in muscle 30 days after administration. Weeks and Oakley (1955) found that rats showed an extreme retention of cesium in the body and the various metabolic processes.

Varied retention times of radiocesium have been found to be a result of a differential or preferential uptake and excretion by various organs. A group from the University of Tennessee (1955) suggested that cesium is bound in different ways by tissues such as the muscle, liver, and kidneys. Hood and Comar (1953) found that younger animals accumulated cesium more readily

than older animals. This was demonstrated by comparing the cesium uptake of one-month old and mature rats. Mraz and Patrick (1957a) also found that a dietary potassium deficiency decreased both urinary and fecal excretion of cesium and potassium. Supplemental potassium was also found to reduce cesium retention in tissues (Wasserman and Comar, 1961).

Retention and excretion studies in cattle, deer, and sheep given cesium-137 orally had shown that ruminants retained less of the nuclide and had a higher fecal to urinary excretion ratio than non-ruminants. The higher excretion ratio is due to the different foods that are ingested. Ruminants usually utilize food materials of a highly absorptive nature (alfalfa, hay), which provides a path which radiocesium follows (Mraz and Patrick, 1957).

The exact location of cesium deposition in the mule deer was investigated by Hakonson and Whicker (1971). They found that 80 percent of the total radio-cesium body burdens were located in the skeletal muscles, while very little accumulated in the bone. In another study (Hakonson and Whicker, 1969), the authors concluded that cesium was readily absorbed and incorporated into the tissue of deer. However, the acute dose was rapidly excreted, therefore posing no long-term biological hazard.

Because of cesium's tendency to remain in the tissues of higher order mammals, trophic level bioaccumulation can be found (Reichle et al., 1970). Nine-fold increases in concentrations of cesium-137 through the plant-mule deer-cougar food chains were noted (Pendleton et al., 1964, 1965). The authors found an increase of three-fold or better between the cesium-137 levels in deer flesh and cougar flesh. These values were in good agreement with the 3-4 level increase that was found in Andersons et al. (1957) study. Hanson (1971) also noted an increase by about a factor of 2 at each successive link in the lichen-

caribou-wolf chain. Auerbach (1965) found that mammals concentrate radiocesium to a higher degree than birds.

Because of the ability of deer to so actively accumulate cesium from the environment, Auerbach et al. (1960) also indicated that these mammals could act as sensitive indicators to environmental contamination of radiocesium.

MANGANESE

The behavior of radioactive isotopes of manganese usually depends upon the valence state of the manganese and the chemical compounds which are produced. These factors determine the probable path of manganese through the biosphere (Wangersky, 1961). Its abundance in environmental samples varies from a few parts per billion to over one percent. Manganese is usually more abundant in plant than animal tissue (Schuman, 1971; Hay, 1967).

In lakes and ponds, most of the manganese in the particulate phase is probably MnO_2 (Marshall and LeRoy, 1973). Dissolved manganese can be bound to organics because Mn (II) would probably oxidize to Mn (IV) in aerobic conditions (Wangersky, 1961). Physicochemical forms can also affect biological availability (Gibbs, 1973).

Field studies have shown that manganese is bioaccumulated by most aquatic organisms to levels above that of the ambient concentrations found in the surrounding water. Concentration factors in aquatic organisms show great variability, but are usually on the order of 10^2 to 10^4 in filter-feeding invertebrates, and somewhat lower (10^1 to 10^3) in fish. In aquatic systems, manganese is accumulated in most consumer organisms from food, rather than through water itself. Concentrations are found to be higher in macrophytic plants and primary consumers than in secondary or tertiary consumers (Cherry and Guthrie, 1977; Kwasnik et.

al., 1978). All aquatic organisms accumulate manganese above normal dissolved concentrations in water. This level is usually less than 100 $\mu\text{g/l}$.

Uptake of manganese also is regulated to some degree by most aquatic organisms. Williams and Murdock (1969) reported that uptake of manganese is greater in dead marsh grass than in living plants. Manganese concentrations are increasingly regulated at higher manganese levels. Other studies at artificially elevated concentrations of manganese have shown that bioaccumulation factors decrease as exposure concentrations increase. Guthrie et al. (1979), in a study comparing manganese concentrations in oysters of varying degrees of polluted waters, found lower concentrations of Mn in oysters in polluted embayments than those areas designated as clean.

Studies of tissue distribution in aquatic organisms indicate that manganese residues are generally higher in the internal organs than in the shells of mollusks (Brooks and Rumsby, 1965). Merlini et al. (1965) have found that manganese concentrations in both the shell and soft tissue increase with the size of the bivalves. After examining freshwater clams in an Italian lake, Merlini (1966) found that, because of the lack of metabolic turnover of incorporated radioactive trace elements, the freshwater clam served as an excellent biological indicator for radiomanganese.

Radiomanganese transfer through the water-soil-plant regime is dependent upon several factors. The availability of manganese to plants is dependent upon many soil factors, including the concentration of totally or easily reducible manganese, pH, concentrations of other cations, anions, total salts, cation-exchange capacities, organic matter content, drainage, degree of soil compaction, and microbial activity (Foy, 1973). Abundant evidence suggests that plants absorb manganese primarily in the divalent state (Adams and Pearson, 1967; Wangersky, 1961). If manganese is in the trivalent state, it can be made available through

simple bacterial degradation. Uptake can also be significantly influenced by the pH of the medium. Lowering the pH favors the reduction of manganese to the divalent state and thereby increases the solubility and availability to plants (Collins and Buol, 1970). Heavy fertilization of acid soils with materials containing a high concentration of certain anions, such as chlorides, nitrates, or sulfates, may increase manganese uptake (Lockman, 1970; Parker et al., 1969). Manganese uptake can be decreased by high concentrations of calcium, magnesium, ammonium ions, iron, or other competing cations in the aqueous medium (Vlams and Williams, 1962). Menzel (1965) believed that pH was the greatest limiting factor in manganese transport. Foy (1964) has found that waterlogging the soil significantly increases manganese uptake because of the reduction of manganese compounds to soluble states readily available to the environment.

Vegetative manganese accumulation occurs primarily in the leaves (Kirsch et al., 1960; Romney and Toth, 1954), particularly in the leaf margins, distal interveinal areas, leaf tips and localized spots in older leaves (Jones, 1970). Manganese content is generally higher in mature leaves than in young ones (Lockman, 1970), while Loper and Smith (1961) found manganese concentrations in alfalfa and lupines to decrease with maturity.

Limited distribution of manganese in plants may be that trace elements, such as manganese, are not freely mobile in plants. Their absorption and transport are slow compared to major elements such as potassium (Wallace and Bhan, 1962). Hooymans (1963) found that the rate of uptake of alkali cations in excised barley roots decreased with time. Doi (1952) found that rice leaves, despite their ability to reduce manganese uptake, accumulated from 5 to 10 times as much manganese as other grasses, including oats, barley, wheat, and ryegrass. Some studies have shown that herbs and grasses have moderate to high manganese

concentrations, while cereals are rather low in manganese content (Anderson and Harrison, 1970).

A definite manganese requirement has been shown in plants. While plants differ greatly in their ability to adsorb and store manganese, all plants have shown traces of manganese (Wangersky, 1961). Manganese-deficient plants produce only a third as much oxygen as normal plants. Ebid and Kutacek (1979) found manganese to have an important role in nitrogen metabolism of maize, especially in protein synthesis. Manganese is thought to enhance production of auxin, which in turn stimulates growth in the tops and roots (Bhatt et al., 1976).

Absorption in mammals is considered to be through the gastrointestinal tract, and the respiratory system. Little is known about the mechanism and site for manganese absorption. Piscator (1979) found that the absorption rate is dependent upon the amount ingested and existing manganese tissue levels. Studies by Greenberg et al. (1943) with radiomanganese indicate that only 3 to 4 percent of orally administered manganese is absorbed in rats. Similar results were obtained by Pollack et al. (1965), who reported absorption of 2.5 to 3.5 percent in rats given oral manganese dose. Manganese is widely distributed in the body, with static concentrations throughout (Cotzias, 1958). Fore and Morton (1952) found the bones, liver, kidney, and endocrine glands carried higher manganese concentrations than other tissues in the body. Underwood (1977) has suggested that because of the good correlation between hair concentration and diet, hair might be a good indicator of manganese exposure. Poor intestinal absorption has also been found in rats and mice (Furchner, 1966). The rapid loss of Mn-54 after oral administration resulted in whole body activities that were less than 1 percent of the administered dose. The authors concluded that the excretion of manganese was largely fecal, with less than 1 percent voided by urinary excretion. The absorption of manganese is dependent upon several factors, including availability,

concentration in the diet, and interaction with other metals or other dietary constituents (Abrams et al., 1976).

The interaction of other metals with manganese has produced varied results. Schroeder and Nason (1976) showed that niobium was associated with the deposition of manganese in the heart. Indium and rhodium have caused increased levels of manganese, principally in the kidney, heart, and spleen. Thus, ingestion of a non-essential metal could enhance the retention of manganese and some other essential trace metals and perhaps avoid the toxicity from the non-essential metals.

Age also played an important factor in manganese uptake, absorption, and retention. Mena et al. (1974) reported four times higher intestinal absorption in young mice and rats than in adults.

STUDY AREA

The Los Alamos Meson Physics Facility waste-disposal ponds lie on the extreme eastern end of Mesito de Los Alamos, at an elevation of approximately 6900 feet. The facility itself lies 3-4 miles southwest of the Los Alamos townsite, and is situated as seen in Figure 3.

The ponds, which were constructed in 1969, were primarily designed to hold all domestic raw sewage generated from the Los Alamos Meson Physics Facility. The ponds also provide a place in which to dispose of a significant majority of the cooling waters of the primary and secondary cooling systems from the LAMPF experimental areas. The original design of the waste-disposal system incorporated a third pond, but the lack of funding and adequate need at the time prevented the completion of the pond. Due to recent increased needs of the LAMPF system, a third pond was created in 1986. This provided the site with greater holding capacities for sewage, and allowed the cooling waters to be retained even longer. This last step allowed the activated elements in the waters to decay even further, before being purged to the environment.

Before wastes are dumped to the ponds, the cooling waters are pumped to holding tanks where samples are drawn and analyses are performed. If the radionuclide concentrations are found to be in excess of the Laboratory's Radiation Protection Group (HSE-1) guidelines, then the wastes are transported to the Waste Management Group (HSE-7) facilities for appropriate action. If the wastes are below HSE-1 concentrations, the cooling waters can then be dumped to the ponds for evaporative treatment.

Each pond is 210 feet on a side, and holds approximately 2.2 million gallons of waste when full (they generally run from 40-60% capacity). The ponds were constructed on a flat mesa top. By levelling, excavating, and

bringing in fill dirt, the ponds and banks were constructed. The sides were reinforced with 3" of pneumatically placed concrete, while the bottom layer of fill dirt was mixed with 1.5 pounds per square foot (equivalent to 4" on the surface) of Bentonite. The wastes are first pumped to a central metering point which provides an accurate record of the amount of wastes entering the ponds. From this box, a 10 inch pipe extends towards the center of each pond where the wastes then exit. The effluent outflow of the two ponds is combined together at the exit weir, where it is slowly released to the overflow stream (see Figure 4 for schematic of pond area).

The study area runs along the stream east of the ponds for approximately 180 meters, until the effluent flows over the canyon's edge. The stream runs a significant distance down the adjacent canyon, where existing studies found significant radionuclide concentrations as far as 0.80 miles downstream (LA-9762, 1983). At that point, the flow decreases to a point where surface flow subsides into the alluvium. It does not appear again except during heavy thundershower activity.

The fauna and flora surrounding the stream are typical of northern New Mexico pinyon-juniper habitat (US DOE-EIS-0018). A few grasses, such as *Hordeum jubatum*, which are more representative of a high moisture gradient, are "artificially" propagated in this area. They provide an adequate transfer medium to higher trophic levels.

The soil is considered to be a rocky outcrop, mesic type soil with a 5-30% slope. It has 5% very shallow, underdeveloped soil on bedrock, while 5% is considered a Hackroy soils (Nyhan et al., 1978). These soils, typical of very shallow, well-drained soils, are composed of a reddish brown clay, gravelly clay, or a clay loam (about 20 cm thick). The soil characteristics

Figure 4. Schematic of LAMPF Pond Area

show slow permeability, low available water, and is considered to be slightly (mildly) alkaline (Nyhan et al., 1978).

The study area has a semiarid, temperate mountain climate. The average annual temperature for 1981 was 49.6 F, with a mean temperature of 62.0 F (for the April-August period). Average precipitation level was 11.47" for 1981; approximately 3" above normal. Approximately 56.6% of the annual moisture falls between April and August. The winter of 1981 had an average snowfall of 51". Because 85-90% of the species utilizing the ponds are non-residents, climatological conditions during the winter are relatively unimportant. Daily wind patterns blew to the south/southwest, with an average wind speed of 3.42 m/s (7.00 mph), with 9.2% calm. Nightly winds prevailed mostly from the north-east, with an average wind speed of 2.84 m/s (5.81 mph), and 16.4% calm. Figures 5 and 6 provide 1981 records of wind velocities and directions around the ponds for DAY and NIGHT time periods (Bowen, 1983).

Figure 5. Average Wind Speed and Direction Over Pond Area, Day 1981
(Bowen, 1983)

Figure 6. Average Wind Speed and Direction Over Pond Area, Night 1981
(Bowen, 1983)

METHODS AND MATERIALS

PRELIMINARY STUDIES

Preliminary investigation and analysis of the study area was conducted during the summer of 1981. Its goal was to determine the possibility of a significant difference in contaminant concentrations between the pond area sampled and the control sites. Was there adequate evidence to support a study examining the transfer and interactions of a variety of radionuclides from the ponds to the surrounding biota?

The study was conducted in 3 separate phases. The first phase, in the summer of 1981, was to determine species distribution and usage around the waste-disposal ponds. Could these ponds provide a significant source of contamination to the surrounding biota? The observation period consisted of three days a week (randomly distributed) from 1/2 hour before sunrise, until 9:30 a.m., and then in the evening, from 4:00 p.m. to sunset. These observations were conducted for a period of one month. The results provided a visual record of the species utilizing the pond and the surrounding area. The results (Appendix A) are very comparable to a list compiled by earlier investigators (US DOE-EIS-0018).

Several meteorological parameters were measured as part of the observations. These included temperature, wind speed and direction, percent relative humidity, and present meteorological conditions. Although these parameters did not factor into the final statistical analysis of the data sets, they do provide an accurate record of the meteorological conditions that existed during this preliminary study.

The second phase of the study was to determine whether or not there existed a significant transfer of radionuclides from these waste-disposal

ponds to the surrounding biota. Because the initial study design incorporated sampling regimes around the ponds in areas where little or no vegetation grew, the primary sampling matrix at the time was the mammalian population (rodents). This involved designing sampling grids that encompassed the ponds. Previous studies (Schultz, 1982; Golley, et al., 1975; White et al., 1981) have suggested using a "filter" trap method utilizing Sherman type live traps. Figure 7 shows the preliminary trapping configurations. The standard prebaiting technique, as used by Golley et al. (1975) and Schemnitz et al. (1980), was used. Traps were set in the early evening and checked early the next morning.

A control site was sampled to provide reference control matrices that were not influenced by the external contamination provided by the waste lagoons. The control site was selected on a mesa top 3-4 miles south of the waste lagoons (Figure 8). The area was selected because of ecological similarity. The site had identical soil and floral characteristics, providing an excellent control site. Trapping was carried out in identical fashion as described by Schultz (1982).

The captured individuals from both the study and control sites were transferred to the laboratory for analysis. In the lab, the mice were weighed, sexed, identified, ear-tagged using monel numbered tags, and then put into small plastic containers for further counting. The analysis of the preliminary data sets showed that there was an insignificant level of radionuclide transport emanating from the ponds edge. In order to better assess the biotic transfer of these radionuclides, the study area was enlarged to encompass the overflow stream running east from the ponds.

Samples were taken to determine the extent of radionuclide transport in this new study site (stream and surrounding site). Sample grids were constructed according to White et al. (1981) and Schultz (1982) (Figure 9). The grid started

Figure 7. Preliminary Trapping Design Around Ponds

Figure 8. Control Site Area Photograph

Figure 9. Stream Transect Configuration

60 meters from the pond outfall, and continued for a length of 90 meters downstream until the canyon edge. The sample grid was not started at the point of outflow due to the construction of the stream channel. The upper 50 - 60 meters of the stream channel is in tuff bedrock 1-1.5 meters deep, providing an impermeable membrane to radionuclide transport (Figure 10). From the beginning of the sampling grid, a transect was located perpendicular to the stream channel and located every 7.5 meters downstream. On each of these transects, sampling locations were marked every 3 meters out on the transect (station number), for a distance of 17 meters from the center sample point.

Because part of the preliminary investigation was to determine the range and regions of contamination, the soil component was selected as the parameter to be sampled. It was theorized that the soil would be a good indicator of biotic and abiotic contamination. If the soil was not contaminated, then there is little chance that any other component would be contaminated. Such a point would be considered a viable contaminated sampling point.

In the sample grid, soil samples were taken at every point on the grid, up to 15 meters away, in accordance with a technique developed by Nyhan et al. (1981) for areas with radionuclide contamination. The samples were placed into labeled plastic bags and returned to the laboratory for analysis. The preliminary soil analysis was conducted by aliquoting the sample into a 500 ml Nalgene bottle, and then counting in the NaI(Tl) well crystal. Again, soil samples were also taken at the control site in a similar fashion.

ENVIRONMENTAL SAMPLING

After the contaminated regions were determined, the third and final phase of this study began. At these specified regions, all other sample matrices would be sampled. All the locations were marked with yellow geological marking flags.

Figure 10. Upper Transect Area. The Stream Channel, in the Upper Photo, is 1.5 Meters Deep in Volcanic Tuff. The Lower Photo Shows the Stream Bed Within the Channel.

The following pages describe the methods used to sample and prepare the matrices for further analysis:

1) WATER - The first water samples were collected by completely filling a 500 ml Nalgene bottle (13.4 cm tall) at each of the sampling transects on the stream channel. The water samples were not acidified because counting was performed immediately after collection, and the radionuclides of interest were not readily adsorbed onto the surfaces of the container. Preliminary analyses on these "point" samples were conducted, and the results were compared to water samples that were acquired over a one week time period (50 ml/24 hrs). The final results provided significant differences among the two techniques. It was then determined that the "point-sampling" technique was not an adequate measure of the true activity of the sample (Table 1). The variations in the concentrations were a result of the cyclic nature associated with the operating periods of the linear accelerator (ie., when it was "up" and activating elements in the cooling waters), the last dumping periods for the holding tanks, and the last major rainshower event. These are variables that could significantly alter the concentration of radionuclides in the stream water at any time. Therefore, multiple sampling sets (5 samples over 3 week time period) were taken at each sample transect site to provide a more accurate determination of the stream concentration. Final results were calculated through the use of radiochemical statistics (Appendix B), which allowed the correct calculation of the final mean value, inclusive of the error;

2) SOIL - Soil samples were aliquoted from the preliminary soil samples. 100 grams (+/- 1.5 grams) were weighed out in a 500 ml Nalgene bottle. This particular weight and sample configuration were essential to utilize the current efficiency values. Other variables recorded were sample height in the bottle, date, and location at which the soil sample was collected;

Table 1. Results of Point-Sampling as Compared to Time-Averaged Sampling for Radioactive Nuclides in Water from the Stream.

