DOE/OR/00033--T740

A COMPARISON OF ^{137}Cs RADIOACTIVITY IN LOCALIZED EVERGREEN AND DECIDUOUS PLANT SPECIES

A Thesis

by

RUBÉN CANALES RANGEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 1996

Major Subject: Health Physics

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Approved as to style and content by:

Milton E McLain

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(Member)

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(Head of Department)

May 1996

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ABSTRACT

A Comparison of ^{137}Cesium Radioactivity in

Localized Evergreen and Deciduous Plant Species. (May 1996)

Rubén Canales Rangel, B.S., Lamar University;

M.F.S. Yale University School of Forestry & Environmental Studies

Co-Chairs of Advisory Committee: Dr. Milton E. McLain
Dr. Woodrow W. Pitt, Jr.

A vegetation study at the Comanche Peak Steam Electric Station (CPSES) near Glen Rose, Texas was conducted in 1991 and 1992. The CPSES is a commercial nuclear power plant owned and operated by Texas Utilities Electric of Dallas, Texas. The U.S. Nuclear Regulatory Commission (USNRC) requires the CPSES to routinely sample broadleaf vegetation in place of milk samples. Few commercial dairies exist in the vicinity. Broadleaf tree species are scarce because the climate and local limestone geology have produced a dry rolling hill topography. An evergreen juniper is the dominant tree species. Few broadleaves during the winter season have hindered year-round sampling. This study compares the environmental ^{137}Cs concentrations between broadleaf and evergreen foliage at CPSES. Soil ^{137}Cs concentrations from each vegetation location were also compared to the foliage ^{137}Cs concentrations. The study's objective was to determine if the deciduous and evergreen vegetation ^{137}Cs concentrations are statistically the same. If the concentrations are statistically the same, then a recommendation could be made to the CPSES for substitution of leaf type sampled. Broadleaf tree leaf samples were collected on and off CPSES. Evergreen leaf samples were collected in close proximity to broadleaf samples. The leaf and soil samples were dried and homogenized for analysis. Gamma-ray spectrometry was performed to measure ^{137}Cs radioactivity in each leaf and soil sample. The ^{137}Cs concentrations for each leaf and soil sample were calculated and statistically compared. The mean values of the ^{137}Cs concentrations in broadleaf and evergreen foliage samples were found to be statistically the same and therefore from the same population. The individual soil sample ^{137}Cs concentration means were also statistically the same and from its own population. The foliage and soil populations, although, were found to be statistically different. This study's conclusion is that evergreen leaves from juniper trees can be used to supplement and/or substitute for the broadleaf samples currently collected. This study may be used by CPSES to petition the USNRC for a modification of the current environmental sampling program. A change in foliage collection would allow the CPSES to better satisfy its environmental sampling regulatory requirements.

DEDICATION

This thesis is dedicated to my wife, Beatríz, and children, Daniella Nathalie and Dante Nicolás Rubén, who during this project have been at my side from start to finish. They have persevered the major changes my schooling and thesis work have brought upon their lives. For their steadfastness and support, I love them dearly. Muchas gracias Familia querida.

ACKNOWLEDGMENTS

I acknowledge the professional assistance and guidance, and personal friendship provided to me by Dr. Milton E. McLain, Dr. Wesley E. Bolch and Douglas Johnson, all of whom were at Texas A&M University (TAMU) during my study. As my first university health physics contact, Dr. McLain answered my many questions on health physics and provided relief to my many questions on what the discipline encompassed. Dr. Bolch was always there to render assistance when I needed him. His energy and intense health physics interest and knowledge always was a source of inspiration. Doug Johnson, as a work colleague, I thank for introducing me to health physics as a profession. He provided crucial information on the discipline when I was deciding what advanced degree and study to pursue in my planned career development. Without Doug's interest and enthusiasm in me, I would not be in the successful health physics position I occupy today. I sincerely thank these gentlemen for playing a strong positive role in molding my professional career.

In addition, I wish to thank Texas Utilities (TU) Electric, Los Alamos National Laboratory (LANL) and the U.S. Department of Energy (DOE). Mr. Douglas Kay of TU Electric's Comanche Peak Steam Electric Station (CPSES) was very receptive and helpful from the start when I approached him on doing my field research at CPSES. I could not have collected my field data without the access he provided to the CPSES site. As a DOE Operational Health Physics Fellow, I had the fortunate opportunity to do my

1991 summer practicum at LANL. By being assigned to LANL's HS-4 Group (Health Physics Measurements), I was given wide latitude and support in learning and working in the Health Physics Analytical Laboratory. The knowledge gained while at LANL was very beneficial to my thesis research. Lastly, I thank the U.S. DOE for providing me with a graduate fellowship to support my pursuit of a health physics graduate education. DOE support played a significant role in my successful completion of the graduate program and in my employment placement.

This thesis was performed under appointment to the DOE Operational Health Physics Fellowship Program administered by Oak Ridge Associated Universities for the U.S. Department of Energy.

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INTRODUCTION

Nuclear reactors used to commercially generate electricity in the United States are widely distributed geographically. All commercial nuclear power plants in the United States are regulated by the U.S. Nuclear Regulatory Commission (USNRC)*. As of August 1992 there were 110 power-generating nuclear reactors in commercial operation in the United States (Nuclear News 1992). *(The acronyms used in this thesis are listed and described in Appendix N).

The Comanche Peak Steam Electric Station (CPSES), with two units, is owned and operated by Texas Utilities (TU) Electric headquartered in Dallas, Texas. The CPSES is located four and a half miles northwest of the town of Glen Rose in north central Texas. CPSES lies in Somervell County and is about eighty miles southwest of Dallas (CPSES 1991). Figure 1 shows the location of the plant site in Texas. CPSES's location in Somervell County and distance to Glen Rose is illustrated in Fig. 2. The Comanche Peak Steam Electric Station is sited on 7,669 acres (3,104 hectares) along Squaw Creek, which is a branch of the Paluxy River. The Paluxy River, in turn, is a tributary of the nearby larger Brazos River (FSAR 1988).

Comanche Peak Steam Electric Station consists of two pressurized water

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This thesis follows the style of Health Physics.