	Continuous Sampling	Spot Sampling	
	(1 wk., 50 ml/24 hr.)	(site #10	#11)
(all results in nCi/l)			
Co-57	0.39 +/- 0.02	0.92 +/- 0.24	0.67 +/- 1.40
Be-7	4.62 +/- 0.27	30.78 +/- 4.03	183.0 +/- 11.92
Rb-83	0.10 +/- 0.04	1.11 +/- 0.39	1.02 +/- 0.31
Cs-134	0.20 +/- 0.17	6.82 +/- 0.31	13.45 +/- 1.17
Mn-54	0.77 +/- 0.04	15.57 +/- 0.65	26.35 +/- 2.48

3) VEGETATION - Vegetation was collected at every plot where the soil was previously determined to be contaminated. Samples were collected by cutting off the entire mass of vegetative growth from the ground level up and depositing the sample in a zip-lock bag. Because it was known that certain species of grass was utilized by rodents to a greater extent than others, that species of grass was selectively sampled. When there was a lack of the preferred species, other grasses were sampled. In this study, Squirreltail (Sitanion hystrix) and Blue gramma (Bouteloua gracilis) were the preferred samples.

After the samples were brought back to the lab, they were washed twice with distilled water, and then placed in an oven at 45° C for least 24 hours. After the grasses were properly dried, they were cut and ground up and compressed with a wooden dowel into a 70 ml plastic bottle to provide a constant, uniform sample for accurate counting purposes. Other measurements associated with the vegetation collection procedure included the height of the compressed sample in the bottle (in cm), weight, date, and sample location;

4) RODENTS - Mice were trapped with Sherman live traps, as was discussed earlier. There were eight trapping sessions which were intended to adequately and completely sample the resident population (a complete sampling would be indicated by the presence of new, non-contaminated species into the area). The mice were brought back to the laboratory, asphyxiated with 5 ml of ethyl acetate, identified, sexed, and weighed. They were then put into 70 ml plastic bottles compacted to provide a constant (semi-uniform) standard geometry. The height of the sample in the bottle after compaction with a wooden dowel was also recorded. A total of 15 mice were taken.

The results from several mice were compared to the mice that had undergone a wet-dissolution technique, and the results suggested problems with the compaction technique. It was then suggested that the remaining mice undergo

the wet-dissolution technique. The technique involves dissolving the mice in a variety of solvents (ie., HNO_3 , H_2O) that break down the major structural components into a homogenous solution. The technique allows for a more precise quantitative representation of the sample in a variety of ways, 1) by allowing the sample to go into solution, the activity is more evenly distributed within the sample, and 2) by lowering the original volume of the sample, the error associated with self-absorption is lowered. Once again, the sample height in the bottle is recorded;

5) CARNIVORE - In this instance, only one carnivore was collected; a Prairie rattlesnake (Crotalus veridis). This carnivore was sampled because of the ease of the collection of the sample. The sample underwent a wet dissolution technique as described earlier. The sample height in the bottle was also recorded.

COUNTING TECHNIQUES

Sample analyses in this study were conducted by utilizing two systems designed to qualify and quantify the amount of radionuclide contamination within a sample; the NaI(Tl) and GeLi type detectors.

The first system utilized consisted of a NaI(Tl) well-crystal, coupled with a bias supply, pre-amp, amp, single channel analyzer and a counter-timer. The system in our configuration was set up to detect the emission of gamma rays in the 0 - 1.0 MeV range. The NaI(Tl) type of solid state detector is extremely suited for this particular type of analysis (gross gamma) because of the detector's high counting efficiency (high sensitivity to a variety of energy particles). The shortfall is the NaI(Tl)'s inability to resolve peaks at levels that other systems can. The NaI(Tl) system can provide the analyst with information concerning the level of activity in the sample, but cannot (unless

properly calibrated) define (resolve) the exact peaks. For this study, the NaI(Tl) was used as a screening tool only, to determine whether further sampling was needed.

All samples (mice and soils, both study and control sites) analyzed by this system were counted in triplicate fashion, for a 5 minute count each time. Suitable backgrounds were calculated from the detector itself to determine the background contribution from an empty detector. The samples (study and control site) were then corrected for the detector background, and a net count derived. The samples were considered contaminated if one of two criteria were met: 1) if the net counts were above 3 standard deviations of the background, the sample was considered contaminated, or 2) if the derived net counts were greater than the counts found in the control site samples, the samples were also considered contaminated. Statistically (and simplistically), if the sample counts are greater than 3 standard deviations above background, the counts are determined to be from external contributing factors other than natural statistical background. By also comparing the samples to the control site, further quantification could be resolved. If the samples were found to meet the above conditions, further investigation was deemed necessary.

The second counting system in use is the Germanium Lithium drifted solid state detector. Our system is coupled either with a Canberra model 8100 or Canberra Series 35 multichannel analyzer (4096 channels)(Figure 11). GeLi's are designed to provide a quantitative (as well as qualitative) analysis of a sample. This type of detector is well suited for quantitative analysis because of its high counting rate and excellent energy resolution - this type of detector has the valuable property of having a pulse size accurately proportional to the energy deposited by a particle in the crystal. The specific design parameters can be seen in Appendix C. Both systems can be seen in Figure 12, which

BLOCK DIAGRAM OF Ge(Li) SYSTEM

Figure 12. Flow Diagram of GeLi System

Figure 13. HSE-9's Nuclear Counting Facility

shows count room set-up. For an excellent description of the theory behind the operation of either the NaI(Tl) or GeLi detector system, see Harvey (1969) or Budnitz et al. (1983).

After the samples have been counted for the specified time period (10-12 hours), the data set is transferred to a VAX/VMS 8200 operating system. If final sample calculations were to be carried out by hand, the data reduction would take an enormous length of time. Fortunately, the Health, Safety, and Environmental Chemistry Group (HSE-9) has a computer code for the dissemination of data from the large 4096 channel spectrums (Goode, 1980). The program interactively queries the user for pertinent sample and counting information (Appendix D), the appropriate spectral data are then read from the system, and plotted on the console terminal for visual examination. Integration limits for the gamma energy peaks of interest are supplied by typing an "x" under the plot at the points that are desired as the low and high limits of each peak. A background of 4 points above and below the peak centroid is then taken, and entered along with all the previous information to help calculate the final results (for a detailed look at the program GAMSPEC, see Appendix E). This information was then recorded in the proper notebooks.

Because the samples encountered in this study were not of the standard shape or isotopic interest, new efficiencies had to be generated to finalize the data reduction process. In the case of the vegetation and the rodents, new containers had to be used in order to maximize the height to width ratio (minimizing the effects of self-absorption). Because of this, the efficiencies of these 75 ml polyethylene bottles had to be generated experimentally. The range of sample heights were determined for both vegetation and rodents, and recorded. Three bottles were made, one containing Be-7, the second holding Rb-83, and the last with the three remaining isotopes (Mn-54, Cs-134, and Co-57).

In each bottle, the range of heights (HI and LOW) associated with the sample set were marked on the side of the bottle. Each of the bottles was filled with known quantities and activities of each isotope, and counted at each corresponding height associated with each sample (5 heights, to give a statistically representative curve) for each detector (3). The final absolute efficiency curves are then calculated for each isotope at each height for each detector (see Appendix F for a representative plot of the efficiency curves). From these curves, new efficiencies for the vegetation and rodent samples can be determined. These efficiencies, in turn, will be utilized in the GAMSPEC program to provide the final data reduction of the samples.

The final concentrations were compiled in a file on the Los Alamos National Laboratories LTSS computing system, called PERO. This file has 325 data points associated with the five trophic levels and five isotopes of interest (Appendix G). Consultation with a biostatistician yielded specific statistical analyses that could be used to accurately interpret the data. The statistical tests utilized included SCATTERGRAMS, REGRESSION analysis, PEARSONS CORRELATION, ANOVA, and MANOVA. Each test provided an analysis of a particular part of the data set, examining different variables, providing both qualitative and quantitative results. The statistical test examined the difference in the means, the difference in the variance of these means of the populations, the contribution of an independent variable against several dependent variables, and the interaction of all independent versus dependent variables. While all the statistical examinations were important, and provided a different view of the data, the PEARSONS CORRELATION, ANOVA, and MANOVA provided the output of greatest concern. The results of all the statistics tests will be examined in the following RESULTS section.

RESULTS

The ultimate goal of the statistical analysis for the data obtained in this study was to determine, and at what level of significance, the extent of the interactions among the dependent (radionuclides) and independent (trophic levels) variables. Is Be-7 being absorbed into the environment (vegetation) at a greater rate than Mn-54? Do the radionuclides accumulate at the levels seen in the literature? Is there truly a significant statistical difference among the sampled variables. These are questions that can be answered by prudent use of the varied statistical tests.

PRELIMINARY STATISTICAL ANALYSES

One of the first questions encountered in this study was the determination of a significant difference between the study and control sites in the preliminary analysis. If no difference existed, then there would be no need to continue the study. Because we were testing for a difference in the counts among two populations (μ_1 , μ_2), a Students' t-test was considered the appropriate statistical test. The data set was entered in both weighted and non-weighted set. In the weighted set, all parameters with counts less than 250 and greater than 3000 were not considered in the statistical exam. Those events outside these parameters were considered random events, and not truly representative of the sample set. In the non-weighted set, all values were considered. From the Students' t-test, the following hypothesis was tested:

$$(1) H_0 \equiv \mu_1 - \mu_2 = 0, \mu_1 = \mu_2$$

$$(2) H_a \equiv \mu_1 - \mu_2 \neq 0, \mu_1 \neq \mu_2$$

A final t-value of 3.62 @ df=12 was derived. After the rejection region was determined from a standard t-test table (3.428 $\therefore$ $\alpha = 0.005$, 4.318

$\therefore \alpha = 0.01$), it was concluded that the null hypothesis be rejected, and accept (with a 95% ($\alpha = 0.05$) probability) the alternative hypothesis that the two sample sets were significantly different ($\mu_1 \neq \mu_2$).

Further analysis of the weighted set (< 250 counts and > 3000 counts) provided a final t value of $t = 2.03$ @ $df = 14$. The rejection regions were found to be determined at $t = 1.761$ ($\alpha = 0.01$), and $t = 2.145$ ($\alpha = 0.05$). Since the t-value fell within this range, it would be acceptable to say that the alternate hypothesis could be accepted with a 90% degree of certainty. Final statistical interpretation suggested that there is a significant difference in the whole body counts between the study and control sites, regardless of a weighted or non-weighted analysis. This statistical test concluded that the the study site samples did indeed have a significant concentration level as compared to the control site. Further analysis into the uptake and interactions within the study site could now be undertaken.

The next series of statistical analyses were to be performed on samples collected from the study site (overflow stream channel and surrounding area). Because I wanted to examine the difference not only among the radionuclides, but also among trophic levels, the sample sets were broken down into subsets for more specific analyses. These included PLOT, TRAN, TROPLVL, and ELEMENTS. These early tests were a guide to determine the extent of the contamination, and provide preliminary results so that other, more complete, statistical analyses could be performed.

One of the first statistical examinations conducted was a Regression analysis. The variables tested were transects (TRAN) and plots (PLOT). The model used to test these variables was:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \epsilon$$

where $x_1 = \text{TRAN}$, $x_2 = \text{PLOT}$, and ϵ was the error term which guided the model to one of a probabilistic type, rather than deterministic (a random error). Values were calculated and showed a varied response. The next question that could be examined under this particular statistical analysis would be whether the elemental uptake in the soils downstream was by linear or exponential (quadratic) fashion. To test this hypothesis, a model was used which compared the transect (TRAN) uptake to either a linear or quadratic function (TRAN^2). The following model was used:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2^2 + \beta_3 x_3 \tau + \epsilon$$

If there was indeed a curvilinear response, this model would best show it. The results show that a great majority ($\geq 75\%$) of the TROPHIC LEVEL ELEMENTS were taken up in an exponential fashion.

The next statistical test analyzed the variances in the uptake of the radio-nuclides (soils and vegetation) within either individual plots (PLOT), or the transects (TRAN). Are the radionuclide concentration gradients greater in the plots than in the transects? An ANOVA analysis was used to test the following statement:

$$H_0: \mu_{\tau 0} = \mu_{\tau 1} = \mu_{\tau 2} = \mu_{\tau \iota},$$

H_a : at least one mean ($\mu_{\tau \iota}$) value is different

The SOUTH side transects had a large majority of the results indicating a significance difference in the uptake within the plots, as compared to little deviation in the transects. The results, as seen in Table 2, show that the downstream radionuclide concentrations (transects) remain constant for all the variables tested. When the plots are examined, there is a significant difference in the concentrations as the distance from the stream is increased.

Table 2. ANOVA Analysis of Transect (TRAN) and Plot (PLOT) Data

Test at $\alpha = 0.05$ level

(SOUTH Side)

Soils	Co-57	by	TRAN	$F = 1.843$ for $F(11,22)$	$F(11,22)$
			PLOT	$= 4.346$	$\alpha = 0.05$
					2.26

Accept H_0 for TRAN, Reject H_0 for PLOT.
There is a significant difference if the
Co-57 concentrations in soils within the
PLOTS.

Be-7	by	TRAN	$F = 0.839$ for $F(11,22)$
		PLOT	$= 1.360$

Accept H_0 for both TRAN and PLOT.

Rb-83	by	TRAN	$F = 1.456$ for $F(11,22)$
		PLOT	$= 3.066$

Accept H_0 for TRAN, reject for PLOT.

Cs-134	by	TRAN	$F = 1.165$ for $F(11,22)$
		PLOT	$= 1.898$

Accept H_0 for both TRAN and PLOT.

Mn-54	by	TRAN	$F = 1.438$ for $F(11,22)$
		PLOT	$= 2.770$

Accept H_0 for TRAN, reject for PLOT.

Vegetation	Co-57	by	TRAN	$F = 1.254$ for $F(11,22)$
			PLOT	$= 1.536$

Accept H_0 for TRAN and PLOT.

Be-7	by	TRAN	$F = 1.671$ for $F(11,22)$
		PLOT	$= 1.731$

Accept H_0 for TRAN and PLOT.

Rb-83	by	TRAN	$F = 1.773$ for $F(11,22)$
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Table 2, cont.

PLOT = 31.377

Accept H_0 for TRAN, reject for PLOT.

Cs-134 by TRAN F = 1.605 for F(11,22)
PLOT = 7.267

Accept H_0 for TRAN, reject for PLOT.

Mn-54 by TRAN F = 1.948 for F(11,22)
PLOT = 10.159

Accept H_0 for TRAN, reject for PLOT.

(NORTH side)

Soils Co-57 by TRAN F = 2.317 for F(11,22)
PLOT = 3.980

Reject H_0 for both TRAN and PLOT.

Be-7 by TRAN F = 0.564 for F(11,22)
PLOT = 0.562

Accept H_0 for TRAN and PLOT.

Rb-83 by TRAN F = 0.951 for F(11,22)
PLOT = 1.559

Accept H_0 for TRAN and PLOT.

Cs-134 by TRAN F = 0.495 for F(11,22)
PLOT = 0.618

Accept H_0 for TRAN and PLOT.

Mn-54 by TRAN F = 0.830 for F(11,22)
PLOT = 0.935

Accept H_0 for TRAN and PLOT.

Vegetation Co-57 by TRAN F = 0.721 for F(11,22)

Table 2, cont.

PLOT = 1.708

Accept H_0 for TRAN and PLOT.

Be-7 by TRAN F = 1.051 for F(11,22)
PLOT = 1.599

Accept H_0 for TRAN and PLOT.

Rb-83 by TRAN F = 1.616 for F(11,22)
PLOT = 14.870

Accept H_0 for TRAN, reject for PLOT.

Cs-134 by TRAN F = 1.230 for F(11,22)
PLOT = 5.057

Accept H_0 for TRAN, reject for PLOT.

Mn-54 by TRAN F = 1.106 for F(11,22)
PLOT = 5.010

Accept H_0 for TRAN, reject for PLOT.

The statistics provided a significant value to reject the null (H_0) and accept the alternate (H_a) hypothesis. The NORTH side did not show the high statistical values as did the SOUTH side analyses; there was a large number that accepted the null (H_0). Many of the results for the vegetation indicated significant differences (reject H_0), while the soils showed little significant variations in the radio-nuclide levels (acceptance of the null hypothesis). Another ANOVA statistical test of the data set examined where the greatest variations in the radiochemical concentrations would lie in the three variables tested (transects (TRAN), plots (PLOT), and the trophic levels (TROPLVL)) for the NORTH and SOUTH sides; see Table 3. The results in all cases showed that the greatest variations were in the PLOT's and TROPLVL's cases. TRAN's again showed little variation.

A final statistical examination of this data set using ANOVA was concerned with whether or not significant differences existed among the radionuclides within each trophic level on each side (NORTH and SOUTH). Table 4 shows the results. All results (both NORTH and SOUTH) showed significant levels (95%) of acceptance of the null hypothesis.

One of the problems associated with the ANOVA subroutine is that there must be an equal number of samples tested within each subset. This was not true in this data set and may be a source of limited errors. Because of this, the ANOVA analysis provided a good approximation of the results.

This test (ANOVA), and those previously mentioned, provided a good initial analysis of the data set. By close examination of these preliminary results, more precise and accurate statistical examinations can be utilized that will provide a more significant result needed for final interpretation of the data. The following pages represent the final two tests conducted on the data set; Pearsons Product Moment Correlation Coefficient, and the Multi-variate Analysis of Variance (MANOVA).

Table 3. ANOVA Analysis of Transects (TRAN), Plots (PLOT), and Trophic Levels (TROPLVL) Data

Test at $\alpha = 0.05$ level

(SOUTH Side)

Co-57	by	TRAN	F = 1.283	Accept	
		PLOT	= 3.723	X	
		TROPLVL	= 8.088		X
Be-7	by	TRAN	F = 1.523	X	
		PLOT	= 2.051		X
		TROPLVL	= 5.539		X
Rb-83	by	TRAN	F = 2.039	X	
		PLOT	= 12.715		X
		TROPLVL	= 39.106		X
Cs-134	by	TRAN	F = 2.181	X	
		PLOT	= 4.066		X
		TROPLVL	= 7.249		X
Mn-54	by	TRAN	F = 2.281		X
		PLOT	= 6.628		X
		TROPLVL	= 12.153		X

(NORTH Side)

Co-57	by	TRAN	F = 1.368	X	
		PLOT	= 3.120		X
		TROPLVL	= 9.715		X
Be-7	by	TRAN	F = 1.523	X	
		PLOT	= 2.051	X	
		TROPLVL	= 5.539		X
Rb-83	by	TRAN	F = 2.039	X	
		PLOT	= 12.715		X
		TROPLVL	= 39.106		X

Table 3, cont.

Cs-134	by	TRAN	F = 2.181	X	
		PLOT	= 4.066		X
		TROPLVL	= 7.249		X
Mn-54	by	TRAN	F = 2.281		X
		PLOT	= 6.628		X
		TROPLVL	= 12.153		X

Table 4. ANOVA Analysis of Trophics Levels and Radionuclides

Tests of Variances of Values Between TROPLVL's
and Radionuclides for SOUTH and NORTH Plots

Test at $\alpha = 0.05$ level

(SOUTH Side)

Water	Co-57	No statistics collected, no cells generated.	
	Be-7		
	Rb-83		
	Cs-134		
	Mn-54		
Soil	Co-57	F = 0.6008 for F(11,21)	F(11,21)
	Be-7	= 0.4776	$\alpha = 0.05$
	Rb-83	= 0.6464	2.28
	Cs-134	= 0.6367	
	Mn-54	= 0.6438	

F value does not fall in the rejection region,
for any of the elements in the soil transects,
therefore, there is no difference in the mean
values of the soil samples in the transects.

Vegetation	Co-57	F = 0.7442 for F(11,14)	F(11,14)
	Be-7	= 1.4583	$\alpha = 0.05$
	Rb-83	= 0.1819	2.56
	Cs-134	= 0.4663	
	Mn-54	= 0.2949	

No significant difference was seen, accept
Ho. One high value (Be-7), but was not
significant.

Rodent	Co-57	F = 107.0998 for F(1,5)	F(1,5)
	Be-7	= 20.7219	$\alpha = 0.05$
	Rb-83	= 6.5427	230.000
	Cs-134	= 0.6500	
	Mn-54	= 4.2972	

Accept Ho, reject Ha. There does seem to be a
great variance between isotopes in this matrice

Carnivore No Cells Generated (Insufficient Data)

Table 4, cont.

(NORTH Side)

Water	Co-57	No statistics generated, no cells generated.	
	Be-7		
	Rb-83		
	Cs-134		
	Mn-54		
Soil	Co-57	F = 0.3934 for F(11,20)	F(11,20)
	Be-7	= 0.4383	a = 0.05
	Rb-83	= 0.4953	2.31
	Cs-134	= 0.3135	
	Mn-54	= 0.4613	

Accept the Ho, no significant statistics to reject alternate hypothesis (Ha).

Vegetation	Co-57	F = 0.5874 for F(11,14)	F(11,14)
	Be-7	= 0.8197	a = 0.05
	Rb-83	= 0.4840	2.56
	Cs-134	= 0.7458	
	Mn-54	= 1.1277	

Accept Ho, reject Ha.

Rodent	Co-57	F = 0.3409 for F(3,2)	F(3,2)
	Be-7	= 1.3389	a = 0.05
	Rb-83	= 0.3360	19.16
	Cs-134	= 0.4079	
	Mn-54	=12.4731	

Accept Ho, reject Ha. All values show relative consistency among themselves, except Mn-54 with the high (almost significant) value.

Carnivore No Cells Generated

PEARSONS PRODUCT MOMENT COEFFICIENT OF CORRELATION

The Pearsons' coefficient of correlation (signified by r), is a numerical descriptive measure of the correlation between the two variables, x and y . The exact computational form can be seen in McClave (1982), and in general, is a measure of the strength of the relationship between two variables. For further interpretation and analysis of the Pearsons' correlation, see McClave (1982), Scheffler (1969), and Snedecor (1980).

In order to provide an abbreviated form of the results, a simple review of the numerical values would help. In the Pearsons' correlation analysis, the sample correlative value, r (the population correlative value, ρ), ranges between a value of $+1$ and -1 . A perfect linear relationship is obtained when a value of 1 is reached (extremely rare in biological studies). When values close to zero are obtained, the variables are said to show little (if any) correlation to one another. If a $+$ number is encountered, a positive linear relationship is assumed (ie., an increase in Y is associated with an increase in X). The same holds true for a negative number (ie., decrease in Y associated with an increase in X). A note of caution on the interpretation of this type of analysis; one must be careful as not to infer a causal relationship upon the basis of a high correlation. A high correlation between two variables does not necessarily imply causation. A significant correlation may suggest such a possibility to the investigator, but supportive evidence of a biological nature must be found before a conclusion involving causation is warranted. As usual, the interpretation of the statistical results should be leavened with common sense and practical biological experience.

The test usually considers whether a hypothesis holds true, or is rejected with a significant degree of certainty. In this particular case, the

Null Hypothesis (H_0) is: ρ (or r) = 0, against the Alternate hypothesis (H_a) that ρ (or r) $\neq$ 0. We are testing the hypothesis that x contributes no information for the prediction of the y variable using the straight line model, against the node that the x does contribute to y . Both again at the $\alpha = 0.05$ level (95% probability).

In this analysis, the data were broken down into three compartments: 1) ENTIRE, 2) NORTH, and 3) SOUTH sides. This was done so as to compare the results of all the data, versus those when broken down into these sides (ie., are there different interactions among the sides?). Also, in order to maintain a clear, concise picture of the numerical data from the various statistical analyses, a condensed format dealing with the data will appear within the next few pages.

Water was the first variable to be sampled. Because water was sampled from the stream, there will be only one numerical value assigned to this matrix (no NORTH and SOUTH number). For this reason, the ENTIRE data set will be the only one analyzed. With Co-57, all the variables had a negative value, with the highest correlative value being the Co-57/Rb-83 relationship, with an $r = -0.5860$, while Be-7 showed very little correlation at $r = -0.0132$. In the situation where Be-7 was the y variable, Rb-83 showed a negative value (-0.1781), Cs-134 with a $r = 0.5160$, and Mn-54 with little correlation (0.0087). With Rb-83, Cs-134 showed a fair correlative value ($r = 0.6487$), while Mn-54 showed an extremely significant value (0.8114). For Cs-134, Mn-54 obtained a value of $r = 0.7755$, with $\alpha = 0.001$; quite significant to reject the H_0 (null).

The next variable of concern was the parameter soil, with three sets of complete data to compare: ENTIRE, NORTH, and SOUTH. In the Co-57/Be-7 matrix analysis, the highest correlative values were found in the NORTH side ($r = 0.7619$, $\alpha = 0.001$), followed by the SOUTH with a $r = 0.7513$, $\alpha =$

0.001, while the ENTIRE data set had an $r = 0.7513$, $\alpha = 0.001$. For the Co-57/Rb-83 situation, it was found that the SOUTH has the highest value ($r = 0.9354$), followed by the ENTIRE and NORTH data sets ($r = 0.9218$ and 0.9094 , respectively). It was interesting to note the extremely high correlative values found here.

For Co-57/Cs-134, the same order of significance was observed as in the Co-57/Rb-83 analysis of before (SOUTH, ENTIRE, NORTH - $r = 0.8740$, 0.8530 , and 0.8211 , respectively). For Co-57/Mn-54, again the same order, SOUTH, ENTIRE, NORTH ($r = 0.9663$, 0.8962 , and 0.8764 , respectively). In the Be-7 analysis, Be-7/Rb-83 was highest in the NORTH, followed by ENTIRE and SOUTH ($r = 0.8735$, 0.7743 , and 0.6860 , respectively). In the next series of breakdowns, Be-7/Cs-134 and Be-7/Mn-54, the same orders of importance were found - NORTH, ENTIRE, and SOUTH. In all cases, those values found in the NORTH data set were found to be quite significant ($\approx p = 0.90$, $\alpha = 0.001$), while the remaining values did not attain those particular levels. They were adequate to reject the Null hypothesis at the $\alpha = 0.05$ level.

The Rubidium-83 analysis, the Rb-83/Cs-134 value was the greatest in the NORTH transect, followed by the ENTIRE and SOUTH data sets ($r = 0.9125$, 0.8896 , and 0.8841 , respectively). In the Rb-83/Mn-54 test, the SOUTH showed the highest correlation with an $r = 0.9791$, $\alpha = 0.001$. The ENTIRE set followed with a $r = 0.9284$, $\alpha = 0.001$, and then NORTH with an $r = 0.9090$ ($\alpha = 0.001$). The Cs-134/Mn-54 analysis provided the greatest correlative value in NORTH data set ($r = 0.9777$, $\alpha = 0.001$), followed by the SOUTH set with an $r = 0.9232$ ($\alpha = 0.001$), and the ENTIRE set ($r = 0.9141$, $\alpha = 0.001$). As was noticed in all the previously conglomerated data sets for the soil variable, all values were found to be extremely high and showed excellent correlations.

Except for a few in the 0.6000 range, most values were quite adequate to reject the H_0 and accept H_a with a high degree of probability.

The next independent variable to be examined was the parameter vegetation. Once again, the values of the three sampling methods were analyzed to determine where the greatest mode of uptake occurred. For the Co-57/Be-7 matrix, the highest values were found in the NORTH set with an $r = 0.5579$ ($\alpha = 0.002$) followed by the ENTIRE and SOUTH side analyses ($r = 0.5469$ and 0.2650 ; $\alpha = 0.020$, 0.095 , respectively). The Co-57/Rb-83 analysis showed that the NORTH set had again the highest value ($r = 0.5928$, $\alpha = 0.001$), with the ENTIRE and SOUTH following ($r = 0.3157$, $\alpha = 0.011$; $r = 0.2873$, $\alpha = 0.077$). In the Co-57/Cs-134 test, the NORTH data set showed again the highest correlative value ($r = 0.3721$, $\alpha = 0.031$), followed by the SOUTH and ENTIRE sets ($r = 0.3203$, $\alpha = 0.055$; and $r = 0.2879$, $\alpha = 0.019$, respectively). As for the Co-57/Mn-54 analysis, the SOUTH set showed the highest value ($r = 0.5702$, $\alpha = 0.001$), followed by ENTIRE ($r = 0.4927$, $\alpha = 0.001$), and finally the NORTH data set ($r = 0.4741$, $\alpha = 0.007$). The values seen here represent a wide range of interpretations, from the rejection to the acceptance of suitable hypotheses.

For beryllium analysis, the Be-7/Rb-83 test showed the SOUTH set with an $r = 0.5799$ ($\alpha = 0.001$), followed by ENTIRE ($r = 0.5579$, $\alpha = 0.001$), and NORTH ($r = 0.5281$, $\alpha = 0.003$). In the next two tests involving Be-7/Cs-134 and Be-7/Mn-54, the same order of significance was found as in the previous analyses, and therefore warranted no need to discuss them here. The values seen in this set of analyses all tended to show a significant level of rejection of the Null hypothesis.

In the analysis of Rb-83/Cs-134, the SOUTH again attained the highest value with an $r = 0.7936$ ($\alpha = 0.001$), with ENTIRE ($r = 0.7645$, $\alpha = 0.001$), and NORTH with an $r = 0.7488$ ($\alpha = 0.001$). For the Rb-83/Mn-54 matrix, the SOUTH

had the highest value again ($r = 0.8347$, $\alpha = 0.001$), while the NORTH was next in importance with an $r = 0.8264$ ($\alpha = 0.001$), and ENTIRE ($r = 0.8148$, $\alpha = 0.001$) last. Once again, there seemed to be a high probability of rejection of H_0 . Cesium analysis showed the Cs-134/Mn-54 correlative values to be the highest in the NORTH data set ($r = 0.8968$, $\alpha = 0.001$), followed by the ENTIRE set ($r = 0.8702$, $\alpha = 0.001$), and the SOUTH set ($r = 0.8486$, $\alpha = 0.001$).

For the complete vegetative analysis, the SOUTH data set projected the highest correlative values, with a few exceptions in the Cs/Mn matrix analyses. Generally, there was a trend to reject H_0 , and accept the H_a with a high degree of significance.

The last independent variable to test was the rodents. In the cobalt analysis, the Co-57/Be-7 results showed the SOUTH the highest with an $r = 0.1187$, then ENTIRE ($r = 0.1154$, $\alpha = 0.354$), and last NORTH ($r = 0.0305$, $\alpha = 0.477$). For Co-57/Rb-83 analysis, NORTH showed the highest ($r = 0.7041$, $\alpha = 0.059$), then SOUTH ($r = 0.6355$, $\alpha = 0.060$), and ENTIRE ($r = 0.6192$, $\alpha = 0.012$). The next results of Co-57/Cs-134 showed NORTH again with the highest, followed by ENTIRE and SOUTH. In the Co-57/Mn-54 matrix, the SOUTH data set showed the highest correlative value, with an $r = 0.8489$, $\alpha = 0.008$, followed by NORTH ($r = -0.2135$, $\alpha = 0.342$), and ENTIRE ($r = 0.1954$, $\alpha = 0.261$). Cobalt analysis, as a whole, showed a general trend to accept H_0 , while the Co-57/Mn-54 matrix in the SOUTH transect tended towards a high correlative value to reject the null.

For beryllium analysis, Be-7/Rb-83 results showed the SOUTH to have an $r = 0.7958$, $\alpha = 0.016$, ENTIRE with an $r = 0.6111$ ($\alpha = 0.013$), and NORTH with a $r = 0.2499$, $\alpha = 0.316$). For the Be-7/Cs-134 matrix, the highest value again came from the SOUTH data set ($r = 0.5861$, $\alpha = 0.083$), then NORTH ($r = -0.2619$, $\alpha = 0.308$), and ENTIRE ($r = 0.1604$, $\alpha = 0.300$). Be-7/Mn-54 tests had

the SOUTH with the highest $r = 0.5148$ ($\alpha = 0.119$), followed by ENTIRE ($r = 0.1736$, $\alpha = 0.285$), and NORTH ($r = -0.0547$, $\alpha = 0.459$). Except for the Be-7/Rb-83 matrix values in the SOUTH and ENTIRE data sets, all statistical results were found to accept the null hypothesis.

In the rubidium analysis, Rb-83/Cs-134 test showed the SOUTH with the highest value ($r = 0.8632$, $\alpha = 0.006$), then NORTH ($r = 0.8383$, $\alpha = 0.019$), and finally ENTIRE ($r = 0.7817$, $\alpha = 0.001$). For Rb-83/Mn-54, the highest value was obtained in the SOUTH data set again ($r = 0.9093$, $\alpha = 0.002$), followed by ENTIRE and NORTH ($r = 0.5724$ and 0.4053 , respectively).

In the last analysis, Cs-134/Mn-54 concluded that the SOUTH had the highest level of correlation ($r = 0.9074$, $\alpha = 0.002$), followed by the ENTIRE data set ($r = 0.6319$, $\alpha = 0.010$), and NORTH ($r = 0.4965$, $\alpha = 0.158$). These values indicated a significant level of rejection for the SOUTH and ENTIRE data sets, while the NORTH set accepted the null hypothesis.

The results of the correlation analysis from the rodents data set indicated that a high percentage of values were rejecting the H_0 (null) in the SOUTH data set, while the ENTIRE and NORTH sets showed a higher percentage of acceptance of the null hypothesis. The statistical results for this Pearsons Correlation Coefficient analysis can be seen in Appendix H.

MANOVA

Before an in-depth analysis of MANOVA analysis (Multivariate Analysis of Variance) can proceed, an interpretation of what is being tested, some of the variables, and what specific tests are being conducted would greatly aid in the understanding of what the results indicate, along with what is trying to be accomplished.

MANOVA is a statistical analysis that examines the contrasting variations between two or more populations, each with several samples from each population. The statistical examination needs only one model, the fixed model one-way MANOVA. In algebraic form, the model decomposes an individual data vector (point estimate) into a grand centroid, treatment and error effect:

$$X_{ijk} = \mu_j + \alpha_{ij} + \epsilon_{ijk}$$

where $K = 1, 2, \dots, n$ individuals, $j = 1, 2, \dots, p$ observations on an individual, and $i = 1, 2, \dots, g$ groups or populations. This test is specifically designed to determine whether or not there is some differential uptake among the variables examined. For example, the impending question could be asking if all the dependent variables for a fixed independent variable were taken up equally, or differentially? A hypothesis is then constructed that will test the previously stated question. In this specific case, our general model is of the following design:

$$y = \mu + \beta_1(\mu_1 - \mu) + \beta_2(\mu_2 - \mu) + \beta_3(\mu_3 - \mu)$$

or more exactly,

$$y = \mu_1 + \beta_1(\mu_1 - \mu_2) + \beta_2(\mu_1 - \mu_3) + \beta_3(\mu_2 - \mu_3)$$

If the above models are found to be true, then the null hypothesis (H_0) would consist of the following statement:

$$H_0 : \mu_1 = \mu_2 = \mu_3 = \mu$$

(the population centroids are equal)

meaning that there are no differences in the mean values tested.

On the other hand, we assign the alternate hypothesis (H_a) to infer the following:

$$H_a: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$$

concluding that at least one mean of the data set is not equal (the population centroids are unequal or at least one differs). For both hypotheses, determination of an acceptable limit at which both values could be accepted or rejected was found. This is usually considered to be set at the 95% probability level ($\rho = 0.05$) of acceptance.

For further examples or interpretations of MANOVA analysis, consult Hull and Nie (1981), Cooley and Lohnes (1971), Green (1978), Snedecor and Cochran (1980), or Pimentel (1979).

When examining the distributional uptake of the elements studied within this system, it was interesting to note where the uptake between the parameters was the greatest (which showed significant uptake). The parameters of interest included TRAN (transect), PLOT (plot on the transect), TROPLVL (the specific trophic level sampled), and SIDE (the side sampled).

The first parameter of importance was SIDE. The MANOVA analysis was run for the entire data set, then for the NORTH and SOUTH side values alone. It could then be determined if there was any differential uptake between the sides by comparing the statistical values of ALL versus NORTH and SOUTH sides according to the output of the SIDE analysis (highest F value was $F = 1.4248$, with $\rho = 0.234$, unacceptable; accept $H_0: \mu_1 = \mu_2 = \mu_4$). Upon closer analysis of the NORTH and SOUTH side data, there was a small discrete difference. In general, the SOUTH side values came closer to rejecting the null than did those values seen in the NORTH side data. This was true for all the parameters tested - TRAN, PLOT, and TROPLVL.

TRAN, which encompassed the 12 line transects along the stream, was the next parameter under analysis. Once again, it was interesting to see the difference among the uptake for each of the five elements. In the ENTIRE analysis, Co-57 was seen to be taken up differently at some point along the transect, with an F value equal to 2.322, and a probability level of 0.012. The reason for the significant difference was primarily due to the transect 11, where $t = 2.461$, $p = 0.015$. When comparing these ENTIRE values with those seen in the NORTH and SOUTH side analysis, once again, a difference was seen, but not at the same level as the ENTIRE data. Both NORTH and SOUTH showed significant differences in transect 11 (ie., reject H_0 and accept the alternate), with relatively close values at transects 2N, 4 & 7S.