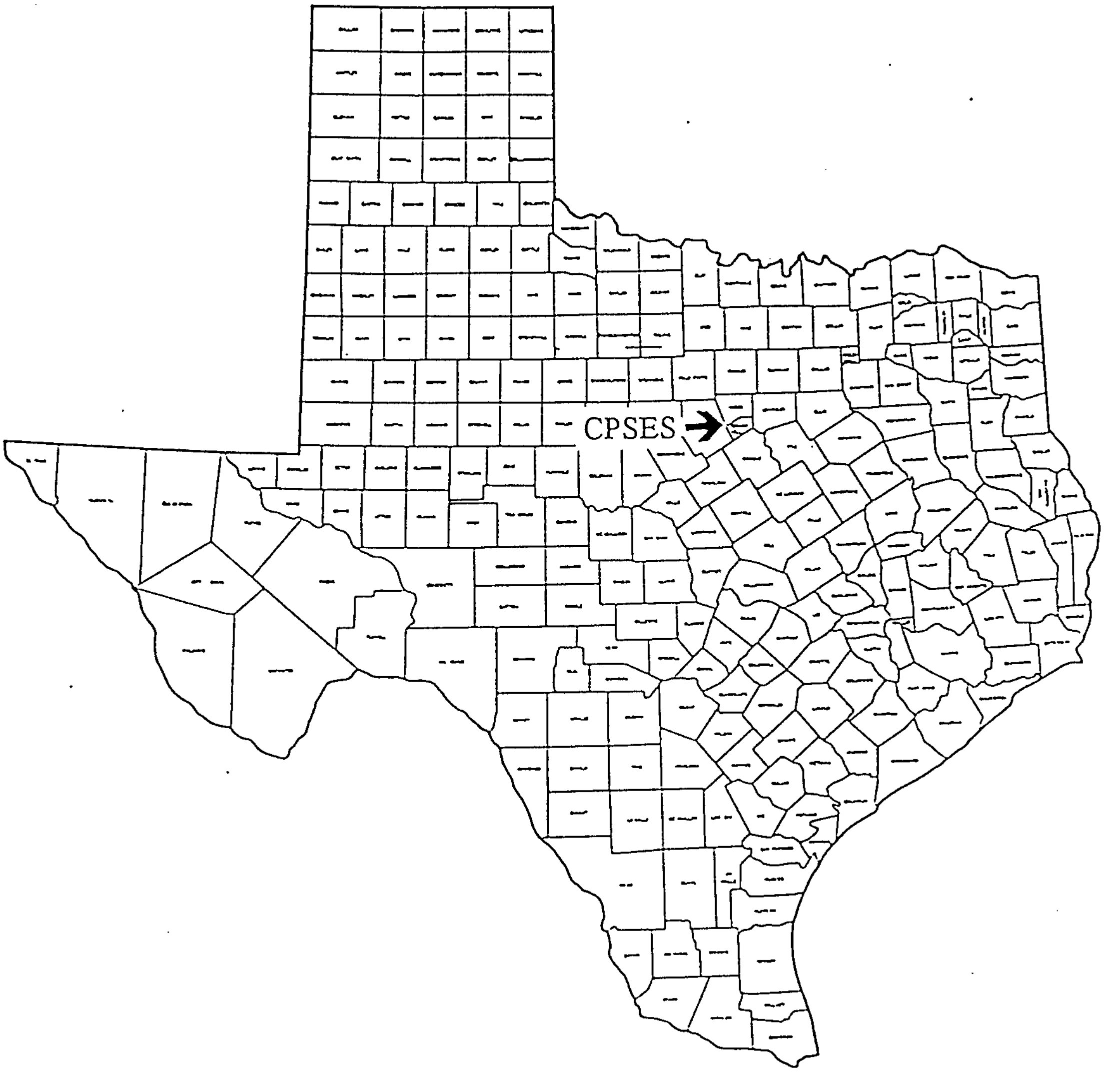
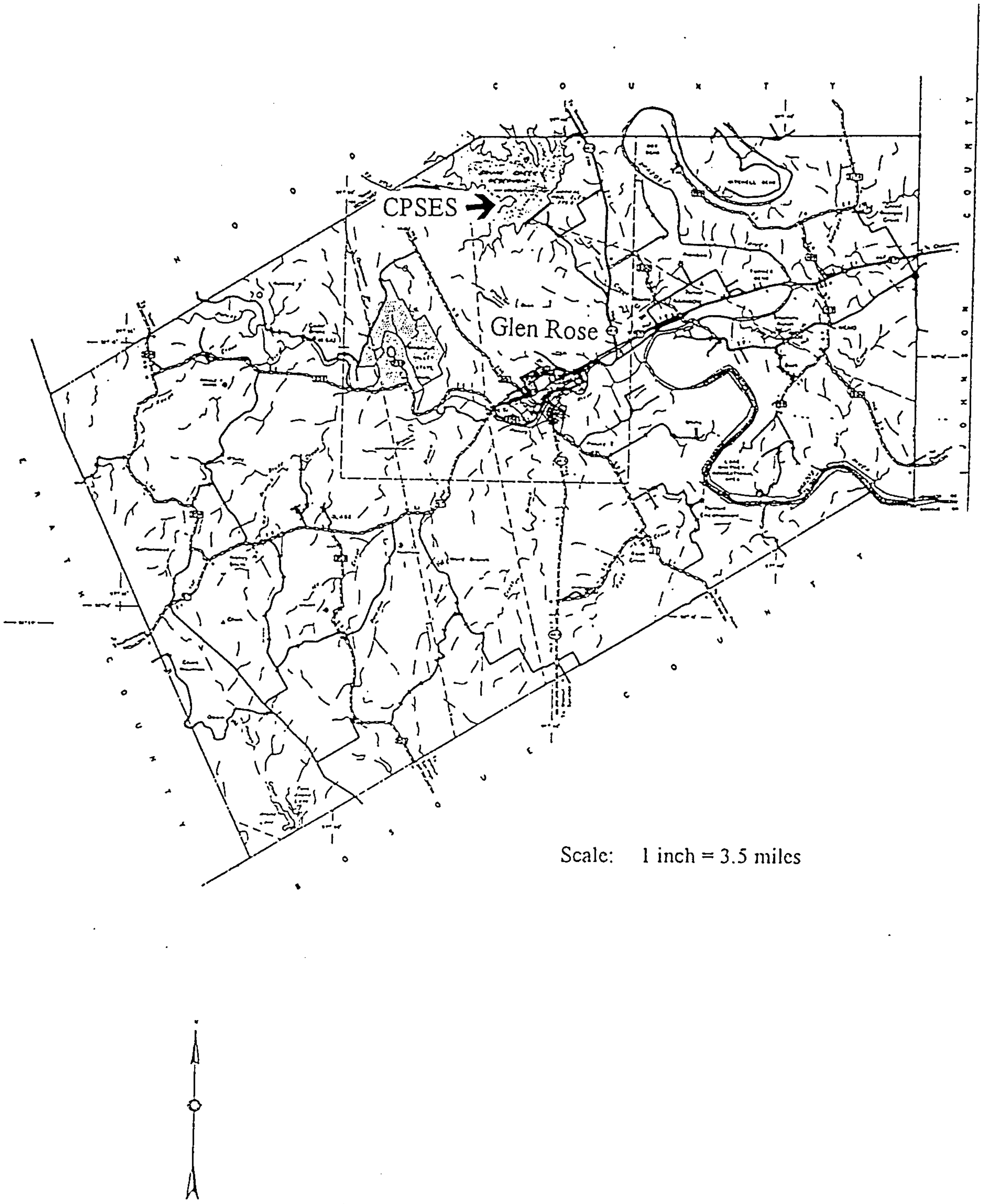


Fig. 1. CPSES Location in Texas (FSAR 1988)



Scale: 1 inch = 3.5 miles

Fig. 2. CPSES Location in Somervell County (TSDHPT 1985)

reactors (PWRs), each of which is designed to operate at a power level of about 1,150 megawatts electrical (MWe). Unit I began full commercial operation on August 13, 1990 after receiving a full power license from the USNRC (REMPAR 1990). During fall 1991 and spring 1992 when field samples were collected for the research portion of this thesis, Unit I was in operation and Unit II was under construction. Unit II's construction was completed in 1993. CPSES's Unit II began commercial operation on August 3, 1993.

The USNRC requires nuclear power plants be operated so that levels of radioactive effluents to unrestricted areas are kept as low as reasonably achievable (ALARA) (USNRC 1991). The USNRC also requires the establishment of a radiological environmental monitoring program to detect and measure normal background radiation and any releases of radioactivity from a nuclear power plant. The Comanche Peak Steam Electric Station has such a radiological environmental monitoring program. During the field research (1991 and 1992) of this thesis, the program's environmental field samples were collected by CPSES staff and analyzed under contract by Teledyne Isotopes of Westwood, New Jersey (REMPAR 1990). The CPSES Radiological Environmental Monitoring Program requires year-round collection of broadleaf vegetation in and around the CPSES site. However, since the broadleaf (deciduous) vegetation is seasonal it is unavailable year-round. In contrast, evergreen vegetation is available year-round.

The objective of this thesis research was to determine quantitatively if the radioisotope ^{137}Cs is present in significantly differing concentrations in the localized evergreen and deciduous plant species about the CPSES. The CPSES radiological environmental sampling program could be enhanced through the knowledge obtained by measuring and comparing the ^{137}Cs concentrations in different plants. The required sampling could be adjusted by collecting plant species shown to have more or the same environmental radioactivity as the routinely collected deciduous plants.

Research Site Description

The Comanche Peak Steam Electric Station is situated on the north side of the county of Somervell. Figure 3 illustrates the nuclear power plant location next to Squaw Creek Reservoir in northern Somervell County. Squaw Creek was dammed as part of the construction of CPSES, and the resulting reservoir serves as the cooling water supply for the nuclear reactors. The exact location, in greater detail, of CPSES in relation to Squaw Creek Reservoir is shown in Fig. 4.

Somervell County, with Glen Rose as the county seat, is characterized by open prairie grasslands and juniper-covered limestone hills (Coburn 1978). There are sandy areas on the uplands and along the Brazos River. The flow of the Paluxy and Brazos Rivers has produced a rough terrain of eroded plateaus and ravines. The elevation of the county ranges from about 183 meters at the river bottom to 411 meters in the southwestern county edge. The approximate elevation of the CPSES site is 247 meters (FSAR 1988).

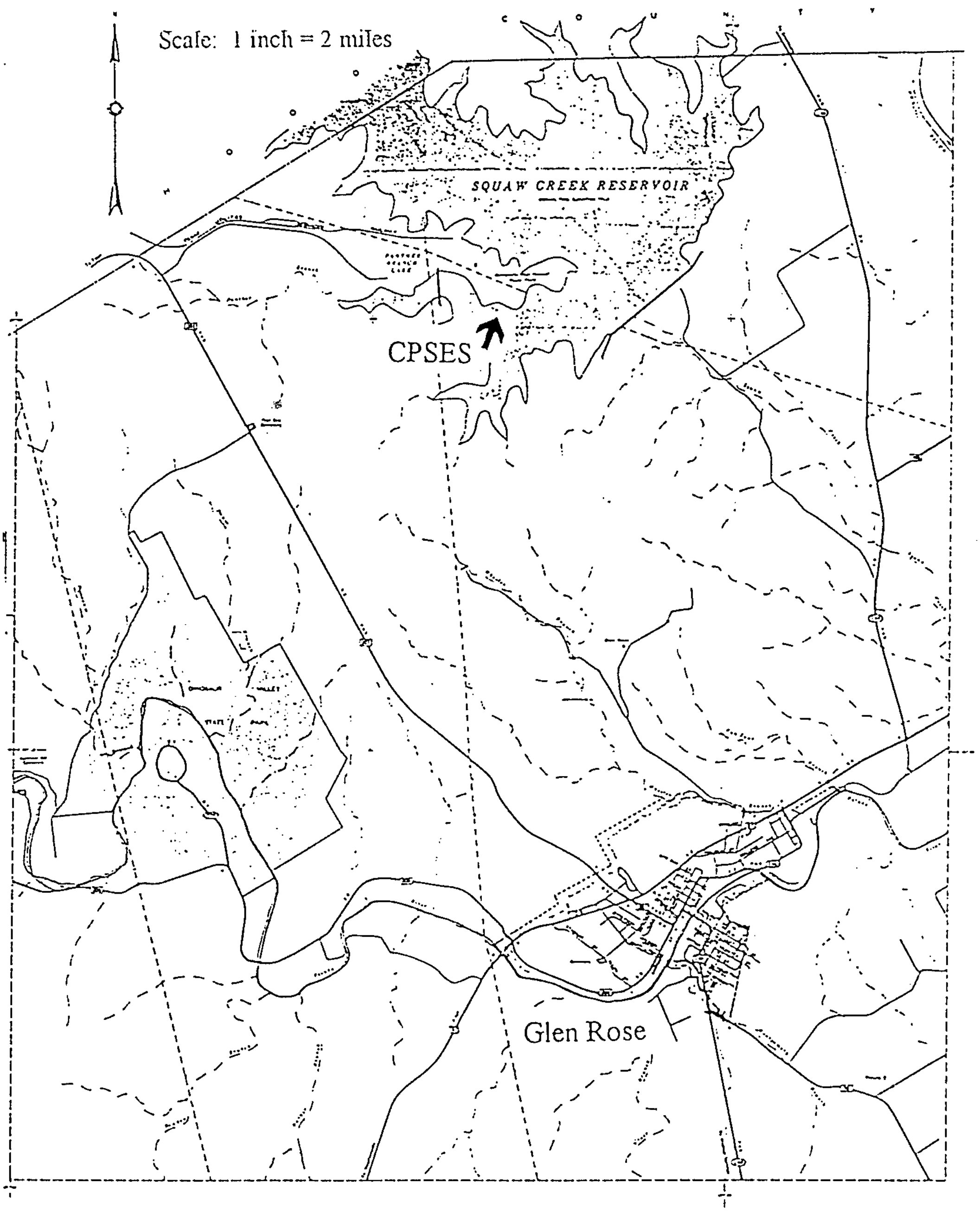
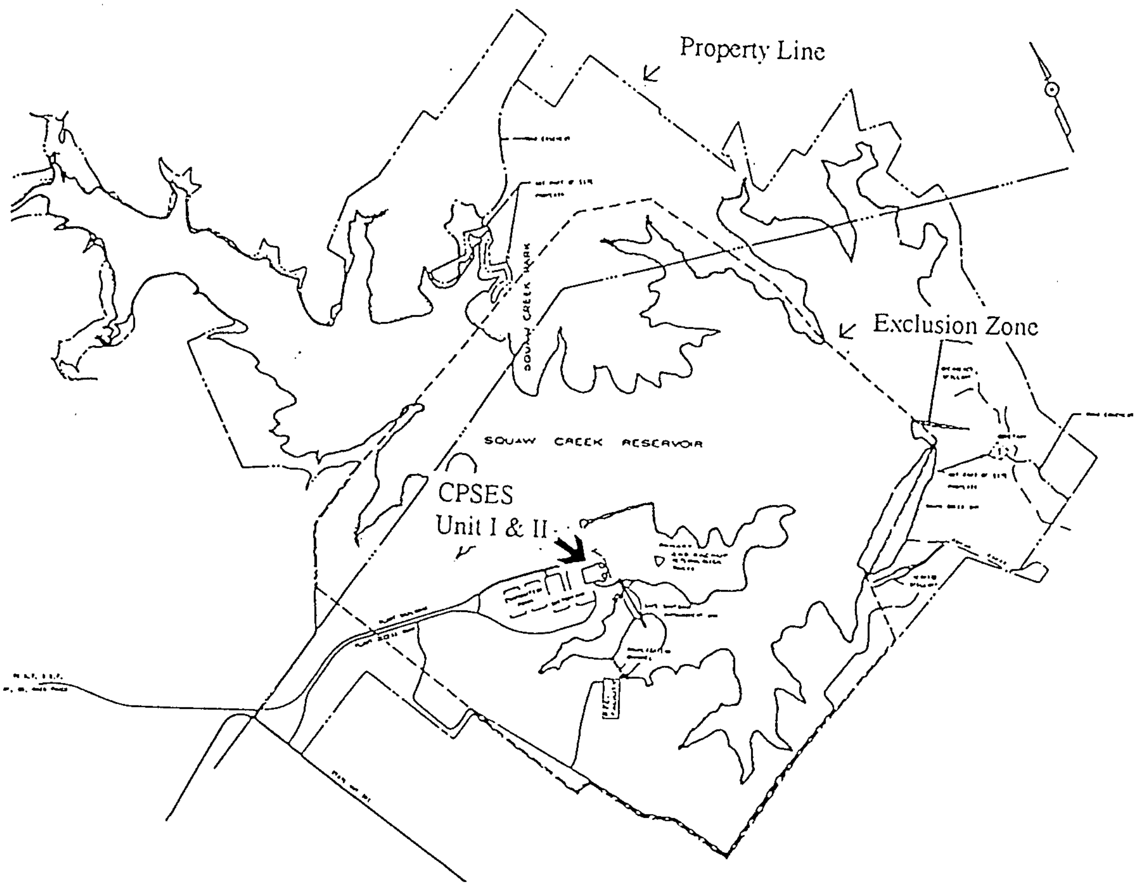