Beryllium-7 analysis showed no relative difference ($F = 1.509$, $p = 0.130$, accept the H_0). A more in-depth analysis of NORTH and SOUTH sides showed no significant difference in the uptake among transects with a $p = 0.682$ and 0.485, respectively. Even in the SOUTH transects, where an $F = 0.967$ with $p = 0.485$, when examining transect 11, there is a $p = 0.077$; which is acceptable. The overall F value was found to accept H_0 and reject H_a .

With Rubidium-83, the ENTIRE value of $F = 2.028$ ($p = 0.030$) rejected H_0 and accepted H_a , defining a difference in the means of the transects. No values contained an adequate significant value to reject the null, but the overall values were adequate. When breaking the group into the NORTH and SOUTH categories, it was found that the SOUTH data set obtained an $F = 1.016$ with a $p = 0.444$; this value accepted H_0 - no difference in any means of the 12 line transects on the NORTH and SOUTH sides. In the NORTH transect, a $F = 2.069$ ($p = 0.039$) was found to reject the null and accept the alternate (there was at least one mean with a difference in the values of the 12 transects) with a greater than 95% probability. Further in-depth analysis showed

that transects 2 and 10 were suggested as the reasons for the high F value.

Cesium-134, the potassium analogue, was also found to reject the null and accept the alternate in the ENTIRE data set, with $F = 2.170$ ($p = 0.019$). Once again, transect 11 was an important factor in acceptance value, with transects 3 and 6 also providing support. In further analysis of the NORTH data, it was found that there was an acceptance of H_0 ($F = 1.147$, $p = 0.343$); no difference in the means of this side. In the SOUTH side analysis, null acceptance was also found, with an F value of 1.05, $p = 0.413$; no difference in this side either. One suggestion for the high F value and rejection of H_0 in the ENTIRE data set, while acceptance was seen in the both NORTH and SOUTH sides, could have been due to the interactions of all the means of the data sets.

In the Manganese-54 analysis, the overall set showed an $F = 2.265$, $p = 0.014$, which rejected the null and accepted the alternate with a greater than 98.5% probability of the means being different. In the NORTH side data, an $F = 1.396$ ($p = 0.202$) was found that accepted the null. In the SOUTH set $F = 1.361$ ($p = 0.215$) also was found to accept the null and reject the alternate hypothesis. Once again, the null hypothesis was accepted in the breakdown of the NORTH and SOUTH sides, while the ENTIRE data set showed rejection of the null and acceptance of the alternate with a relative high degree of probability. The combined overall numbers produced the high F values, while alone, the F values did provide such a substantive value.

The next parameter of importance concerned the independent variable PLOT, the plot on the specific line transect. The information contained within suggests how far the contamination had spread from the stream to the surrounding biota.

With Co-57 in the ENTIRE data set, the F value of 5.419 ($\rho = 0.00001$) was found to be extremely significant at greater than 99.999% probability of rejecting the null and accepting the alternate. The contamination spread through at least PLOT 1 and 2 ($\rho = 0.0000$, $\rho = 0.0036$, respectively), where the remaining plots (3-9) were found to accept the null. In a breakdown of sides, the SOUTH also showed a high probability of rejection of H_0 , with an $F = 3.723$ ($\rho = 0.0054$). Further breakdown showed PLOT's 1 and 2 to be the major contributor to the rejection, while the rest were found to accept the null hypothesis of the model. The NORTH data set produced a high level of rejection with $F = 3.119$ ($\rho = 0.0058$), while in-depth analysis showed PLOT's 1 and 2 to be the major reasons for the rejection ($\rho = 0.0058$, 0.0003 , respectively); with PLOT 5 also being a minor contributor.

With the variable Be-7, the F value of 2.028 ($\rho = 0.047$) was obtained for the data set. Subdivisions showed once again the significance of PLOT's 1 and 2 in the value of the rejection regions. When considering the SOUTH side data set, an $F = 1.832$ ($\rho = 0.120$), thereby accepted the null hypothesis of the means being equal. Further analysis revealed PLOT's 1 and 2, with values of $\rho = 0.051$ and 0.056 , respectively; indicating that these points rejected the null. A conclusive interpretation of these data will be conducted in the DISCUSSION section.

For Rb-83, the ENTIRE data set evolved an $F = 12.680$ ($\rho = 0.00001$), quite significant to reject H_0 . In this case, PLOT 1 was the major contributor, with a slight chance of rejection seen in PLOT's 4 and 5. In the breakdown of the data, SOUTH had an $F = 10.722$ ($\rho = 0.0001$), which was also considered quite significant. PLOT 1 remained the prime contributor ($\rho = 0.0000$), while PLOT's 4 and 5 added. In the NORTH side, an F of 6.629 ($\rho = 0.00001$) was also

calculated; PLOT 1 ($\rho = 0.0000$), PLOT 4 ($\rho = 0.0939$), and PLOT 3 contributing slightly. All results shown above strongly rejected H_0 and accepted the alternate hypothesis of the model with at least greater than 98% probability.

The next dependent variable was Cs-134. An F value of 4.058 ($\rho = 0.00025$) was found, with PLOT's 1 and 2 contributing a great deal to the rejection of H_0 ($\rho = 0.00013$ and 0.0145 , respectively). Further analysis showed the SOUTH side data with an $F = 3.116$ ($\rho = 0.0146$), with PLOT's 1, 2, and 5 contributing slightly to the rejection of the null. In the NORTH side, a $F = 1.927$ ($\rho = 0.0749$) was found, which should have accepted the (because $\rho = 0.05$ is considered the limit). It could then be determined that PLOT's 2 and 5 added some to the final interpretive value. In general, all of the above F values were found to reject the null and accept the alternate hypothesis ($\mu_1 \neq \mu_2 \neq \mu_3$), with a high degree of probability.

The last element of concern was Mn-54. The determined F value was an 6.570 ($\rho = 0.00001$) for the ENTIRE set; PLOT's 1 and 2 added significantly, with $\rho = 0.00000$ and 0.0439 , respectively. These values were found to reject the null and accept the alternate. In the breakdown of the SOUTH side, an F value of 7.029 ($\rho = 0.00003$) was obtained, with PLOT 1 ($\rho = 0.00001$) contributing. In the NORTH set, a value of $F = 2.393$ ($\rho = 0.027$) was derived, with PLOT 1 having a $\rho = 0.0007$, and PLOT 2 adding some to the final rejective value.

The final independent variable of interest was TROPLVL, the trophic level sampled. The subcomponents tested were water, soil (if one considered these first two "abiotic" components trophic levels), vegetation, and rodents. The ENTIRE data set for Co-57 yielded an F equal to 18.720 ($\rho = 0.00001$); highly significant at greater than 99.9% probability for the rejection of the null, and the acceptance of the alternate hypothesis (H_a). In the breakdown,

it was found that TROPLVL 1 and 2 had significant values of rejection of H_0 ($\rho = 0.00616$ and 0.00000 , respectively). When looking at the SOUTH side data itself, an F value of 8.088 ($\rho = 0.00014$) was discovered to be quite significant. TROPLVL 1 and 2 showed probabilities of $\rho = 0.0625$ and 0.00002 , respectively. For the NORTH values, $F = 9.7147$ ($\rho = 0.00003$) was obtained, while TROPLVL 1 and 2 also yielded valuable results of $\rho = 0.0667$ and 0.00000 . All values were found to significantly reject the null.

For the Beryllium-7 analysis, the ENTIRE data set had an F value of 5.521 ($\rho = 0.00134$), with only TROPLVL 2 yielding a significant number ($\rho = 0.00016$), rejecting the null. In SOUTH values, an $F = 2.6103$ ($\rho = 0.0599$) was obtained. Theoretically, this value should be accepted to H_0 , but since it was so close, and a larger sample size would undoubtedly change it, the value could be considered adequate to reject the H_0 . If the previous statement is accepted, then the TROPLVL 3 ($\rho = 0.0114$), is quite adequate to reject H_0 . In the NORTH side data, an F value of 2.5857 ($\rho = 0.0627$) was also obtained. Since the F was accepted in the SOUTH side data set, the data must also be accepted for the same reasons. Further endeavors yielded TROPLVL 2 with $\rho = 0.0091$; quite enough to reject H_0 and accept the alternate hypothesis.

While examining the Rb-83 results, a F value for the ENTIRE data set was calculated, where $F = 39.2514$ ($\rho = 0.00001$). Further analysis showed all sub-components to have significant values to reject H_0 ($\rho = 0.00000$, 0.00393 , and 0.00000 , respectively). When looking at the SOUTH side, an $F = 16.830$ ($\rho = 0.00001$) was found, with all three subcomponents also rejecting the H_0 ($\rho = 0.00002$, 0.01263 , and 0.00000) at quite high levels of probability. In the NORTH analysis, an $F = 22.614$ ($\rho = 0.00001$) was obtained. All three sub-units were significant to reject the null hypothesis (H_0).

For Cesium-134, the ENTIRE data set showed an F value of 7.1728 ($\rho = 0.00017$), with TROPLVL's 1, 2, and 3 yielding $\rho = 0.0125$, 0.00005, and 0.0527, respectively. In the SOUTH analysis, the F = 3.1715 ($\rho = 0.0308$) was found, with TROPLVL 2 being the only significant value ($\rho = 0.00439$). In the NORTH data, an F value of 3.5287 ($\rho = 0.0209$) was obtained from the statistical analysis, with TROPLVL's 2 and 3 showing significant results ($\rho = 0.01200$, and 0.06021, respectively). TROPLVLs' 1 value was close, but exceeded the limit of acceptance. In general, the H_0 was rejected at TROPLVL's 2 and 3, and was accepted with a high level of probability.

The last dependent variable of interest was Mn-54. The ENTIRE data set arrived at an F value of 12.1178 ($\rho = 0.00001$), with all subunits reaching high values of acceptance ($\rho = 0.00033$, 0.00004, and 0.00004). All values considered rejected the null and accepted the alternate. When looking at SOUTH side data, it was seen that an F value of 6.6366 ($\rho = 0.00063$) was reached, with all subsequent subunits also with significant values for rejection ($\rho = 0.00639$, 0.00164, and 0.00308). In the NORTH data set, an F = 5.1318 ($\rho = 0.00344$) was also obtained. All TROPLVL's (ie., 1, 2, and 3) were found to have high probability values ($\rho = 0.03276$, 0.01153, and 0.00592, respectively). The results for the ENTIRE, NORTH, and SOUTH data sets for Manganese-54 showed that the null was highly rejected, and that the alternate hypothesis of differential uptake was strongly accepted with at least a greater than 99.9% probability level.

DISCUSSION

Along with the increasing use and development of nuclear reactors and other systems utilizing nuclear components, arises the increased availability of transuranics and a multitude of other radioisotopes that are being produced as a consequence of these activities. All contaminants have the possibility of readily moving through the environment, reacting and accumulating with other partitions (trophic levels). This idea of accumulation and retention in the environment is not all that well understood at this time. Investigators are interested in the behavior, accumulation rates, and physical attributes that exist as a consequence of the radionuclides' availability to the various environmental levels. There also a significant interest in the transfer and accumulation rates in the higher trophic levels, such as man. Questions that arise as a result of these interests include 1) What is the possibility of the accumulation and transfer (and the level of significance) of these radionuclides within the environment, especially among the higher order trophic levels?, 2) Are these contaminants (radionuclides) of any metabolic or physiological importance?, or 3) Do the radioisotopes interact to increase or decrease the availability to other biological systems.

In an attempt to address these questions, this study was designed to provide accurate estimates of the contamination available to the environment from these waste-water ponds, an understanding of the biopathways and interactions of the radionuclides, and to develop procedures that may alter or eliminate the exposures to which the biota are exposed. Other problems that might be addressed when analyzing these data sets could include a mathematical analysis of the transfer coefficients of the radionuclides. Can a model be devised that would accurately predict the pathways and concentrations at any level in the foodchain? By

gathering data such as accumulation rates and concentrations, bioaccumulation factors, site concentrations, soil and water characteristics, along with various climatological data, modelers (Eberhardt and Nakatani, 1969; Eberhardt and Hanson, 1969) can attempt to accurately predict the concentrations at any time, at any level (Reichle et al., 1970; Kitchings et al., 1976, Auerbach, 1965).

The first question concerned the possibility of significant distributions of radionuclides within the surrounding biota. The water concentrations were directly related with the variable quantity and time of the outflow associated with the beam-stop. Soil penetration around the ponds was negligible because of the concrete and clay sealers applied to the ponds during construction. Vegetation was virtually non-existent on the periphery of the ponds. After consultation with a biostatistician, appropriate sample grids were constructed, and several trapping sessions were conducted. The mice were analyzed with a NaI(Tl) type detector to determine gross gamma activity. The results indicated that while some of the mice were contaminated ($\simeq 41\%$), only 4% were considered sufficiently contaminated for further quantitative analysis. These results were in good agreement with results found by Garten (1981) and Garten et al. (1981), where they compared actinide uptake in cotton rats inhabiting the shoreline of a waste disposal pond. Garten found that because there was a lack of sufficient transfer medium (vegetation) that would provide a vector of transport of the radionuclides in the ponds, there was little radionuclide contamination within the rats. If the ponds lacks sufficient vegetation to support a small population of rodents, then the possibility of external contamination to the next trophic level is unlikely. Garten also noted that there could be contamination uptake through the ingestion of contaminated soil particles. After careful consideration of the preliminary data collected from measuring the rodents, the

contamination directly around the ponds was considered negligible. There was no further investigation in this area.

A better, more indicative study site of the contamination scenario was selected. This area was the outflow stream flowing east of the ponds. Here, an adequate transfer medium existed in abundance, supporting further study. Preliminary analysis was conducted, giving rise to the question concerning the difference between samples in the study and control sites. A Student's t-test was performed on the two sets of data. The results provided a t-statistic that rejected the null (H_0), and accepted the alternate hypothesis (H_a) that there was a significant difference in the contamination between the study and control site populations

The next question concerned the distribution of the contamination within the study site. At each sample site, soil and vegetation samples were collected and brought back for analysis. Trapping sessions were also conducted to determine species distribution and whole body concentrations. All vegetation collected were of the Gramineae family. These plants had been shown by Golley et al. (1975) and Martin et al. (1951) to be one of the primary food sources for small rodents in this habitat type, especially since approximately 90% of the mice captured were of the species Peromyscus maniculatus. Important reasons for using Peromyscus maniculatus as the study animal was that 1) a large proportion of their diet may consist of hard-bodied arthropods, which Van Horne (1982) and Reichle et al. (1970) consider to be an excellent bioindicator of radionuclide contamination, and 2) this species is considered to be omnivorous feeder.

The next test examined whether differences existed in the concentrations of the radionuclides within the plots (PLOTS) or the transects (TRAN). After the ANOVA analysis was completed, the SOUTH side plots were found to be statis-

tically different, while the transects did not. The soils PLOT results followed expected cobalt distribution through a stream bed (Kitchings et al., 1976). Kitchings et al. found lower concentrations as you moved farther away from the stream channel, as what was found here. They attributed this effect to the filtering effect of distance away from the source. In the NORTH data set, the vegetation data set accepted the null, while the soil rejected it. These results showed that there was no statistical significant difference in the concentrations of the radionuclides down the stream (Station Numbers). This would be expected since the flow down the stream should be homogeneous. The significant difference was found within the plots, away from the stream. The variation of the activities of the soils and vegetation could be a function of the distance away from the stream, varying pH of the water and soil moisture, cation-exchange capacity of the surrounding soils, clay fraction, percent organic material, the soil moisture and solubility of nutrients within the soils (Menzel, 1954; Arthur, 1982; and Essington et al., 1981). Figures 13, 14, 15, 16, and 17 to provide a graphical representation of the concentrations of each elements and matrices sampled along the study site.

The analysis of data through the use of Pearsons' Product Moment Coefficient of Correlation was used to determine the interaction among the dependent variables (the elements). The statistical values ranged from +1 (positive relationship) and -1 (negative relationship). The value zero indicated no relationship (an independent function).

The cobalt/rubidium interaction within the waters provided a statistically significant negative relationship. One probable cause for these results could be seen in work by Bate and Leddicotte (1961), where their results suggested that the decline in concentrations could be due to high eutrophication of the water body, which would tend to complex cobalt into an insoluble and unavailable form.

Figure 13. Co-57 Activity Distribution Gradients within the Varying Matrices Sampled Around the Outflow Stream.

Figure 14. Be-7 Activity Distribution Gradients within the Varying Matrices Sampled Around the Outflow Stream.

Figure 15. Rb-83 Activity Distribution Gradients within the Varying Matrices Sampled Around the Outflow Stream.

Figure 16. Cs-134 Activity Distribution Gradients within the Varying Matrices Sampled Around the Outflow Stream.

Figure 17. Mn-54 Activity Distribution Gradients within the Varying Matrices Sampled Around the Outflow Stream.

Similar results have been seen by Vanderploeg et al. (1975). The most independent interaction found was the Co/Be matrix. Fairhall (1960) suggested that the high level of independence could be due to beryllium's strong tendency to form insoluble hydrolytic species in neutral aqueous solutions.

Beryllium/Cesium interactions provided a significant positive interaction. Finston and Kinsley (1961) suggested that the positive relationship among these two elements (as one increases, so does the other) could be due to variable chemical state of cesium, and its high solubility.

Rubidium analysis provided few significant statistical values (positive relationships). It has been assumed that chemical elements of the same elemental group (ie., chemical analogues) were considered to react or behave similarly in solutions or other environments. If the element has a lower atomic number in that same period, then it is more electronegative and perhaps more reactive. This finding was not supported by the test statistics calculated in this study. Spiers (1968) found that the uptake or distribution of a radioisotope in a system was fundamentally controlled by its chemical behavior, which depended upon numerous factors in that particular system. He concluded that just because an element is an analogue of another, one cannot expect it to follow the same pathways. Even though both radionuclides provided a high level of positive significance, the Rb/Mn value was the highest encountered. One probable reason for the lower Rb/Cs ratio could be caused from the high eutrophication of the pond that is complexing a large amount of the cesium and not allowing that portion of soluble cesium to be free (Vanderploeg et al., 1975). Low cesium values could also be a result of the large amounts of clay in the ponds complexing the cesium (Eyman and Kitchings, 1974), pH of the water and soluble potassium concentrations (Alberts et al., 1979). The mixed test statistics could also be due to the valence state of the manganese compound present (Wangersky, 1961).

The cesium/manganese interaction in waters provided a high statistical degree of significance, a positive relationship. The values gathered here suggests that even though there was a difference in uptake by the water, both were taken up in a similar positive rate. This then suggested that manganese did not totally exclude cesium distribution in the pond water.

In the soils, the following data sets were compared: 1) NORTH, 2) SOUTH, and 3) ENTIRE. The data were analyzed in this fashion to determine if the side in which the sample was taken had any affect on the final statistical value.