Fig. 3. CPSES, Glen Rose and Squaw Creek Reservoir (TSDHPT 1985)



Scale: 1 inch = 2.2 miles

Fig. 4. Squaw Creek Reservoir Around CPSES Unit I & II (FSAR 1988)

The CPSES site is dominated by a woody plant community of One-seeded Juniper (*Juniperus monosperma*). The presence of a dry upland limestone substrate is responsible for the existence of this dominant plant community. Prairie Sumac (*Rhus lanceolata*), a deciduous shrub-tree, is present in small populations among the evergreen junipers. Post Oak (*Quercus stellata*) and Mesquite (*Prosopis sp.*) are also present in scattered groups in the juniper parks. The second prominent plant community in the CPSES area is made up of Silver Bluestem Grass (*Bothriochloa saccharoides*) and Texas Winter Grass (*Stipa leucotricha*) (Frye et al. 1984). The grassland is dominated by herbs. Few woody plants are present in this plant community. The natural drainage of Squaw Creek and the wet areas produced by the CPSES water impoundments are populated by hydrophilic deciduous plant species. Sugar Hackberry (*Celtis laevigata*), Greenbrier (*Smilax sp.*), Black Willow (*Salix nigra*), Grapevine (*Vitis sp.*), and Eastern Cottonwood (*Populus deltoides*) are examples of the diverse plants found along the water drainages.

The climate of Somervell County is continental and typical of most of Texas (FSAR 1988). The summers are hot and the winters are mild. Rainfall can occur throughout the year, but is usually highest during the fall and spring (Coburn 1978). The surface wind characteristics for the CPSES site are shown as a wind rose in Fig. 5. The prevailing winds are from the south-southeast. It is, therefore, expected that the CPSES site winds would predominantly transport and deposit any released gaseous and airborne particulate radioactive material in the north-northwest direction. Use of a CPSES accidental release diffusion model for a radioactive noble gas indicated the north-

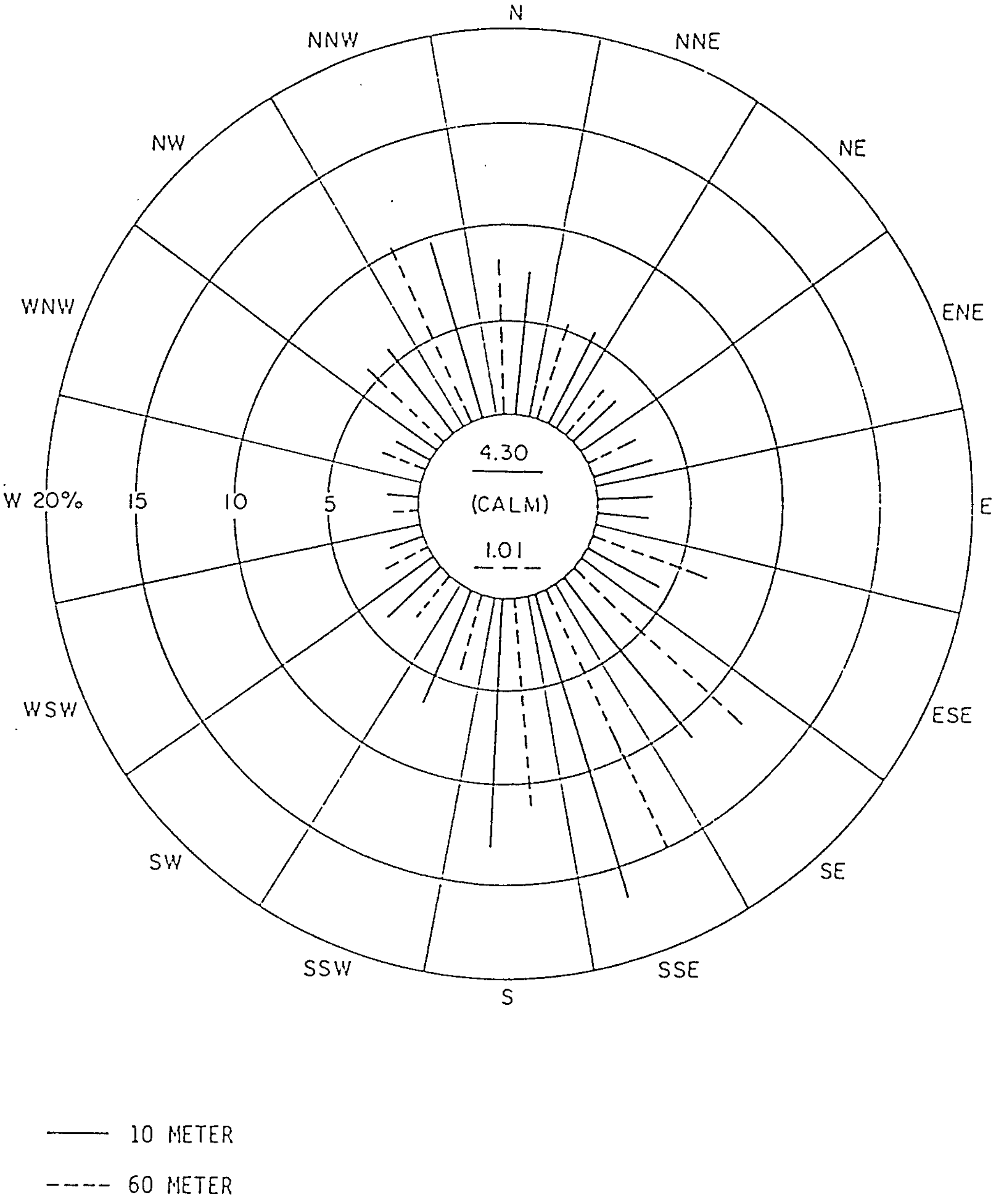


Fig. 5. CPSES Wind Rose (FSAR 1988)

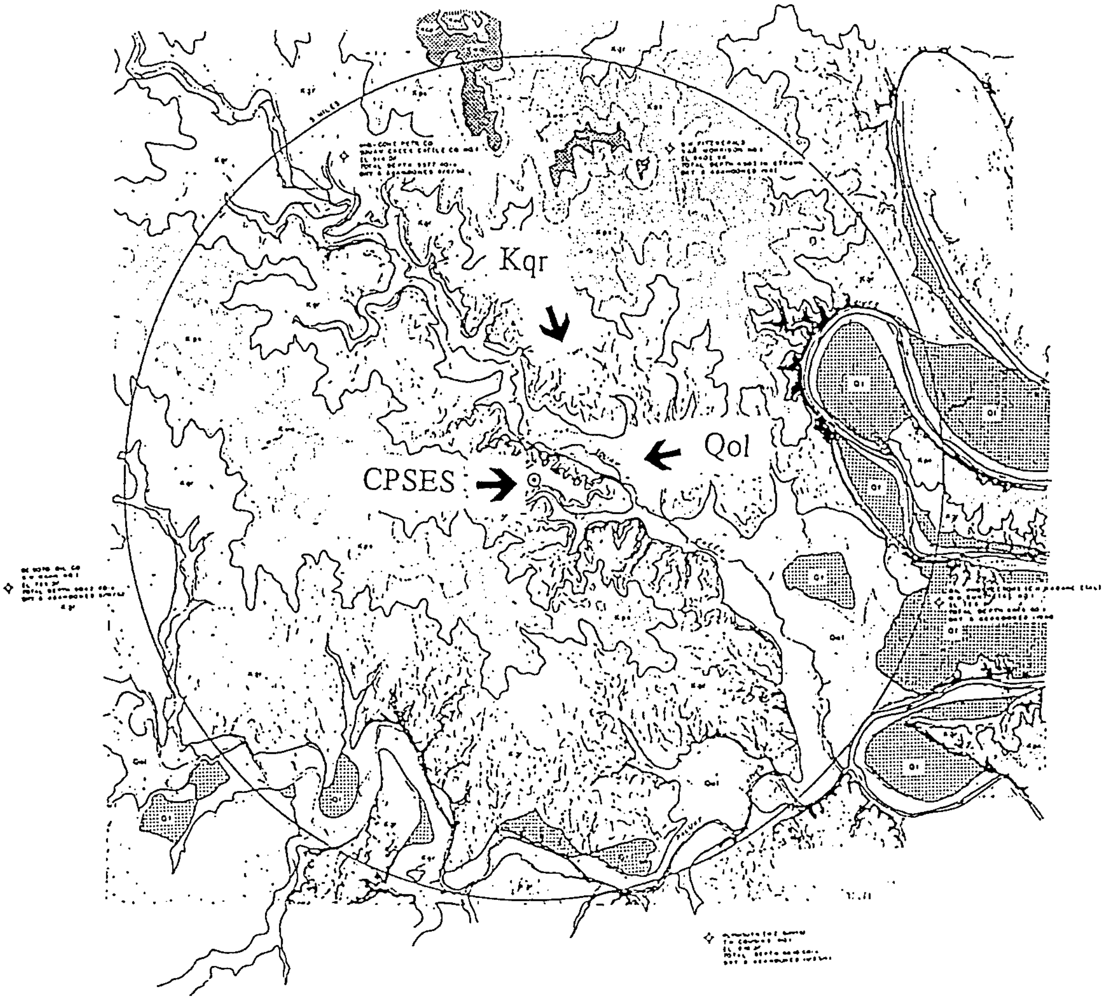
northwest sector as the most probable direction for airborne radioactive material deposition (FSAR 1988).

Somervell County is rural and has an economic base primarily of farming. The county population was sparse in the early days of CPSES construction (U.S. Census 1976). The population was projected to slowly increase after CPSES Unit I began operation with some of the growth attributable to the construction of Unit II (FSAR 1988). The latest United States census lists 5,360 people living in Somervell County (U.S. Census 1990). Glen Rose has the largest population in the area and is the only town that is physically close to the CPSES. Figure 6 lists the 1989 population distribution within an eight kilometer (five mile) radius of CPSES (REMPAR 1990).

The map in Fig. 7 illustrates the geology of the area. There are five general soil types in Somervell County. The CPSES site, though, is composed of only two of the five general soil types. These are the Tarrant-Purves and Frio-Bosque soil units. The Tarrant-Purves soils are described as very shallow to shallow, undulating to hilly, clayey soils that formed in limestone on the uplands. The Frio-Bosque soils are described as deep, nearly level, clayey and loamy soils that formed in calcareous, clayey and loamy alluvium on bottom lands (Coburn 1978). The Frio-Bosque soil are present in the drainage of Squaw Creek. Most of this drainage is inundated by Squaw Creek Reservoir. The rest of the Frio-Bosque soil is located downstream from the reservoir dam along Squaw Creek. The Tarrant-Purves soil is present in all areas of the CPSES site except the Squaw Creek natural water drainages.

Sector	Distance (Kilometers)					
	0-1.6	1.6-3.2	3.2-4.8	4.8-6.4	6.4-8.0	Total
N	-	-	3	26	71	100
NNE	-	-	8	71	21	100
NE	-	-	50	82	184	316
ENE	-	-	39	5	24	68
E	-	-	26	124	23	171
ESE	-	-	11	92	100	203
SE	-	-	47	21	26	94
SSE	-	18	32	26	2534	2610
S	-	21	8	21	103	153
SSW	-	3	3	3	50	59
SW	-	79	8	34	21	142
WSW	-	82	3	5	-	90
W	-	53	5	26	8	92
WNW	-	-	5	26	60	91
NW	-	-	5	-	-	5
NNW	-	-	3	26	11	40
TOTAL	-	256	256	588	3236	4336

Fig. 6. CPSES 8 km (5 mi) Radius Population Distribution (REMPAR 1990)



LEGEND:

Qol = Alluvium
Kqr = Glen Rose Limestone

Scale: 1 inch = 2.25 miles

Fig. 7. CPSES Geology Map (FSAR 1988)

Nature of the Problem

As part of the Radiological Environmental Monitoring Program required by the USNRC, CPSES periodically collects terrestrial biologic samples for radionuclide analyses. The programmatic sampling of the environment is a means to detect and measure any deposited radioactivity released from the nuclear power plant. The USNRC required a pre-operational radiological survey of the CPSES site before start up of the reactors. Pre-operational radiological monitoring must commence at least two years before commercial operation start-up. The purpose of the pre-operational survey is to determine the natural background radioactivity level and establish reference baseline data for future measurements. The pre-operational environmental monitoring survey also helps evaluate operational procedures, monitoring equipment, and sampling techniques (USNRC 1975). Pre-operational radiological surveys were conducted at CPSES from 1981 to 1989 (REMPAR 1990).