Cobalt provided a high level of statistical significance to reject the null hypothesis; there was a difference in concentrations in the sides. The cobalt/manganese matrix in the SOUTH side provided the highest level of interaction. Broseus (1970) concluded that areas with high soil moisture and low cation-exchange capacity would increase the availability of cobalt very effectively. This increased soil moisture is surely present along the stream bed. Analysis of similar soil types by Nyhan et al. (1978) found cation-exchange capacities of approximately 40-50 meq/100 g. This data could suggest the reason for high cobalt uptake in the soils around the overflow stream. The only factor that might alter the uptake and interaction between the sides could be due to the site's topography. Since the study site has a slight southward slope, this might cause that side to have a slightly higher soil moisture percentage, thereby lending to increased availability. When examining the high manganese uptake, these aforementioned factors could be altering the interactions. The availability of soil manganese was also closely related to the activities of microorganisms that alter the pH and oxidation-reduction potentials (Bromfield, 1958). Adding organic material to soils can reduce manganese availability by increasing populations of manganese-oxidizing microorganisms and by forming organic manganese

complexes (Timonin and Giles, 1952). Morgan (1966) observed that a high pH value was required to initiate precipitation of Mn from a pure Mn^{+2} solution, to one of availability ($pH > 8$); these factors all vary the manganese availability at the LAMPF ponds. First, the soils are of low organic content (Nyhan et al., 1978), which thereby lessens the number of microorganisms that bind the manganese. Next, McCorkle (1982) found extremely high pH values in the pond water (average $pH > 10$), which could alter the soil pH, and thereby provide a relatively good source of available manganese without the interference of various other soil parameters.

In the remaining results of the various elemental interactions in soils, the beryllium/cesium interaction was highest in the NORTH block. This could be due to the high soil fixing capacities or interactions with other elements (Cummings et al., 1969). The rubidium/manganese interaction in the SOUTH side could be caused by high interaction among the other elements.

Vegetation, the next variable to be examined, showed a high variation in the results. The cobalt/rubidium test statistic provided the highest level of positive interaction, with the remaining elemental interactions showing significant levels of interaction. Menzel (1965) found that both rubidium and manganese were strongly concentrated in vegetation in the presence of cesium. He also suggested that plants might act as ion-exchangers and exhibit selectivity or preference for rubidium over sodium. Elevated manganese levels could be due to the valence state of the manganese present, of the pH of the medium in which the plants grow (Adams and Pearson, 1967; Parker et al., 1969). Vlamis and Williams (1962) believed that a high pH in the aqueous medium would complex manganese into an insoluble form (since the ponds have a high pH value, one would expect this situation to occur). In contrast, Menzel (1975) believed that most of the salts of the elements were soluble in water, and their solubilities did not change with

the pH of the solution. The reason for the greater interactions in the NORTH than in the SOUTH vegetation data set has not yet been determined, especially since greater interactions were found to occur in the SOUTH soil data set. A suggestion for this variation might stem from the fact that the SOUTH side has highly elevated soil moisture conditions, providing a more conducive environment for soil uptake. The soil might be too saturated for vegetative uptake, reducing probable interaction within the plants.

Beryllium test statistics for the ENTIRE and NORTH data sets were found to accept the null hypothesis, while the SOUTH data set rejected the null. The beryllium/cesium provided the highest level of significance. Romney and Childress (1965) found that beryllium can have an inhibitory effect on manganese levels. Beryllium may also out-compete other elements (Arthur, 1982). The rubidium analysis showed similar results as seen in the beryllium set. Manganese interactions were now elevated over cesium, since the beryllium inhibition was gone. In the cesium results, the high coefficients of determination were found in the NORTH, where soil factors may have pre-determined the availability of manganese on this side.

The next trophic level to be examined for radionuclide interactions was the rodents (mice). The results varied, with no trends distinguishable. A high cobalt/manganese interaction was contradictory to previous ideas. Greenburg et al. (1943) and Pollack et al. (1965) indicated that manganese uptake in small mammals was poor. Ekman (1969), also noting variations in his data, suggested that various chemical states of the radionuclides ingested, the composition of the diet, the physiological and nutritional state of the animal, along with the age and genetic characteristics of the animals could greatly vary the interaction of the elements within the organism. Cobalt assimilation within mammals was also poor (Kaye and Dunaway, 1962). One suggestion for the inconsistent findings

might be that when two poorly assimilated elements are at work in the presence of one another, there can be a synergistic relationship emerging between the elements that might allow for such a high coefficients of determination. Abrams et al. (1976) suggested that manganese assimilation could be altered by various metals or other dietary constituents - perhaps this was so in this case. Rubidium was also shown to attain a high statistical significance. It seems that rubidium (being the more electronegative) was taken up to a greater degree than what was seen in the previous analyses. This is contrary to earlier conclusions suggested by Hamilton (1947), where he found higher (100%) metabolism with cesium. Relman et al. (1957) even suggested that cesium uptake would be greater than rubidium.

The beryllium/cesium statistic provided variation in the NORTH and SOUTH sides. The NORTH side showed a negative causal relationship between the two radionuclides. Hood and Comar (1953) suggest that the low cesium interaction in the rodents may be due in part to the age of the animal. The older the animal, the less uptake and greater interferences caused by other elements. The reverse was evident on the SOUTH side, a high positive relationship. No theory why this occurs has been suggested.

The cesium/manganese relationship provided a high positive level of significance. One suggestion might be due to some chemical constituent (ie., higher alkali or metal concentrations as a consequence of the lower flushing rates associated with the drier NORTH site), that might be affecting the distribution of these elements (Abrams et al., 1976).

MANOVA

Within this set of statistical analyses, the distribution and accumulation of the nuclides within the study area was being examined, along with the deter-

mination of the variance associated with the variables SIDE, PLOT, TRAN, and TROPLVL; a multivariate analysis (results are seen in Appendix I). The exact interactions are not the focus of attention with this particular statistical approach. In this examination, the sites where the accumulation and the variations associated with each independent variable occur are more important.

The ENTIRE data set was the first to be analyzed. By examining the final F statistic, it was determined that this set showed no significant difference in the data set. This indicated an acceptance of the null hypothesis; there were no significant differences in the means of any set of that block of data. Upon closer examination of the NORTH and SOUTH data sets, some significant differences were noted. Rb-83 provided the highest significant test statistic to reject the null hypothesis, with regard to sides. Leddicotte (1962) suggests that high variations in rubidium could be caused by the solubility of the element in water. Due to the variation of percent soil moisture by sides, the SOUTH side rubidium levels may be decreased as a consequence of the highly saturated soils.

TRAN, the next variable to be analyzed, compared the differences between transects down each of the NORTH and SOUTH sides, along with the ENTIRE data set. Cobalt analysis for the ENTIRE set of TRAN provided only one significant difference; transect number 11 - rejection of the null hypothesis. Both NORTH and SOUTH sides at transect 11 also showed a high degree of significance to reject the null. This significant rejection of the null hypothesis could be based on two facts: 1) In this area, the number of samples taken in these last plots were significantly greater than those taken in any other transects (6 vs. 2), and thus allowed a better statistical estimate, and 2) Due to the physical layout of the area, there tends to be a "delta" of soil that had been washed from upstream, and has therefore spread contamination over a greater area than the confines of the upper portion of the stream channel. This provides a gradient

of contamination readily seen in the statistical analysis (again, refer to Figures 13-17 for graphical representation of the contaminant concentration gradients). Another reason for other contaminated zones could arise from the accidental sampling of "hot" spots; non-homogeneous sampling.

Beryllium analysis provided no statistic to reject the null hypothesis. Perhaps the sealants in the pond absorbed the beryllium to a degree that inhibited the variation among the transects. Another suggestion might be that the vegetation acted as a buffer to the excess contamination, and that it might also have maintained a stable vegetative concentration (Hoagland, 1952; Maze and Maze, 1939). Rubidium analysis provided significant statistics to reject the null, in many cases. In the ENTIRE set, transects 6 and 7 showed major differences, while in the NORTH, transect 4, 2, and 10 provided a minor difference. The stream configuration played an important part in this statistic set as was previously seen. Both cesium and manganese concentrations provided similar variations in the latter transects. This could be due in part to the fact that soil has been found to partially regulate cesium uptake in a variety of species (Shanks and DeSelm, 1961; Arthur, 1982).

The next breakdown in the MANOVA analysis concerns the variable PLOT. The statistical test examines the varying concentrations observed as one moves away from the stream. Cobalt analysis showed significant statistical differences out to the second plot, which is equivalent to 6 meters (18 feet). Several factors (which were common inhibitors of the other elements as well), could have altered the distribution. Among them, cation-exchange capacities (Eisenbud, 1973), high soil moisture or potassium levels (Broseus, 1970), and the organic content (Garner, 1972). It has been generally considered that even with the best of conditions, migration of an element into the biota becomes extremely limited as a function of the distance (Lerman, 1972).

Beryllium concentrations were only found to differ in the ENTIRE data set with little significance, while both NORTH and SOUTH test statistic accepted the null hypothesis. Variances could have been a product of 1) The high number of samples collected, altering the final F-value, or 2) Because of the bentonite lining of the ponds and its extreme affinity for beryllium (Romney and Childress, 1965), extremely low concentrations may have been passing without penetrating the soil to any degree.

The remaining three dependent variables to be tested (Rb-83, Cs-134, and Mn-54) all showed significant values to reject the null. For all cases, except rubidium in the ENTIRE and SOUTH sets' plots 4 and 5, all figures were significant for the first 2 plots (6 ft.). Again, previously mentioned factors that played a part in earlier elemental distribution were active in these regions also.

The last, and probably most important variable of interest, dealt with the trophic levels (TROPLVL), and the variance between them. In the first analysis, which dealt with cobalt, concentrations were found to be significant to reject to null in the first two trophic levels (water and soil); for all data sets. What was interesting to note was the extreme significance of the second trophic level, and its difference from the first. This halt at the second level tended to follow earlier beliefs by Vanderploeg et al. (1975) that these metals were easily complexed with organic molecules, which then significantly lowered the availability to the plants. Since the role of cobalt in these terrestrial ecosystems was so dependent upon the availability of the nutrients to the organisms, and if the levels were reduced to lower trophic levels, then bio-accumulation could certainly be decreased. If, by chance, the soil factors allowed the transfer of cobalt, it could not have been actively concentrated in the plants according to Menzel (1965), and even less in the higher vertebrates

(Reichle et al., 1970; Halford et al., 1979; Abrunia, 1963B; and French et al., 1965).

The beryllium analysis found that all data sets had significant statistics to reject the null, up through the first two trophic levels. The possible suggestion for the great variance in the second trophic level may be a result of the high clay content in the soil; perhaps too tight to allow transport to the next levels (Romney and Childress, 1965). Menzel (1965) even considered beryllium to be actively excluded from plants. In the next trophic level, the uptake and distribution was extremely limited, if not actively excluded. Crowley et al. (1949) found no evidence to suggest any concentration in rats, while Mullen et al. (1972) found that orally administered doses were rapidly excreted within the first four days after administration.

When analyzing the rubidium results, extremely high values (ie., $F = 39.25$) were found that significantly rejected any null hypothesis; this was true for all the sides. Results indicated acceptance of the alternate hypothesis at the first three trophic levels, with strong implication on the fourth. In the NORTH data set, a close level of rejection was found at the second trophic level (90% probability), most likely due to a slight statistical fluctuation in the data set. The concentrations in water followed trends seen in earlier studies by Scott and Hayward (1969). The soil and soil-plant transfer also followed what had been seen in earlier studies. Fried et al. (1959) found that rubidium was actively concentrated in soil, and the rate was affected by the presence of high levels of soil potassium or added (stable) carrier rubidium. Soil-plant concentrations for rubidium had been shown to be extremely high (10 - 10,000 times) by Menzel (1965). Most likely due to the plants ability to selectively concentrate rubidium over other major soil constituents.

Richmond (1958) and Kilpatrick et al. (1956) have shown rubidium to be

concentrated in animals, with 98 - 100% absorption from the gastrointestinal tract. Mraz and Patrick (1957a) found that the diet played an important part of this accumulation. They concluded that if no suitable materials were present in the gut to remove or absorb rubidium at the time of ingestion, then the rubidium would pass back into the body fluids and either be excreted or recycled.

The cesium results provided a high level of significance to reject the null in both the ENTIRE and NORTH data sets, while the SOUTH provided statistics to reject the null at the second trophic level. Essington et al. (1981) found that cesium was rapidly absorbed and concentrated in the various soils studied. When cesium was transferring from soil to plants, concentrations occurred, but not at the levels previously suggested. This could be seen in the data comparing the two F statistics - the plant F-values were less significant than those of the soil. Many factors may have affected the concentration in the plants, such as the length the isotope had been fixed in the soil matrix (Shanks and DeSelm, 1961), and the age of the plant (Cline, 1981).

The levels found in the rodents were significant. The values encountered were somewhat lower than was suggested in the literature, where Hamilton (1947) found 100% absorption from orally administered doses. Baker and Dunaway (1969), and Garten (1979) found high retention and distribution of cesium in rodents. One theory by Wasserman and Comar (1961) suggests that as the dietary potassium level increases, cesium retentions within the body decreases. Fried et al. (1959) found that increased potassium levels decreased the fixation of rubidium in the soil, and allowed an increased uptake in the plants. Cesium has also been known to increase in concentration levels (accumulate) in higher order trophic transfers, such as the plant - mule deer - cougar relationship seen by Pendleton et al. (1964), the lichen - caribou - eskimo system (Hanson, 1971), and other mule deer concentration studies (Hakonson and Whicker, 1969, 1971). The results of this study

correspond well with the literature. Reasons for the for the low accumulation in the SOUTH data set has yet to be determined, especially since higher concentrations were found in the soil set (SOUTH) in earlier analyses.

Manganese-54 was found to be quite significant in all levels in all the data sets. In the aqueous medium, concentrations were prevalent and varied, especially changing with the level of eutrophication within the ponds. Marshall and LeRoy (1973) found manganese to concentrate on the order of 10^2 to 10^4 in aquatic systems. Foy (1973) found that the accumulation of manganese within soils varied greatly with the physical aspects of the soil.

Tissue concentrations varied with such conditions as the amount ingested and the existing tissue levels (Piscator, 1979). Generally, absorption and accumulation was considered to be relatively poor (Greenberg et al., 1943); Pollack et al. (1965) reported that only 2.5 - 3.5% of an orally administered dose was absorbed by the rats. This data was supported by the low test statistic derived from the mice data set. Suggestions concerning minimal uptake might be caused by the ability of manganese to interact with other metals in the system (Diez-Ewald et al., 1968).

CONCLUSIONS

The goal of the study was to examine the comparative uptake and interaction of five radionuclides (Co-57, Be-7, Rb-83, Cs-134 and Mn-54) in the abiota/biota portions surrounding the Los Alamos Meson Physic Facility (LAMPF) waste-water pond outflow. Can the interactions among the radionuclides be altering the availability of these isotopes to the ecosystem? Can the biotic and abiotic portions of the ecological community become "biological sinks" for these radionuclides? To answer these questions, a variety of statistical examinations were employed to test the raw data set, as was discussed in the earlier sections.

Pearson's Correlation Coefficient statistical examination tests the significance of interactions among the elements. Most of the radionuclide interactions examined followed what had been defined in the literature. The cobalt/manganese interaction provided a significant positive relationship. Broseus (1970) found high levels of cesium in soils that had low pH, high percent soil moisture, and a high cation-exchange capacity. These factors also allow the high uptake of manganese within the same medium (Collins and Buol, 1970). Rubidium, which closely resembles cesium in its chemical behavior, provided high positive interactions. Beryllium, which closely resembles manganese (Fairhall, 1960), had the highest positive statistic (0.9645). All statistics concerned with the vegetative interactions, which were significantly lower than seen in the soils, showed positive relationships. With the highest test statistic (0.8968), and both elements considered to accumulate in high levels (Spitsyn et al., 1958; Lockman, 1970; Parker et al., 1969), cesium and manganese showed significant positive relationships. The interactions in the rodent test was variable. The highest test statistic was encountered in the rubidium/manganese test, not in the rubidium/cesium as was expected (Weeks and Oakley, 1955). This could be

due to the ability of rubidium (a potassium analogue) to out-compete cesium for the available sites in the body (Relman et al., 1957, Follis, 1943).

The final statistical analysis (MANOVA) examined the various levels of accumulation among the five dependent and independent variables. This test, while similar to the ANOVA statistical test, provided the ability to distinguish not only the independent variable with which high test statistics were associated, but the component within which was producing the high test value. While all components of position in the study area were examined (ENTIRE, NORTH, and SOUTH), only the side values were considered in the final analysis.

In the transect (TRAN) analysis, and all the varied radionuclides, provided all test statistics to accept the null, except for Rb-83 on the north side. This again may be explained by the stream configuration at the lower end of the stream, where a "delta" exists that broadens the range with which the nuclides can diffuse. This can also be noted by the variations in the t-values of the number 11 transect component, in all the transects.

The plot (PLOT) variable provided suitable test statistics to reject the null hypothesis for every radionuclide. The data provides evidence that higher F-values do exist on the SOUTH side of the study area. This may be a function of the general soil characteristics found on that side. The most prominent feature may be the percent soil moisture in this side due to the general topological features of the site (slight sloping to the south). The literature (Garner, 1972; Eisenbud, 1973; Fairhall, 1960; Adams and Pearson, 1967) has suggested that variables such as this can, and do, affect the availability of the radionuclides in the soil. Be-7 showed the lowest level of significance (difference in concentrations within the different plots), due to its propensity to tightly adhere to clay particles (Romney and Childress, 1965). Rubidium, with the highest test statistic, was readily available due to its sol-

ubility in soils with high percentages of soil moisture (Leddicotte, 1962). The test statistics generated by the NORTH side provided positive, but less impressive, test values as found in the SOUTH side.

The statistical analysis of the trophic levels provided interesting test values. All matrices tested provided test values significant to reject the null and accept the alternate hypothesis, although the difference in the side of the study site did not factor into these statistics. Beryllium-7 once again had the lowest test statistic. This could be due to 1) that because the beryllium is held tightly in the soil matrix, or accumulated in the plants (Menzel, 1965), that the remaining trophic levels have little left to accumulate, or that 2) in higher order mammals, beryllium is readily removed from the body (Scott et al., 1950). Both conclusions are supported by the data; a high t-value (2.6130) in the plant compartment, with a low test statistic in the mammal (-0.6612). While both tests provided positive test statistics, these results contradict earlier work. Menzel (1965) suggests that cobalt is an element that is "not concentrated", while the test statistic for the plant component is significant at 4.6740. Cesium on the other hand, is an element that is considered highly concentrated within the trophic level hierarchy, more so in the higher trophic levels (Halford et al., 1981; Halford et al., 1982; Hamilton 1947). While Cummings et al. (1969) suggests low level accumulation within the lower trophic levels, the test statistics show a significant value in the plant compartment (2.965). The next compartment in the trophic level was the cesium-134 test component. A element which should accumulate to significant levels (Ballou and Thompson, 1957; Hakonson and Whicker, 1971), provided a relatively poor test statistic value of 0.7500. Manganese accumulation was prevalent in the plants, as Wangersky (1961) suggested. The test statistic also showed a significant t-value in the last compartment of the trophic level. Greenberg et al. (1943) had previously shown that this element was

not accumulated. The results from this suggests that some form of accumulation was taking place (3.0894). As was discussed earlier, all of the test statistics for the north side followed the pathways found in the south side, except for rubidium. An extremely high test statistic (7.4478) was noted in the trophic level examination. This could be due to rubidium's proximity to potassium, and its ability to assimilate in the body relatively easily (Clark, 1922; Relman et al., 1957; Macleod and Snell, 1948).