Samples of a variety of media to track and measure the transport of radioactive substances to the environment and man via various pathways are collected in the Radiological Environmental Monitoring Program. The major pathways to man are ingestion, inhalation, and direct external exposure. A good illustration of the many paths radioactivity can take that result in off-site exposure dose to members of the public is shown in Fig. 8.

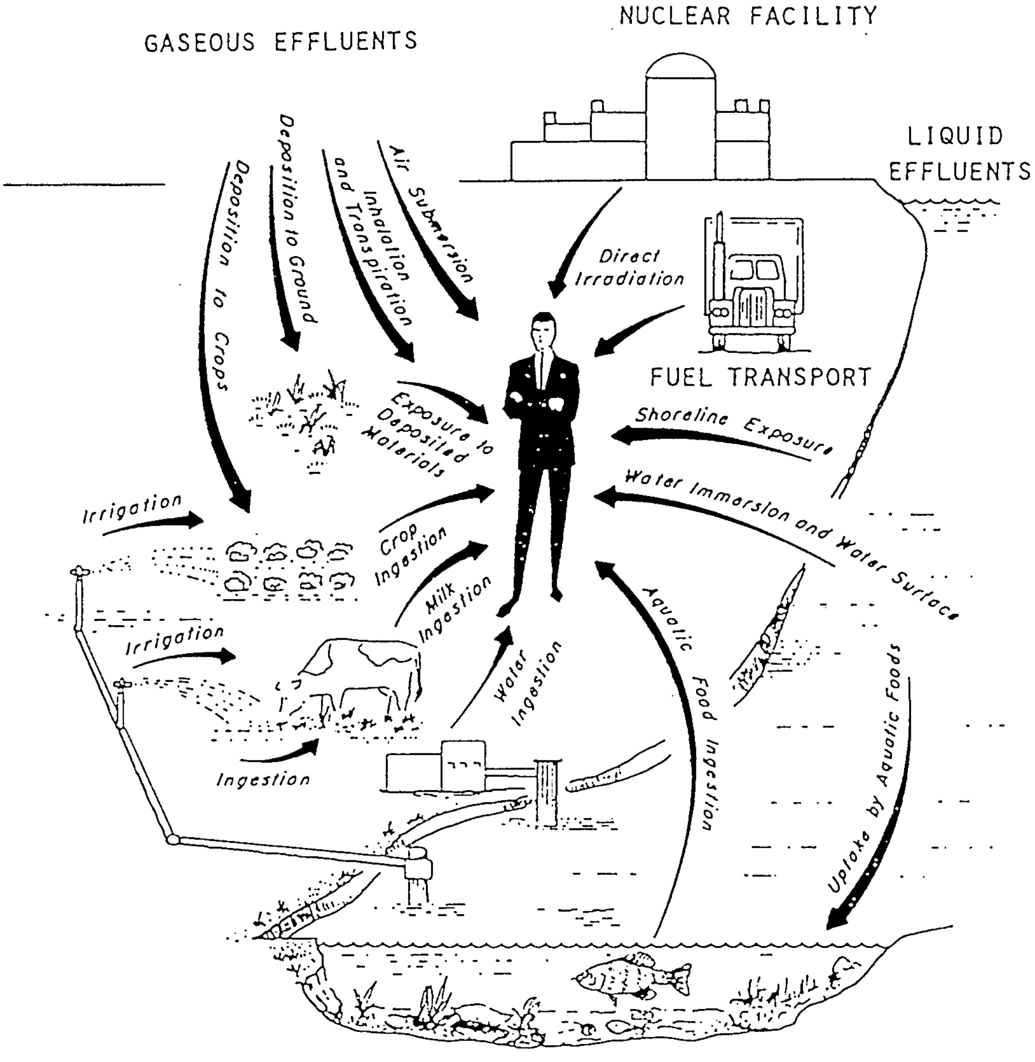


Fig. 8. Radioactivity Pathways to the Public (FSAR 1988)

In radiation protection one of the routinely sampled pathways is the Grass-Cow-Milk-Human Ingestion Pathway. The milk pathway is very important because of the radionuclide ^{131}I. ^{131}I is produced as an abundant fission product by nuclear reactor operation. ^{131}I attains equilibrium of 26 kCi/MWt (9.6×10^{14} Bq/MWt) of steady-state reactor operation. It is also a fission product of nuclear weapons detonation at a rate of 125 MCi/megaton (4.6×10^{18} Bq/megaton). The primary mode of decay of ^{131}I is by β radiation. Elemental iodine is an essential nutrient required for the proper functioning of the human thyroid gland (Eisenbud 1987). ^{131}I is a radioactive isotope of iodine, which means ^{131}I is taken up by the human body and used in metabolic and physiologic processes as if it were the stable non-radioactive elemental iodine. Absorbed dose to the thyroid gland due to radiation from ingested ^{131}I can lead to tissue damage and serious health effects. Even though ^{131}I has a short half-life of eight days, it is possible for a dairy cow near a nuclear power plant to consume ^{131}I contaminated grass and produce contaminated milk. The contaminated milk can then reach the consumer in a short period of time. It is therefore necessary to routinely sample the milk pathway as part of the radiological environmental monitoring program at nuclear power plants.

The Comanche Peak Steam Electric Station's Radiological Environmental Monitoring Program (REMP) requires the collection of milk samples from surrounding dairy farms. Because there are few dairy farms in the vicinity of CPSES, the REMP's standard operating procedures, as per the USNRC, allows for the collection of broadleaf vegetation at certain locations in lieu of milk samples (FSAR 1988).

In 1989 only two sites around the CPSES had milk cows. Routine milk sampling was established at these sites by the CPSES. The cows were located 3.5 and 22 kilometers in the south-southeast and southwest sectors, respectively. The 16 directional sectors around the CPSES have the reactor buildings as the center point. The southwest sector milk sampling location in Erath County was established as the control station (FSAR 1988). For this study, a control station is defined as a sampling site situated outside of the CPSES exclusion area boundary of 4,170 acres (1688 hectares). The control station is placed upwind and far enough away as not to be affected by the power plant normal operations. The near-site and off-site milk sample stations at 3.5 and 21.7 kilometers, respectively, remained the same during 1990 (REMPAR 1990). Milk sampling was continued at these sites during 1990. Because of the scarcity of dairy cattle, CPSES has collected and analyzed broadleaf vegetation samples on-site and around its boundary pre-operationally and currently as part of its Radiological Environmental Monitoring Program (REMPAR 1988, 1989; 1990).

The collection of vegetation defined as "broadleaf" is a requirement to fulfill Title 10 Part 50 of the Code of Federal Regulations (10 CFR 50). These regulations fall under the oversight of the USNRC. The broadleaf plant species in the CPSES area are few and are all deciduous. At CPSES the broadleaf species are found primarily along streams and other sources of surface and near-surface water. Their poor and uneven distribution on the rolling hills is due to the arid soil conditions produced by a porous limestone substrate. The deciduous plants are replaced at the higher elevations by a community of One-seeded Juniper (*Juniperus monosperma*). In contrast to the broadleaf plant species, the One-seeded Juniper is evergreen and a xerophyte. A xerophyte is a plant that normally grows in dry habitats.

The monthly collection of one kilogram of broadleaf samples as required by the REMP, has been hampered by the natural scarcity of broadleaf vegetation and its deciduous nature. The leaves of broadleaf species may be absent in late fall, winter, and early spring depending on the severity of cold weather. During these seasons, the CPSES may have difficulty collecting environmental plant samples. Presently, only broadleaf samples are routinely collected by the REMP to meet USNRC regulations on this part of environmental sampling. The CPSES has approached USNRC with a proposal for substituting evergreen plant samples for the broadleaf samples as a means to make vegetation sampling more representative on a year-round basis. This proposal was declined, but the agency representative suggested that data favorably comparing evergreen and broadleaf vegetation could be reviewed with possible vegetation species substitution and/or addition allowed in the future (Kay 1991).

Research Objective

The objective of the thesis research was to measure ^{137}Cs radioactivity from airborne foliar deposition and/or soil intake in the foliage of pre-defined juniper and broadleaf tree species. ^{137}Cs was chosen because it is ubiquitous in the environment, is non-increasing in quantity, has a long half-life (30.2 years), and is easily detectable by its progeny's (^{137m}Ba) single gamma-ray emission of 661.7 kilo-electron volts (keV). The quantitative measurement of ^{137}Cs in the foliage of juniper and broadleaf species would yield information on the distribution of this radionuclide in the two plant categories. The quantitative measurement of the underlying soil of each sample station would also contribute valuable information on how ^{137}Cs is distributed in the soil and foliage of each specific collected plant. It was anticipated, because of its evergreen nature, higher leaf surface area per volume, and resinous foliage nature, that the juniper tree species would have higher levels of ^{137}Cs radioactivity in its foliage than the broadleaf tree species. This anticipation would be supported by the measurement of unequal ^{137}Cs concentrations in the juniper and broadleaf species foliage. In this scenario, the ^{137}Cs concentration in the soil samples would be the same.

If juniper species could be quantitatively shown to "collect" airborne deposited ^{137}Cs in greater or same quantities as broadleaf species, then it could be inferred that other air pathway radionuclides would also be present in higher or equal radioactivity levels in the junipers as compared to the broadleaf species. The measured ^{137}Cs in vegetation foliage would be interpreted as originating from airborne deposited particles on leaves and particles in leaves from soil uptake. Therefore, based on such research conclusions, a proposal to the USNRC could be supported for the substitution of evergreen vegetation samples for the broadleaf samples. The use of juniper vegetation samples could be justified if the research results show equal or higher radioactivity concentration in the juniper foliage. The use of juniper foliage in routine vegetation sampling and analyses could yield more accurate information on environmental radioisotope concentrations and distributions throughout the year, since the juniper trees may be better radioisotope "collectors", are evergreen, and are uniformly distributed over the CPSES area.

Sources of ^{137}Cs Radioactivity

Stable Cs occurs in nature only as the isotope ^{133}Cs. The other 35 known isotopes of Cs are all radioactive and have been produced artificially (Walker et al. 1989) (Perleman 1965). ^{137}Cs is a high yield fission product with its source being commercial nuclear reactors and ^{235}U and ^{239}Pu fission reactions in nuclear weapons testing. ^{137}Cs makes up about six percent of the atoms produced by fission (Fowler and Christenson 1959).

Atmospheric testing of fission nuclear releases radioactive debris into the environment. The subsequent deposition of the radioactive debris over the earth's surface is called fallout (Langham and Anderson 1959). There are three categories of fallout with the differences being the length of the time the radioactive material remains in the various atmospheric strata until its deposition (Libby 1956). The main source of ^{137}Cs in soil and vegetation foliage, historically, has been from the atmospheric testing programs of the United States and other countries.

In nuclear reactors, ^{137}Cs is found in the primary coolant system. As part of normal operations of commercial nuclear reactors, low levels of ^{137}Cs are discharged in the plant liquid effluent. Even though there are operational losses and planned releases, the amount of radioactive materials from nuclear power plants that actually reach the environment is extremely small (Sagan 1974). Very small amounts of ^{137}Cs in aerosol form can also be released to the environment from the stacks of nuclear power plants. The airborne and liquid releases of ^{137}Cs from commercial nuclear power plants are extremely small in comparison to the historical releases by atmospheric nuclear testing. Figure 9 illustrates the mechanisms for atmospheric dispersion and removal of airborne radioactive material.

^{137}Cs is dispersed widely and locally in the environment through airborne deposition from above ground nuclear weapons testing. Nuclear power plants can also contribute ^{137}Cs to the environment through airborne and liquid pathways by controlled and accidental releases. Once in the environment, ^{137}Cs is deposited on vegetation, water and soil (Glasstone and Jordan 1980). From dry ground, it can also be re-suspended into the air for re-deposition by wind action. Another mechanism for re-deposition of ^{137}Cs is rain splash. Heavy rains are able to splash contaminated soil particles up onto the foliage of local vegetation (Dreicer et al. 1984). The radioactive contamination may remain on the foliage until removal by a physical or biological force (Foster et al. 1985). Because ^{137}Cs has a strong tendency for ion exchange, it may be tightly bound to the soil and thus unlikely to be taken up by plants (Nishita et al. 1956, Comar 1965). A study of the transport of ^{137}Cs from the atmosphere to milk concluded that root uptake is slight (Wilson et al. 1969). Therefore, the majority of ^{137}Cs in the environment is expected to be found in or on the ground, and more on vegetation than in vegetation.