Because of the on-going debate concerning the effects of long-term low level radiation on biological systems (Upton, 1982), it is felt that the interpretation of data such as this must be undertaken in a realistic fashion. The evaluation of the hazard from environmental radioactive contamination must consider not only the metabolic utilization of the radioisotopes, the various soil characteristics, but also the ecological and behavioral influences which affect the availability of the material. The physical aspects of deposition of the radionuclides within the environment must also be known. The ultimate goal is to be able to provide data and develop the capacity to assess the potential impacts from radionuclides released from all sources in the "nuclear" cycle.

RECOMMENDATIONS

The following is a set of recommendations that I feel would benefit future studies of a similar nature. These suggestions were generated during (and at the completion of) the course of this study, when the shortcomings and problems associated with this study were encountered. The following suggestions should be addressed when examining any type of radioecological study, similar or otherwise:

- 1) A much more detailed soil analysis program is needed in order to determine the exact parameters needed to analyze radionuclide transfer. Because the soil can have such a significant effect on the transfer of radionuclides in ecosystem, this can probably be one of the most important variables examined;
- 2) In the statistical analysis, all tests were based on a point-estimate value. This was the calculated mean value of that data set. A more interesting point of view would be to take all the values, calculate their ranges through the standard deviations, and then incorporate these new numbers (one low and one high) in the statistical analysis. Then observe the nature of the results obtained through this particular method, would we see greater variations within the data set?;
- 3) To get an exact analysis of what transfers, define a specific trophic level and model it. Excellent examples of this are seen in studies by Eberhardt et al. (1969), Labellarte (1973), and Patten and Witkamp (1967), where specific systems were modeled, and accurate estimates were made of the radionuclide transfer in that specific system;

4) An internal dosimetry program using the rodents which inhabit the environment of the waste-pond area overflow area, for the determination of actual doses received (ie., Halford and Markham, 1978), or mark the regions in a grid system and plant TLD's (thermoluminescent dosimeters) for accurate surface dosage determination;

5) A compartmental study of the exact distribution in one species, such as the violet-green swallow, would be an excellent method for the exact determination of the uptake and accumulation for a variety of radionuclides of interest;

6) Determine the bioaccumulation factors for this particular aquatic system, such as seen in the study by Vanderploeg et al. (1975); and

7) Try and implement various techniques ascribed to halt or alter the transfer of radionuclides in a situation such as this; ie., flocculation, sedimentation, filtration (biotic and abiotic), and acidification of the ponds and the outflow stream.

These recommendations were made in part through the careful examination of other studies, and are intended to benefit future studies of this particular nature. Several of the suggestions mentioned would have made an excellent addition to this study, but time and monetary limitations prevented them from becoming part of this particular study.

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APPENDIX A

Species List of the LAMPF Lagoons

Species Utilizing the Pond

Birds-

Violet-green Swallow (*Tachycineta thalassina*)
Olive-sided flycatcher (*Nuttallornis borealis*)
Spotted Sandpiper (*Actitis macularia*)
Red-winged blackbird (*Agelaius phoeniceus*)
Wilson's phalarope (*Steganopus tricolor*)
Common raven (*Corvus corax*)
Song sparrow (*Melospiza melodia*)
Common nighthawk (*Chordeiles minor*)
Barn swallow (*Hirundo rustica*)
Rufous-sided tohee (*Pipilo erythrophthalmus*)
Western blackbird (*Sialia mexicana*)
Mourning dove (*Zenaidura macroura*)
House finch (*Carpodacus mexicanus*)
Killdeer (*Charadrius vociferus*)
Mountain bluebird (*Sialia currucoides*)
White-throated swift (*Aeronautes saxatalis*)
Cassin's kingbird (*Tyrannus vociferous*)
American coot (*Fulica americana*)
Common (gilded) flicker (*Colaptes aurata*)
Say's phoebe (*Sayornis saya*)

Mammals-

Desert cottontail (*Sylvilagus auduboni*)

Species Seen Around the Ponds

Birds-

Red-tailed hawk (*Buteo jamaicensis*)
Blue-grey gnatcatcher (*Poliophtila caerulea*)
Stellar's jay (*Cyanocitta stelleri*)
Pinon Jay (*Gymnorhinus cyanocephalus*)
Canyon wren (*Catherpes mexicanus*)
Graces' warbler (*Dendroica graciae*)
Mallard (*Anas platyrhynchos platyrhynchos*)
Turkey vulture (*Cathartes aura*)
American robin (*Turdus migratorius*)
Chipping sparrow (*Spizella passerina*)
Peregrine falcon (*Falco peregrinus*)

Tracks Seen Around the Ponds

Mule deer (*Odocoileus hemionus*)
Striped skunk (*Mephitis mephitis*)
Coyote (*Canis latrans*)

RADIOCHEMICAL STATISTICS

$$\langle X_i \rangle = \frac{\sum \frac{(X_i)}{(\sigma_i)^2}}{\sum \frac{1}{\sigma_i^2}}$$

FOR THE DETERMINATION OF THE MOST PROBABLE MEAN
VALUE ASSOCIATED WITH A SET OF ACTIVITY VALUES

$$\langle \sigma_i \rangle = \frac{1}{\sqrt{\sum \frac{1}{\sigma_i^2}}}$$

FOR THE DETERMINATION OF THE APPROPRIATE STATISTICAL
ERROR ASSOCIATED WITH THE ABOVE EQUATION

INSTRUMENT EFFICIENCY OF
GeLi SYSTEM

FOR MODEL 8100 AND SERIES 35 ANALYZERS
RESOLUTION OF 0.05% FULL SCALE

FOR DETECTORS:

#1- RESOLUTION 2.10 KeV FWHM @ 1.33 MeV

WARRANTED EFFICIENCY=
15.0% OF RATIO OF AREA
UNDER PHOTOPEAK TO THAT OF
A 3"x 3" NaI(ti) MEASURED
AT 1.33 MeV SOURCE TO
DETECTOR DISTANCE OF 25cm

#3- RESOLUTION 2.09 KeV FWHM @ 1.33 MeV
EFFICIENCY - 20%

#4- RESOLUTION 3.00 KeV FWHM @ 1.33 MeV
EFFICIENCY - 8.0%

APPENDIX D

Sample Spectrum & Parameter Definition

FILE= 2552 (File Number)

SAMPLE ID= 87.08668 (Sample Number)

OWNER= RW (Owner's Initials)

ANALYSIS= CS-137 (Requested Analysis)

QUAN,FACTOR,T(1/2)= 0.5000 1.0000 11012.0000 (Quantity (gms or liter),
Normalizing Factor, Half-Lives (days))

LOWER,UPPER= 640 680 (Integrated Limits)

EFF,SIGEFF,DET BKG,UNITS= 0.01060 0.15000 0.15000 PCI/L (Generated
Efficiency Values, Standard Deviation (%),
Background in CPM, and Units)

T0-HR,MIN,DATE= 12 1 8/28/87 (Collection Date, HH,MM,MM/DD/YY)

CT-HR,MIN,DATE= 12 1 9/29/87 (Count Date, HH,MM,MM/DD/YY)

PEAK TOTAL	BKGD	COUNT/SEC	CONCENTRATION
405.	397.	10000.	-19.23 +/- 32.80 PCI/L

APPENDIX E

PROGRAM GAMSPEC

C
C GAMMA SPECTRAL ANALYSIS PROGRAM FOR USE WITH RSX-11 FORTRAN
C INPUT: SAMPLE INFORMATION FROM THE TERMINAL,SPECTRAL DATA
C FROM DEVICE "US".
C OUTPUT: PLOT SPECTRUM OF INTREST, COMPUTE AND OUTPUT SAMPLE
C ACTIVITY.
C PROCESSING: INTEGRATE PEAK FROM USER PROVIDED INTEGRATION LIMITS,
C ESTABLISH BACKGROUND AND COMPUTE ISOTOPE CONCENTRATION.
C

C BILL GOODE, MAY 1980
C

INTEGER I,J,K	!INDEX VARIABLES
INTEGER ANAL(3)	!ANALYSIS NAME
INTEGER XL,XU	!LOWER AND UPPER PLOT BOUND
INTEGER LB,UB	!LOWER AND UPPER PEAK BOUND
INTEGER T0HR,T0MIN	!TIME ZERO HR AND MIN
INTEGER CTHR,CTMIN	!COUNTING HR AND MIN
INTEGER T0DATE(3)	!TIME ZERO DATE
INTEGER CTDATE(3)	!COUNTING DATE
INTEGER B1,B2,B3,B4	!MARKERS FOR BKG DETERMINE
INTEGER UNITS(5)	!ANALYSIS UNITS
INTEGER FILE(2)	!FILE SEQUENCE IDENTIFIER
INTEGER INFIL(9)	!INPUT FILE SPEC
INTEGER BASE	!OFFSET FROM BOTTOM OF SPEC
INTEGER RP R	!REC POINTERS IN DATA FILE
INTEGER HARD	!HARD COPY FLAG
INTEGER IDUM(2)	!DUMMY VARIABLE
INTEGER ID(5)	!SAMPLE ID
INTEGER WORD(5)	!10 CHAR WORD HOLDER
INTEGER OWN(2)	!SAMPLE OWNER
INTEGER NDATE(5)	!DATE FOR .GSL FILE NAME
REAL Q	!SAMPLE QUANTITY
REAL EFF	!COUNTING EFFICIENCY
REAL SIGEFF	!STD DEV OF COUNTING EFF
REAL DETBKG	!DETECTOR BKG
REAL Y(150)	!SPECTRAL DATA
REAL CTIME	!COUNT TIME IN SECONDS
REAL FAC	!CONVERSION FACTOR
REAL THALF	!HALF LIFE IN DAYS
REAL AX,SAX	!SAMPLE ACT,STD DEV OF ACT
LOGICAL OPEN	!UNIT 1 OPEN FLAG
LOGICAL*1 LBUFF(72)	!LINE BUFFER
COMMON /OVHD/LBUFF	
DATA INFIL(1),INFIL(2),INFIL(3)/'US','M','CA'/	
DATA INFIL(4),INFIL(5),INFIL(6)/'.D','AT',';' '/'	

C
C
CALL ERRSET(29,TRUE,.,FALSE,.,TRUE,.,TRUE,.,31)
CALL ERRSET(39,TRUE,.,FALSE,.,TRUE,.,TRUE,.,31)
OPEN=.FALSE. !SET FILE NOT OPEN

```

3   CALL DATE(ID)                !GET CURRENT DATE
   CALL TIME(WORD)              !CURRENT TIME OF DAY
   CALL IDATE(I,J,K)            !GET NUMERIC FORM OF DATE
   ENCODE(2,5,NDATE(1))I       !GET MONTH
   IF(I.LT.10)NDATE(1)=NDATE(1).OR."20 !OR IN BLANK IN FIRST DIGIT
   ENCODE(2,5,NDATE(2))J       !GET DAY
   IF(J.LT.10)NDATE(2)=NDATE(2).OR."20 !OR IN BLANK IN FIRST DIGIT
   ENCODE(2,5,NDATE(3))K       !GET YEAR
   IF(K.LT.10)NDATE(3)=NDATE(3).OR."20 !OR IN BLANK IN FIRST DIGIT
   NDATE(4)='G'                !SET UP FILE EXTENSION
   NDATE(5)='SL'                ! " " " "
5   FORMAT(I2)
   WRITE(5,6)(ID(I),I=1,5),(WORD(J),J=1,4) !WRITE HEADER
   WRITE(5,7)                   !GET BKG INTERVAL
13  READ(5,8,ERR=13)INT
   DATA IWID/3/                !GET BKG WIDTH
C
C
4   WRITE(5,10)                 !REQUEST FILE ID,COPY FLAG
   READ(5,*)I,HARD              !HARD=1 GENERATES FILE
11  IF(I.EQ.0)GO TO 65          !IF SAME FILE, SKIP OPEN
   IF(OPEN)CALL CLOSE(1)       !CLOSE OPEN DATA FILE
   ENCODE(4,12,INFIL(7))I      !CREATE FILE NAME SPEC
30  OPEN(UNIT=1,NAME=INFIL,READONLY,TYPE='OLD',ERR=4)!MCA DATA FILE
   READ(1,8,ERR=4)             !TRY TO OPEN,GOTO4 ON FAIL
   REWIND 1
   OPEN=.TRUE.                 !MARK FILE OPEN ON SUCC
   RP=0
65  IF(.NOT.(HARD))GO TO 75     !HARDCOPY FILE?
73  CALL ASSIGN(2,NDATE,10)     !LUN 2 = HARDCOPY FILES
   WRITE(2,81)(INFIL(I),I=7,8) !WRITE GAMSPEC HEADER
75  WRITE(5,82)(INFIL(I),I=7,8)
C
C GET PARAMETERS FOR ANALYSIS, ECHO TO HARDCOPY FILE IF NECESSARY
C FIELDS WHICH ARE NOT ENTERED (OR ARE ENTERED AS 0 OR BLANKS)
C ARE COPIED FROM THE PREVIOUS ANALYSIS CYCLE
C
85  WRITE(5,90)
   CALL GETWRD(ID,5)            !GET SAMPLE ID
   WRITE(5,700)(ID(I),I=1,5)    !ECHO TO TI:
700  FORMAT(' ',T28,5A2)
   IF(.NOT.(HARD))GO TO 110
   WRITE(2,90)(ID(I),I=1,5)
110  WRITE(5,115)
   CALL GETWRD(OWN,2)           !GET OWNER
   WRITE(5,701)(OWN(I),I=1,2)   !ECHO TO TI:
701  FORMAT(' ',T28,2A2)
   IF(.NOT.(HARD))GO TO 116
   WRITE(2,115)(OWN(I),I=1,2)
116  WRITE(5,118)              !GET ANALYSIS
   CALL GETWRD(ANAL,3)
   WRITE(5,702)(ANAL(I),I=1,3)  !ECHO TO TI:
702  FORMAT(' ',T28,3A2)
   IF(.NOT.(HARD))GO TO 130

```

```

WRITE(2,118)(ANAL(I),I=1,3)
130 WRITE(5,135)
READ(5,145,ERR=130)T,T1,T2      !GET QUANTITY,FACTOR,T(1/2)
IF(T.NE.0)Q=T
IF(T1.NE.0)FAC=T1
IF(T2.NE.0)THALF=T2
WRITE(5,703)Q,FAC,THALF          !ECHO TO TI:
703  FORMAT(' ',T24,3F10.4)
IF(.NOT.(HARD))GO TO 150
WRITE(2,135)Q,FAC,THALF
150  WRITE(5,155)
READ(5,156,ERR=150)IDUM(1),IDUM(2) !GET LOW AND UP PLOT BNDS
IF(IDUM(1).NE.0)XL=IDUM(1)
IF(IDUM(2).NE.0)XU=IDUM(2)
WRITE(5,704)XL,XU                !ECHO TO TI:
704  FORMAT(' ',T25,2I6)
IF(.NOT.(HARD))GO TO 160
WRITE(2,155)XL,XU                !GET EFF,SIGEFF,DETBKG,
160  WRITE(5,165)                !AND UNITS
READ(5,166,ERR=160)T,T1,T2,(WORD(I),I=1,5)
IF(T.NE.0)EFF=T
IF(T1.NE.0)SIGEFF=T1
IF(T2.NE.0)DETBKG=T2
CALL ASWAP(UNITS,WORD,5)
WRITE(5,705)EFF,SIGEFF,DETBKG,(UNITS(I),I=1,5)
705  FORMAT(' ',T26,3F9.5,1X,5A2)
IF(.NOT.(HARD))GO TO 170
WRITE(2,165)EFF,SIGEFF,DETBKG,(UNITS(I),I=1,5)
170  WRITE(5,188)                !GET T0-HR,MIN,DATE
READ(5,189,ERR=170)IDUM(1),IDUM(2),(WORD(I),I=1,3)
IF(IDUM(1).NE.0)T0HR=IDUM(1)
IF(IDUM(2).NE.0)T0MIN=IDUM(2)
IF(WORD(1).EQ.0)GO TO 175
DO 173 I=1,3
173  T0DATE(I)=WORD(I)
175  WRITE(5,706)T0HR,T0MIN,(T0DATE(I),I=1,3)
706  FORMAT(' ',T27,2I3,1X,2(I2,'/'),I2)
IF(.NOT.(HARD))GO TO 172
WRITE(2,188)T0HR,T0MIN,(T0DATE(I),I=1,3)
172  WRITE(5,197)                !GET COUNTING-HR,MIN,DATE
READ(5,189,ERR=172)IDUM(1),IDUM(2),(WORD(I),I=1,3)
IF(IDUM(1).NE.0)CTHR=IDUM(1)
IF(IDUM(2).NE.0)CTMIN=IDUM(2)
IF(WORD(1).EQ.0)GO TO 178
DO 176 I=1,3
176  CTDATE(I)=WORD(I)
178  WRITE(5,707)CTHR,CTMIN,(CTDATE(I),I=1,3)
707  FORMAT(' ',T27,2I3,1X,2(I2,'/'),I2)
IF(.NOT.(HARD))GO TO 182
WRITE(2,197)CTHR,CTMIN,(CTDATE(I),I=1,3)

```

C

C PARAMETER LIST NOW COMPLETE

C

C READ IN PROPER PART OF SPECTRUM

```

C
182  IF(RP.NE.0)GO TO 501          !READ TIME CHAN?
      READ(1,62,ERR=507)CTIME      !YES
      RP=1                        !SET RECORD POINTER TO 1
501  R=(XL-INT)/10+1              !DEFINE BEGINNING DATA REC
      IF(R.LT.1)R=1                !CAN'T BE < 1
502  IF(R.EQ.RP)GO TO 508          !DONE?
      IF(R.LT.RP)GO TO 506          !SKIP BACKWARD?
      READ(1,*,ERR=507,END=512)    !NO, SKIP FORWARD
      RP=RP+1                      !INC REC POINTER
      GO TO 502                    !LOOP AGAIN
506  REWIND 1                     !REWIND, (FASTER THAN BSP)
      READ(1,*)                    !SKIP TIME CHAN
      RP=1                         !SET REC POINTER
      GO TO 502                    !LOOP AGAIN
508  BASE=(RP-1)*10               !SET BASE ADDR OF DATA
      K=0
510  READ(1,62,ERR=507,END=512)(Y(I),I=(K+1),(K+10))
      K=K+10
      RP=RP+1                     !INC REC POINTER
      IF(((RP-1)*10).LT.(XU+INT))GO TO 510 !DONE YET?
      GO TO 187                    !YES, DONE
507  TYPE 509                     !READ ERROR ,ABORT ANAL
      REWIND 1                     !RESET FILES AND
      REWIND 2                     !PARAMETERS AND START
      RP=0                         !ANOTHER CYCLE
      GO TO 320
512  TYPE 514                     !EOF ENCOUNTERED
514  FORMAT(///,' **WARNING: INSUFFICIENT DATA CHANNELS ')
      DO 516 K=K,150              !ZERO REST OF ARRAY
516  Y(K)=0.
      GO TO 507
187  CALL PLOT(Y,XL,XU,HARD,BASE)  !PLOT THE SPECTRUM
C
C READ INTEGRATION LIMITS FROM TERMINAL
C
      READ(5,185)(LBUFF(I),I=1,72) !FILL LINE BUFFER
      I=9
      LB=0
      UB=0
190  IF(LBUFF(I).EQ.' ')GO TO 195  !IGNORE SPACES
      IF(LB.NE.0)GO TO 192          !1ST NONBLANK=LOWER BND
      LB=I-9+XL-BASE
      GO TO 195
192  UB=I-9+XL-BASE                !2ND NONBLANK=UPPER BND
      GO TO 200
195  I=I+1
      IF(I.LT.72)GO TO 190         !CAN'T EXTEND PAST COL 72
C
C INTEGRATE PEAK AREA AND CALCULATE RESULTS
C
C FIND BKG. WIDTH=IWID, INTERVAL=INT
C
200  K=LB                          !LOW SIDE OF PEAK

```

```

BKGL=1000000.
205 IF(IABS(K-IWID-LB).GT.INT)GO TO 230 !FIND LOWEST IWID CONSEC
    BKG=0. !CHANNELS WITHIN INTERVAL
    J=K-IWID+1 !INT FROM THE PEAK
    DO 210 I=K,J,-1 !BOUNDARIES
210 BKG=BKG+Y(I)
    IF(BKG.GE.BKGL)GO TO 220
    BKGL=BKG
    B2=K
220 K=K-1
    GO TO 205
230 B1=B2-IWID+1 !HIGH SIDE OF PEAK
    K=UB
    BKGU=1000000.
235 IF(IABS(K+IWID-UB).GT.INT)GO TO 260
    BKG=0.
    J=K+IWID-1
    DO 240 I=K,J
240 BKG=BKG+Y(I)
    IF(BKG.GE.BKGU)GO TO 250
    BKGU=BKG
    B3=K
250 K=K+1
    GO TO 235
260 B4=B3+IWID-1
C
C WRITE OUT BOUNDARY MARKERS
C
    DO 270 I=1,8
270 LBUFF(I)=' '
    DO 280 K=XL,XU
        J=K-BASE !NORMALIZE INDEX
        I=I+1 !WRITE "B" @ BKG BNDS
        LBUFF(I)=' '
        IF((J.EQ.B1).OR.(J.EQ.B2).OR.(J.EQ.B3).OR.(J.EQ.B4))
1 LBUFF(I)='B'
280 IF((J.EQ.LB).OR.(J.EQ.UB))LBUFF(I)='P' !WRITE "P" @ PEAK BNDS
    WRITE(5,185)(LBUFF(J),J=1,I)
    IF(.NOT.(HARD))GO TO 300
    WRITE(2,185)(LBUFF(J),J=1,I)
C
C CALCULATE RESULTS
C
300 BKG1=(BKGL+BKGU)*(UB-LB+1)/(2*IWID) !BKG UNDER PEAK
    BKG2=(DETBKG/60*CTIME) !TOTAL DET BKG
    PEAKT=0
    DO 310 I=LB,UB !INTEGRATE PEAK
310 PEAKT=PEAKT+Y(I)
    T=ET(T0DATE,T0HR,T0MIN,CTDATE,CTHR,CTMIN) !DECAY CORRECTION
    T=EXP(-.693*T/THALF)
    AX=(PEAKT-BKG1-BKG2)*60/(EFF*CTIME*FAC*Q*T) !ANALYTE CONC
    SAX=ABS(AX*SQRT(((PEAKT+(UB-LB+1)*BKG1/(2.*IWID)+BKG2)/
1 (PEAKT-BKG1-BKG2)**2+SIGEFF**2+(.01)**2))) !STD DEV OF AX
C
C REPORT RESULT

```

C

```

WRITE(5,314)(ID(I),I=1,5),(ANAL(I),I=1,3)
WRITE(5,315)PEAKT,BKG1,CTIME,AX,SAX,(UNITS(I),I=1,5)
IF(.NOT.(HARD))GO TO 320
WRITE(2,315)PEAKT,BKG1,CTIME,AX,SAX,(UNITS(I),I=1,5)
CALL CLOSE(2) !CLOSE HARD COPY FILE
320 WRITE(5,325)
READ(5,*)I,HARD !CONTINUE?
IF((HARD.EQ.0).OR.(HARD.EQ.1))GO TO 11
IF(HARD.NE.7)HARD=0
IF(HARD.EQ.0)GO TO 4 !CRUDE BUT EFFECTIVE--DP.

```

999 STOP

C

C FORMAT STATEMENTS

```

6  FORMAT(///,' PROGRAM GAMSPEC',2(1X,5A2),///)
7  FORMAT(' ENTER GLOBAL ANALYSIS PARAMETERS-',/,
1  ' DISTANCE FROM PEAK IN WHICH BKG MUST BE ESTABLISHED:',$,)
8  FORMAT(I2)
10 FORMAT(/,' FILE,HARDCOPY:',$,)
12 FORMAT(I4)
25 FORMAT(///,' SPECTRUM NOT FOUND, TRY AGAIN')
62 FORMAT(10F7.0)
81 FORMAT('1',T34,'GAMMA ANALYSIS',1H ,/,1H ,/, ' FILE=',18X,2A2)
82 FORMAT(' ',T34,'GAMMA ANALYSIS',1H ,/,1H ,/, ' FILE=',18X,2A2)
90 FORMAT(/,' SAMPLE ID=',16X,$,5A2)
115 FORMAT(/,' OWNER=',20X,$,2A2)
118 FORMAT(/,' ANALYSIS=',17X,$,3A2)
135 FORMAT(/,' QUAN,FACTOR,T(1/2)=' ,7X,$,3F10.4)
145 FORMAT(3F10.4)
155 FORMAT(/,' LOWER,UPPER=' ,14X,$,2I6)
156 FORMAT(2I5)
165 FORMAT(/,' EFF,SIGEFF,DET BKG,UNITS=' ,1X,$,3F9.5,5A2)
166 FORMAT(3F9.5,5A2)
185 FORMAT(72A1)
188 FORMAT(/,' T0-HR,MIN,DATE=' ,11X,$,2I3,1X,2(I2,'/'),I2)
189 FORMAT(2I3,I2,1X,I2,1X,I2)
197 FORMAT(/,' CT-HR,MIN,DATE=' ,11X,$,2I3,1X,2(I2,'/'),I2,////////)
314 FORMAT(///,' SAMPLE NUMBER: ',5A2,5X,' ANALYSIS: ',3A2)
315 FORMAT(3(1H ,/),' PEAK TOTAL',3X,'BKGD',3X,'COUNTSEC',14X,
1'CONCENTRATION',/, ' -----',3X,'-----',3X,'-----',14X,
2'-----',/,F10.0,1X,F8.0,1X,F8.0,7X,F11.4,' +/- ',F10.4,
31X,5A2,9(1H ,/))
325 FORMAT(' ENTER FILE,HARDCOPY TO CONTINUE OR 7,7 TO STOP: ',$,)
509 FORMAT(' DATA ERROR, ANALYSIS ABORT')
END

```

APPENDIX F

Example of Efficiency Curve Determinations
(Efficiency versus Sample Height (cm))

APPENDIX G

Original Data File (PERO) for SPSS Program

Location	* Co-57 Conc.		* Be-7 Conc.		* Rb-83 Conc.		* Cs-134 Conc.		* Mn-54 Conc.	
	+ S.D.		+ S.D.		+ S.D.		+ S.D.		+ S.D.	
00A1	006.74	00.21	0052.04	01.89	00.66	00.88	0004.62	00.15	0009.72	00.31
00A2	076.56	03.90	0178.92	09.80	00.44	00.35	0070.33	03.61	0009.57	00.52
00A3	011.50	00.66	0056.50	07.28	52.01	02.83	0249.31	12.83	0301.60	15.47
00A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00D1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00D2	021.92	01.13	0000.42	00.88	01.26	00.56	0000.40	00.14	0018.90	01.06
00D3	010.92	00.91	0032.24	28.55	03.44	01.85	0001.34	00.88	0014.89	01.33
00D4	002.05	00.26	0046.26	16.79	10.38	03.57	0012.07	00.68	0001.56	00.30
00D5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00F1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00F2	000.14	00.06	0000.17	00.68	00.32	00.26	0000.19	00.10	0000.51	00.10
00F3	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00F4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
00F5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01A1	007.92	00.25	0027.10	00.99	00.61	00.09	0004.48	00.15	0011.32	00.34
01A2	064.97	03.32	0163.34	08.89	03.94	00.59	0002.33	00.16	0008.82	00.47
01A3	093.77	04.86	0039.84	07.18	69.00	03.85	0241.48	12.41	0454.81	23.26
01A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01C1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01C2	028.65	01.48	0001.46	02.31	01.31	00.55	0000.48	00.27	0022.80	01.23
01C3	006.29	00.96	0049.19	44.58	10.82	03.18	0004.70	00.94	0003.69	01.24
01C4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01C5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01D1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01D2	010.86	00.56	0001.74	01.17	00.67	00.40	0000.19	00.14	0008.65	00.48
01D3	006.00	00.66	0022.49	20.60	00.05	01.86	0000.18	00.09	0008.53	01.08
01D4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
01D5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02A1	012.12	00.39	0154.20	04.47	00.46	00.09	0004.55	00.17	0004.08	00.16
02A2	362.15	18.47	1509.92	77.37	50.22	03.19	0803.15	40.97	0336.04	17.16
02A3	017.04	01.18	0149.81	17.67	74.75	04.29	0578.91	29.76	0413.04	21.26
02A4	000.45	00.07	0011.97	06.60	02.17	01.28	0010.08	05.04	0000.65	00.15
02A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02B1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02B2	006.97	00.37	0002.40	01.62	01.37	00.52	0000.83	00.18	0005.67	00.35
02B3	024.56	01.49	0058.07	35.30	06.53	04.00	0001.11	01.35	0000.38	00.94
02B4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02B5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02D1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02D2	004.72	00.28	0003.59	02.52	00.91	00.54	0000.38	00.17	0003.98	00.28
02D3	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02D4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02D5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02E1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02E2	000.11	00.05	0000.69	00.50	00.11	00.17	0000.09	00.05	0000.22	00.05
02E3	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
02E4	000.68	00.07	0006.67	05.40	00.23	00.35	0000.91	00.13	0000.10	00.10
02E5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
03A1	007.14	00.22	0066.00	02.43	00.85	00.13	0006.32	00.21	0013.92	00.44
03A2	015.58	00.82	0149.87	08.20	00.80	00.78	0000.71	00.25	0008.60	00.52
03A3	000.02	00.47	0015.31	06.86	23.25	01.81	0007.84	01.12	0019.58	01.43
03A4	000.08	00.10	0006.56	04.49	00.08	00.34	0000.11	00.14	0000.09	00.14
03A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
04A1	008.44	00.26	0068.67	02.36	00.63	00.12	0005.82	00.20	0012.09	00.38
04A2	158.54	08.09	0149.22	08.62	14.52	01.19	0038.31	02.00	0081.26	04.18
04A3	002.95	00.31	0018.00	04.58	51.17	02.72	0054.51	02.92	0022.96	01.31
04A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
04A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05A1	010.06	00.34	0063.38	02.50	00.81	00.11	0006.37	00.23	0015.59	00.53
05A2	143.94	07.35	0233.49	12.55	15.46	01.25	0041.60	02.19	0061.78	03.20
05A3	001.27	00.22	0007.24	03.29	35.66	01.99	0058.66	03.10	0046.15	02.44
05A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00

* (Water Concentration - nCi/L, All Other Trophic Levels - pCi/g)

[illegible]

05A3	004.98	00.47	0035.25	05.57	29.97	01.76	0141.13	07.31	0109.08	05.63
05A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05B1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05B2	001.70	00.12	0003.52	01.12	00.40	00.35	0000.50	00.13	0000.51	00.11
05B3	000.72	00.35	0009.73	03.81	01.00	00.60	0000.13	00.60	0000.38	00.42
05B4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05B5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05D1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05D2	002.87	00.16	0001.10	00.77	00.11	00.21	0000.23	00.09	0003.18	00.18
05D3	000.09	00.70	0039.54	10.71	01.41	01.01	0001.32	01.03	0009.92	00.88
05D4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
05D5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
06A1	012.65	00.38	0124.71	03.78	00.50	00.07	0006.15	00.19	0000.43	00.03
06A2	049.82	02.55	0320.78	17.31	10.46	01.16	0093.68	04.82	0049.16	02.55
06A3	-000.48	00.37	0054.31	08.70	70.96	04.38	0334.58	17.24	0332.54	17.09
06A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
06A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
06B1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
06B2	001.40	00.10	0001.37	00.62	00.22	00.22	0000.28	00.06	0000.26	00.07
06B3	002.53	00.65	0019.17	09.30	00.97	01.48	0001.25	01.07	0000.65	00.90
06B4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
06B5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07A1	011.47	00.35	0027.93	01.10	00.94	00.14	0007.36	00.23	0016.61	00.52
07A2	197.76	10.10	0636.86	33.02	25.94	01.99	0178.60	09.15	0111.39	05.78
07A3	005.08	00.40	0038.74	06.53	39.00	02.25	0072.87	03.82	0047.18	02.50
07A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07B1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07B2	004.80	00.26	0006.13	01.65	00.04	00.41	0000.64	00.12	0000.88	00.11
07B3	022.46	03.35	0065.42	25.95	06.32	06.16	0006.98	04.42	0009.01	03.44
07B4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07B5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07C1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07C2	000.14	00.09	0001.50	01.67	00.66	00.54	0000.33	00.15	0000.51	00.13
07C3	003.23	00.75	0006.71	11.78	00.72	01.13	0001.45	01.16	0003.09	01.26
07C4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
07C5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
08A1	012.31	00.38	0095.44	03.33	00.94	00.14	0008.39	00.27	0020.01	00.62
08A2	308.18	15.72	0941.07	48.62	45.44	02.98	0407.14	20.80	0276.81	14.15
08A3	010.08	00.75	0069.00	09.40	76.03	04.35	0115.66	06.00	0299.89	15.41
08A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
08A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
08B1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
08B2	015.89	00.81	0012.41	01.58	00.94	00.29	0000.70	00.09	0004.45	00.25
08B3	004.38	01.31	0052.90	17.42	04.37	03.27	0003.42	02.10	0005.72	01.53
08B4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
08B5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09A1	011.78	00.38	0071.21	02.71	00.71	00.10	0007.18	00.25	0017.97	00.58
09A2	247.14	12.61	1030.04	52.87	38.88	02.47	0355.64	18.18	0170.66	08.73
09A3	020.52	01.06	0013.40	05.33	94.31	04.90	0015.13	01.13	0028.09	01.65
09A4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09A5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09B1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09B2	002.73	00.23	0001.48	01.56	00.63	00.45	0000.62	00.23	0000.59	00.17
09B3	009.64	01.83	0038.78	21.07	03.93	02.70	0005.60	03.09	0003.89	02.80
09B4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09B5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09C1	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
09C2	001.29	00.08	0000.48	00.46	00.08	00.18	0000.17	00.06	0000.26	00.07
09C3	000.68	00.43	0021.47	05.63	02.43	01.00	0000.17	00.69	0000.11	00.55
09C4	001.33	00.26	0035.07	20.60	03.05	01.82	0000.80	00.27	0000.03	00.28
09C5	004.62	00.26	0023.86	03.89	15.43	00.88	0077.63	03.97	0002.40	00.19
10A1	000.92	00.05	0030.78	01.25	01.11	00.18	0006.82	00.24	0015.57	00.49

10A2	479	81	24	47	1285	41	66	61	33	33	03	23	0583	33	29	78	0366	74	18	73
10A3	006	64	00	51	0116	54	11	91	83	05	05	18	0566	01	29	00	0325	83	16	72
10A4	000	44	00	06	-0002	53	04	11	00	04	00	31	0000	31	00	08	-0000	10	00	09
10A5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10B1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10B2	111	29	05	67	0026	37	02	03	01	21	00	46	0000	98	00	19	0087	90	04	50
10B3	-001	02	01	05	0041	08	11	85	07	51	02	34	0007	03	02	20	0016	17	01	80
10B4	004	64	00	26	0006	51	01	88	05	50	00	44	0017	41	00	96	0000	76	00	21
10B5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10C1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10C2	036	26	01	85	0003	84	01	41	00	41	00	46	0000	66	00	17	0031	34	01	62
10C3	009	91	00	87	0010	31	07	17	02	18	01	08	0005	16	01	30	0012	62	01	58
10C4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10C5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10D1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10D2	007	35	00	38	0003	19	00	78	-00	12	00	20	0000	34	00	09	0003	69	00	22
10D3	003	12	00	42	0023	81	16	77	01	52	00	80	0000	67	00	42	0001	16	00	62
10D4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10D5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10E1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10E2	001	31	00	09	0000	38	00	58	00	28	00	17	0000	01	00	01	0000	27	00	06
10E3	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10E4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10E5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10F1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10F2	000	41	00	11	0001	72	02	08	00	71	00	52	0000	41	00	15	0000	53	00	13
10F3	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10F4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10F5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10G1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10G2	002	62	00	17	0005	48	01	43	00	34	00	45	0000	38	00	14	0001	52	00	15
10G3	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10G4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10G5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10H1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10H2	001	29	00	09	0000	93	01	17	00	41	00	26	0000	20	00	10	0000	69	00	11
10H3	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10H4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10H5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10I1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10I2	000	17	00	21	0006	87	03	02	02	58	01	01	-0000	02	00	28	0000	77	00	23
10I3	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10I4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
10I5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11A1	000	67	00	06	0183	00	05	77	01	02	00	19	0013	45	00	45	0026	35	00	85
11A2	495	94	25	30	1226	19	63	39	32	94	02	56	0231	56	11	88	0349	43	17	88
11A3	018	12	01	12	0065	84	09	95	99	99	06	63	0375	30	19	31	0273	74	14	10
11A4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11A5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11B1	540	19	27	54	6330	30	99	99	75	84	06	06	1501	12	76	56	1009	67	51	50
11B2	034	76	01	98	0162	08	23	73	82	97	05	10	0278	48	14	58	0292	09	15	18
11B3	001	41	00	21	0025	84	15	82	01	06	01	15	0001	07	00	25	0000	47	00	25
11B5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11C1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11C2	051	79	02	65	0079	02	05	13	04	32	00	95	0000	83	00	31	0021	81	01	19
11C3	-001	02	01	24	0044	81	17	34	30	73	03	67	0030	72	03	03	0026	85	02	31
11C4	000	83	00	06	0000	31	00	51	00	09	00	07	0002	65	00	19	0000	08	00	08
11C5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11D1	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11D2	002	11	00	15	0002	22	01	68	00	62	00	40	0000	38	00	12	0001	13	00	14
11D3	-000	30	00	71	0068	81	47	53	04	97	04	69	0004	41	01	29	0000	52	00	97
11D4	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00
11D5	000	00	00	00	0000	00	00	00	00	00	00	00	0000	00	00	00	0000	00	00	00

11E1	000.00	00.00	0000.00	00.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00
11E2	000.91	00.18	0001.55	01.66	00.96	00.55	0000.82	00.19	0001.29	00.17	
11E3	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00	
11E4	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00	
11E5	000.00	00.00	0000.00	00.00	00.00	00.00	0000.00	00.00	0000.00	00.00	

APPENDIX H

Pearsons' Product Moment Coefficient of Correlation Results

	North	South	Entire
Water			
Co/Be			-0.0132
Co/Rb			-0.5860*
Co/Cs			-0.4414
Co/Mn			-0.4583
Reject Ho for Co/Rb Matrix, accept all others			
Be/Rb			-0.1781
Be/Cs			0.5160*
Be/Mn			0.0087
Reject Ho for Be/Cs Matrix, accept all others			
Rb/Cs			0.6847
Rb/Mn			0.8113*
Reject Ho for both cases			
Cs/Mn			0.7755
Reject Ho			

Soil

Co/Be	0.7619*	0.7513	0.7317
Co/Rb	0.9094	0.9354*	0.9218
Co/Cs	0.8211	0.8740*	0.8534
Co/Mn	0.8764	0.9663*	0.8962

All values had sufficient coefficients to reject Ho and accept Ha. Highest values seen in the SOUTH data set.

Be/Rb	0.8735*	0.6860	0.7743
Be/Cs	0.9708*	0.7165	0.8184
Be/Mn	0.9645*	0.8120	0.8924

All values in the NORTH set were adequate to reject Ho, while the remaining values accepted Ho.

Rb/Cs	0.9125*	0.8841	0.8896
Rb/Mn	0.9090	0.9791*	0.9284

All values were adequate to reject Ho.

Cs/Mn	0.9777*	0.9232	0.9141
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All values were adequate to reject Ho.

Vegetation

Co/Be	0.5579*	0.2650	0.5469
Co/Rb	0.5928*	0.2873	0.3157
Co/Cs	0.3721*	0.3203	0.2879
Co/Mn	0.4741	0.5702*	0.4927

Be, Rb, and Cs accept the null (Ho), while the remaining reject the null hypothesis (Ha).

Be/Rb	0.5281	0.5799*	0.5579
Be/Cs	0.6615	0.7999*	0.7242
Be/Mn	0.6489	0.7023*	0.6726

All values are adequate to reject the Ho, while the most prominent values were seen the in the SOUTH data set.

Rb/Cs	0.7488	0.7936*	0.7645
Rb/Mn	0.8264	0.8347*	0.8148

All values significant to reject the Ho.

Cs/Mn	0.8968*	0.8486	0.8702
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All values significant to reject the Ho.

Rodents

Co/Be	0.0305	0.1887*	0.1154
Co/Rb	0.7041*	0.6355	0.6192
Co/Cs	0.6963*	0.6193	0.6580
Co/Mn	-0.2135	0.8489*	0.1954

Rb and Cs in NORTH, Rb,Cs,Mn in SOUTH set, and Rb and Cs in ENTIRE set were significant to reject Ho.

Be/Rb	0.2499	0.7958*	0.6111
Be/Cs	-0.2619	0.5861*	0.1604
Be/Mn	-0.0547	0.5148*	0.1736

All SOUTH data set, along with Rb in ENTIRE set, are significant to reject Ho and accept Ha.

Rb/Cs	0.8383	0.8632*	0.7817
Rb/Mn	0.4053	0.9093*	0.5724

All regions significant to reject H_0 , with the exception
of Mn NORTH.

Cs/Mn	0.4965	0.9074*	0.6319
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Reject H_0 for SOUTH and ENTIRE set, accept for NORTH.

APPENDIX I

MANOVA Results (ALL, NORTH, SOUTH)

ALL *****

Co-57

Source of Variation	DF	F	Sig. of F
SIDE	1	0.5544	0.4578
TRAN	11	2.3224	0.0122
PLOT	8	5.4190	0.0001
TROPLVL	3	18.7206	0.0001

ESTIMATES FOR Co-57

SIDE	DF.	T-Value	Sig. of T
1	1	0.7445	0.4578
TRAN			
1		-0.2902	0.7720
2		-0.3984	0.6906
3		-0.0073	0.9941
4		-0.8445	0.3998
5		-0.4680	0.6405
6		-0.8482	0.3978
7		-1.6465	0.1020
8		-0.3244	0.7461
9		0.5362	0.5926
10		-0.3053	0.7605
11		2.4618	0.0151
PLOT			
1		5.2497	0.0000
2		2.9652	0.0036
3		0.6729	0.5022
4		0.4390	0.6613
5		-0.7404	0.4603
6		-0.5948	0.5530
7		-0.6933	0.4893
8		-0.7076	0.4804
TROPLVL			
1		-2.7864	0.0061
2		7.2159	0.0000
3		-0.8970	0.3713

Be-7

Source of Variation SIDE	DF	F	Sig. of F
	1	0.1113	0.7391
TRAN	11	1.5019	0.1381
PLOT	8	2.0289	0.0477
TROPLVL	3	5.5218	0.0013

ESTIMATES FOR Be-7

SIDE	DF.	T-Value	Sig. of T
	1	-0.3336	0.7391
TRAN			
1		-0.0024	0.9980
2		-0.2671	0.7898
3		0.3716	0.7107
4		-0.4778	0.6335
5		0.0618	0.9507
6		-0.5977	0.5510
7		-0.8062	0.4215
8		-0.6886	0.4922
9		-0.7331	0.4648
10		-0.3733	0.7094
11		1.0800	0.2821
PLOT			
1		2.6477	0.0091
2		2.6660	0.0086
3		0.1791	0.8580
4		0.1214	0.9035
5		-0.7335	0.4645
6		-0.3186	0.7505
7		-0.3885	0.6982
8		-0.3945	0.6938
TROPLVL			
1		-0.8372	0.4040
2		3.8823	0.0001
3		-0.8575	0.3924

Rb-83

Source of Variation SIDE	DF	F	Sig. of F
	1	1.4248	0.2347

TRAN			
	11	2.0287	0.0304
PLOT			
	8	12.6808	0.0001
TROPLVL			
	3	39.2514	0.0001

ESTIMATES FOR Rb-83

SIDE			
DF.		T-Value	Sig. of T
1		-1.1936	0.2347

TRAN			
1		0.3140	0.7539
2		-0.5206	0.6035
3		0.7723	0.4413
4		-0.9304	0.3538
5		-0.3200	0.7494
6		-1.4887	0.1389
7		-1.3663	0.1741
8		-0.4549	0.6499
9		0.5243	0.6008
10		0.3052	0.7606
11		0.5417	0.5889

PLOT			
1		6.2947	0.0001
2		0.5101	0.6108
3		-0.9258	0.3562
4		-1.5147	0.1322
5		-1.1159	0.2665
6		-0.1411	0.8879
7		-0.2348	0.8147
8		-0.2303	0.8182

TROPLVL			
1		-6.7974	0.0001
2		2.9364	0.0039
3		9.8538	0.0001

Cs-134

Source of Variation	DF	F	Sig. of F
SIDE			
	1	0.1515	0.6976
TRAN			
	11	2.1722	0.0196
PLOT			
	8	4.0508	0.0002
TROPLVL			
	3	7.1728	0.0001

ESTIMATES FOR Cs-134

SIDE	DF.	T-Value	Sig. of T
	1	0.3893	0.6976
TRAN			
	1	0.1265	0.8995
	2	-0.5553	0.5796
	3	1.4587	0.1470
	4	-0.8729	0.3843
	5	-0.7808	0.4362
	6	-1.1780	0.2409
	7	-0.8970	0.3713
	8	-0.5289	0.5977
	9	-0.0817	0.9349
	10	-0.5932	0.5540
	11	1.5721	0.1183
PLOT			
	1	3.9363	0.0001
	2	2.4777	0.0145
	3	-0.0377	0.9699
	4	-0.3558	0.7225
	5	-1.0658	0.2884
	6	-0.3147	0.7538
	7	-0.3638	0.7165
	8	-0.3647	0.7159
TROPLVL			
	1	-2.5307	0.0125
	2	4.2231	0.0001
	3	1.9545	0.0527

Mn-54

Source of Variation	DF	F	Sig. of F
SIDE			
	1	0.3134	0.5765
TRAN			
	11	2.2658	0.0146
PLOT			
	8	6.5706	0.0001
TROPLVL			
	3	12.1178	0.0001

ESTIMATES FOR Mn-54

SIDE	DF.	T-Value	Sig. of T
	1	-0.5598	0.5765

TRAN

1	0.5005	0.6175
2	0.0059	0.9952
3	1.1351	0.2584
4	-0.8053	0.4221
5	-0.8557	0.3937
6	-1.4815	0.1408
7	-0.9761	0.3308
8	-0.9076	0.3657
9	0.3481	0.7282
10	-1.0216	0.3088
11	1.6756	0.0962

PLOT

1	5.1663	0.0001
2	2.0340	0.0439
3	-0.0291	0.9767
4	-0.5800	0.5628
5	-0.9051	0.3670
6	-0.3616	0.7182
7	-0.4242	0.6721
8	-0.4315	0.6667

TROPLVL

1	-3.6898	0.0003
2	4.2382	0.0001
3	4.2827	0.0001

SOUTH *****

Co-57

Source of Variation	DF	F	Sig. of F
TRAN	11	1.2834	0.2570
PLOT	5	3.7234	0.0054
TROPLVL	3	8.0883	0.0001

ESTIMATES FOR Co-57

TRAN

DF.	T-Value	Sig. of T
1	0.2782	0.7818
2	0.4177	0.6776
3	0.3471	0.7297
4	-1.0818	0.2838
5	-0.3349	0.7388
6	-0.8116	0.4203

7	-1.1056	0.2734
8	-0.3951	0.6941
9	0.3761	0.7082
10	-0.9467	0.3477
11	2.1258	0.0377

PLOT

1	3.5107	0.0008
2	1.6987	0.0947
3	-0.8021	0.4257
4	-0.7913	0.4319
5	-0.7964	0.4290

TROPLVL

1	-1.8987	0.0625
2	4.6740	0.0001
3	-0.6542	0.5155

Be-7

Source of Variation	DF	F	Sig. of F
TRAN			
	11	0.9679	0.4851
PLOT			
	5	1.8320	0.1207
TROPLVL			
	3	2.6103	0.0599

ESTIMATES FOR Be-7

TRAN

DF.	T-Value	Sig. of T
1	0.3698	0.7128
2	0.2660	0.7911
3	0.6389	0.5254
4	-0.3782	0.7066
5	-0.4176	0.6777
6	-0.6889	0.4936
7	-0.4421	0.6600
8	-0.6655	0.5083
9	-0.8442	0.4020
10	-0.7709	0.4438
11	1.7992	0.0771

PLOT

1	1.9849	0.0518
2	1.9449	0.0566
3	-0.6316	0.5301
4	-0.6826	0.4975
5	-0.7396	0.4625

TROPLVL

1	-0.5573	0.5794
2	2.6130	0.0114
3	-0.6612	0.5110

Rb-83

Source of Variation	DF	F	Sig. of F
TRAN			
	11	1.0159	0.4443
PLOT			
	5	10.7223	0.0001
TROPLVL			
	3	16.8303	0.0001

ESTIMATES FOR Rb-83

TRAN

DF.	T-Value	Sig. of T
1	0.5504	0.5841
2	0.2888	0.7737
3	1.5235	0.1330
4	-1.8366	0.0713
5	-0.1417	0.8877
6	-0.6323	0.5296
7	-1.2745	0.2075
8	0.5184	0.6061
9	0.3416	0.7338
10	-0.6052	0.5474
11	0.5909	0.5568

PLOT

1	5.9301	0.0001
2	0.1386	0.8901
3	-0.9605	0.3407
4	-1.4703	0.1468
5	-1.1283	0.2638

TROPLVL

1	-4.6935	0.0001
2	2.5738	0.0126
3	6.3317	0.0001

Cs-134

Source of Variation	DF	F	Sig. of F
TRAN			
	11	1.1474	0.3432
PLOT			
	5	3.1166	0.0146
TROPLVL			
	3	3.1715	0.0308

ESTIMATES FOR Cs-134

TRAN			
DF.	T-Value	Sig. of T	
1	0.5149	0.6085	
2	0.1848	0.8539	
3	1.3265	0.1898	
4	-0.9245	0.3590	
5	-0.7908	0.4322	
6	-1.0137	0.3149	
7	-0.7057	0.4831	
8	-0.1780	0.8592	
9	0.0721	0.9427	
10	-0.8561	0.3954	
11	-1.1314	0.2625	

PLOT		
1	3.0049	0.0039
2	1.8331	0.0719
3	-0.6616	0.5108
4	-0.8774	0.3838
5	-1.0571	0.2948

TROPLVL		
1	-1.6554	0.1032
2	2.9650	0.0043
3	0.7500	0.4562

Mn-54

Source of Variation	DF	F	Sig. of F
TRAN	11	1.3617	0.2157
PLOT	5	7.0294	0.0001
TROPLVL	3	6.6366	0.0006

ESTIMATES FOR Mn-54

TRAN		
DF.	T-Value	Sig. of T
1	0.8341	0.4076
2	0.9272	0.3576
3	1.4501	0.1523
4	-1.5933	0.1165
5	-1.2846	0.2040
6	-1.0652	0.2911
7	-0.9544	0.3438
8	0.0313	0.9751

9	0.3806	0.7048
10	-0.8300	0.4099
11	1.7792	0.0804

PLOT

1	4.8918	0.0001
2	0.7590	0.4509
3	-0.9285	0.3569
4	-1.2382	0.2206
5	-0.8311	0.4092

TROPLVL

1	-2.8296	0.0063
2	3.3039	0.0016
3	3.0894	0.0030

NORTH *****

Co-57

Source of Variation	DF	F	Sig. of F
TRAN			
	11	1.3683	0.2153
PLOT			
	5	3.1197	0.0058
TROPLVL			
	3	9.7147	0.0001

ESTIMATES FOR Co-57

TRAN

DF.	T-Value	Sig. of T
1	-0.9298	0.3566
2	-1.1034	0.2748
3	-0.9172	0.3631
4	0.1456	0.8847
5	-0.3215	0.7490
6	-0.0339	0.3291
7	-0.9848	0.3291
8	0.0776	0.9384
9	0.3915	0.6969
10	0.6300	0.5313
11	1.7947	0.0783

PLOT

1	4.5696	0.0001
2	2.3974	0.0200
3	0.8677	0.3894
4	0.1588	0.8743
5	-1.1991	0.2357

TROPLVL

1	-1.8720	0.0667
2	5.1859	0.0001
3	-0.6022	0.5495

Be-7

Source of Variation	DF	F	Sig. of F
TRAN	11	0.7542	0.6823
PLOT	5	0.8789	0.5402
TROPLVL	3	2.5857	0.0627

ESTIMATES FOR Be-7

TRAN

DF.	T-Value	Sig. of T
1	-0.4435	0.6591
2	-0.5872	0.5595
3	-0.2438	0.8083
4	-0.3083	0.7590
5	0.3668	0.7151
6	-0.0163	0.9870
7	-0.5943	0.5547
8	-0.2403	0.8109
9	-0.2180	0.8282
10	0.2137	0.8315
11	0.4390	0.6624

PLOT

1	1.9229	0.0598
2	1.8845	0.0649
3	0.2008	0.8415
4	-0.1451	0.8851
5	-0.8634	0.3917

TROPLVL

1	-0.4590	0.6481
2	2.7071	0.0091
3	-0.4182	0.6774

Rb-83

Source of Variation	DF	F	Sig. of F
TRAN	11	2.0697	0.0392
PLOT	5	6.6292	0.0001
TROPLVL	3	22.6143	0.0001

ESTIMATES FOR Rb-83

TRAN

DF.	T-Value	Sig. of T
1	-0.4752	0.6365
2	-1.4343	0.1573
3	-1.0173	0.3136
4	0.5082	0.6133
5	-0.3498	0.7278
6	-0.8827	0.5761
7	-0.5625	0.5761
8	-0.6320	0.5300
9	0.5582	0.5790
10	1.2015	0.2348
11	0.7927	0.4314

PLOT

1	5.0949	0.0001
2	0.2641	0.7926
3	-1.1161	0.2694
4	-1.7056	0.0939
5	-0.8806	0.3824

TROPLVL

1	-4.9318	0.0001
2	1.4243	0.1602
3	7.4478	0.0001

Cs-134

Source of Variation	DF	F	Sig. of F
TRAN	11	1.0556	0.4136
PLOT	5	1.9271	0.0749
TROPLVL	3	3.5287	0.0209

ESTIMATES FOR Cs-134

TRAN

DF.	T-Value	Sig. of T
1	-0.5360	0.5941
2	-1.0112	0.3165
3	0.1900	0.8500
4	-0.1201	0.9047
5	-0.2120	0.8329
6	-0.3419	0.7337
7	-0.3723	0.7111
8	-0.4786	0.6341

9	-0.1533	0.8786
10	0.1173	0.9070
11	1.3286	0.1896

PLOT

1	3.2513	0.0020
2	1.7780	0.0811
3	0.1114	0.9117
4	-0.4682	0.6415
5	-0.8448	0.4020

TROPLVL

1	-1.7542	0.0851
2	2.6016	0.0120
3	1.9202	0.0602

Mn-54

Source of Variation	DF	F	Sig. of F
TRAN			
	11	1.3965	0.2021
PLOT			
	5	2.3937	0.0277
TROPLVL			
	3	5.1318	0.0034

ESTIMATES FOR Mn-54

TRAN

DF.	T-Value	Sig. of T
1	-0.3146	0.7542
2	-1.0299	0.3077
3	-0.0185	0.9852
4	0.3807	0.7049
5	-0.0492	0.9608
6	-0.6101	0.5444
7	-0.5202	0.6050
8	-0.9350	0.3540
9	0.2076	0.8363
10	-0.4064	0.6860
11	1.0499	0.2985

PLOT

1	3.5684	0.0007
2	1.7442	0.0869
3	0.1052	0.9165
4	-0.7205	0.4743
5	-0.9491	0.3468

TROPLVL

1	-2.1924	0.0327
2	2.6169	0.0115
3	2.8677	0.0059

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