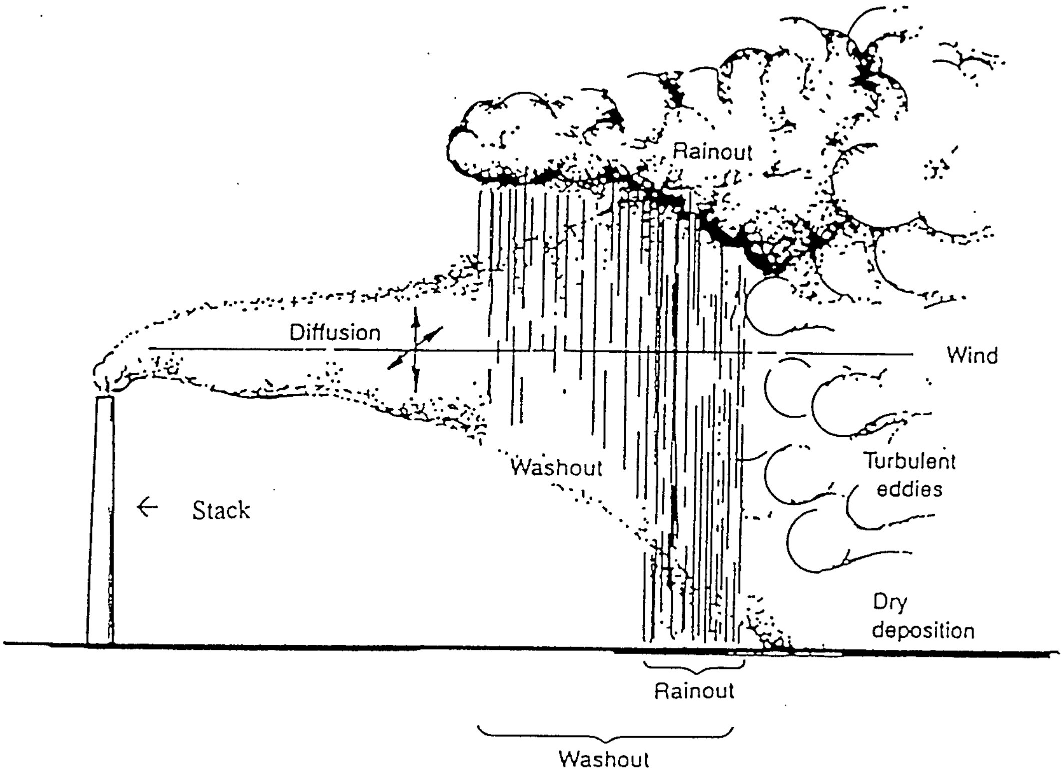


Fig. 9. Mechanisms for Atmospheric Dispersion of Radioactivity (Brent et al. 1983)

The principal modes, energies, and yield of ^{137}Cs radioactive decay are: β^- 0.51 MeV (94%), β^- 1.18 MeV (6%); and γ 0.66 MeV (85%), respectively (Eisenbud 1987). The maximum beta energy decay is 1.18 MeV. The physical half-life of ^{137}Cs is 30.2 years. The 661.7 keV gamma-ray detected from a ^{137}Cs sample is actually the gamma-ray from ^{137m}Ba. This is because the two radionuclides exist in a state known as secular radioactive equilibrium. In secular equilibrium, the ^{137}Cs transformations are equal to that of ^{137m}Ba which has a half-life of 2.55 minutes. It is the gamma-ray of ^{137m}Ba, therefore, that is readily detected by instrumentation.

The ^{137}Cs collected and measured from the CPSES area has as its origin the numerous nuclear weapons atmospheric tests conducted during the late 1950's and early 1960's (Glasstone and Dolan 1977). The ^{137}Cs should be fairly uniformly distributed in the CPSES area due to its airborne deposition before construction of the facility. Pockets of differing concentrations may be present due to natural ^{137}Cs “sink traps” and differential movement caused by random environmental factors over the years. Sink traps can be defined as the concentration of an element or chemical in a locale due to natural conditions. The specific radioactivity concentration of ^{137}Cs over the CPSES area should, although, be fairly uniform because of the cessation of United States nuclear atmospheric testing in November 1962. The United States, the United Kingdom, and the Soviet Union signed in August 1963 a treaty banning nuclear weapon tests in the atmosphere (Hacker 1994). No ^{137}Cs from the CPSES reactors was expected in the sampling locations because Unit I had just began commercial operation at the time of this study’s sample collection. Even though commercial nuclear reactors produce significant quantities of ^{137}Cs in the fuel, little of it is available for environmental release unless there is a fuel leak. The pre-operational radiological survey of the CPSES site showed sample results to be either below the measurement detection limits or indicative of natural terrestrial and cosmic radiation levels (REMPAR 1988, 1989). These measurements do not indicate the presence of any ^{137}Cs atmospheric fallout from the Union of Soviet Socialist Republics (USSR) Chernobyl nuclear reactor accident of April 26, 1986. In regard to Unit II, it was still under construction and non-operational at the time this study's field sampling was initiated and completed.

Another important isotope of Cs is ^{134}Cs. This radioisotope is not a product of nuclear weapons because the fission in the detonations is so rapid. ^{134}Cs is produced in nuclear reactors as an activation product of stable ^{133}Cs which is produced as the end-product of the mass 133 fission product decay chain. The stable ^{133}Cs absorbs a neutron and emits a gamma-ray to transform into ^{134}Cs. ^{134}Cs has a physical half-life of 2.06 years and is also a γ emitter with an energy and yield of 0.605 MeV and 98%, respectively (Eisenbud 1987). It is likely that the presence of ^{134}Cs and ^{137}Cs in the environment would indicate a nuclear reactor fuel leak origin for both. The presence of ^{134}Cs in the CPSES area was not part of this study's objective and none was expected in the environment because of the short time of nuclear reactor operation and effective fuel containment safety measures. The final gamma-ray spectrometry data from this study do not show any presence of ^{134}Cs in the leaf and soil samples (see Tables 22 through 43).

Literature Review

An extensive review of the published scientific literature was conducted with reference to ^{137}Cs radioactivity in vegetation and soils. Searches of scientific articles and studies yielded much information helpful to this thesis. No one single article was found, however, indicating that the objective of this thesis was previously scientifically studied. None of the reviewed studies were on analytical measurements of ^{137}Cs concentrations in deciduous and evergreen tree species. This thesis study is the first, to the author's knowledge, to compare environmental radioactivity levels between juniper and deciduous tree species from the same geographic area. Many of the reviewed scientific articles provided relevant information on environmental origins and transport of ^{137}Cs in air, vegetation, soils, and animals. For example, background information on the environmental aspects of nuclear power was found Eichholz (1976). Factors influencing the biological availability of radionuclides for plants were learned from Menzel (1963). Additional information on ^{137}Cs in soils, vegetation, and atmosphere was obtained from articles by many authors, such as Moorby (1964), Chesire and Shand (1991), Eisenbud (1987), and Sutherland et al. (1991). Reference material on statistical applications were taken from several sources, such as Bishop (1983).

Approximately 120 published articles and books were reviewed for relevancy to this study. Out of this total number, 17 articles had no direct contribution to the preparation and execution of the study. About 26 of the total articles were used as direct references in the study. These are listed in the References portion of this thesis. The remaining articles and studies were used for background information. These other references are listed for their information in the Supplemental References section.

VEGETATION AND SOIL SURVEY

An approach to surveying and sampling the CPSES terrain was developed and implemented. The area vegetation and soils were located and identified as part of the research objective. Knowledge of the vegetation, soil types, and their locations was used to select the research sample sites. Upon site selection, samples of pre-defined vegetation and associated soils were collected following an established procedure.

During the field research portion of this thesis study, still photographs and video of the CPSES and sample collection sites were taken to assist in the study.

Purpose of Vegetation and Soil Collection

In order to test the thesis hypothesis, collection of evergreen and broadleaf vegetation was needed for ^{137}Cs analysis and comparison purposes. Broadleaf vegetation was first collected by the CPSES REMP in 1989 before Unit I began operating commercially. Only tree foliage was supposed to be collected as part of the required sampling program. The REMPAR of 1990 lists the sampled broadleaf vegetation as forage grass, vegetation, weed leaves, bloodweed, Johnson grass, rye grass, sumac leaves, and cottonwood leaves. When tree leaves were unavailable, the REMP substituted native grasses and weeds (REMPAR 1990). Grasses and weeds were probably substituted during the seasons when the broadleaves had fallen and were unavailable. Sumac leaves, tree leaves, and grasses (all without species identification) were collected as broadleaf samples by the CPSES REMP in 1989 (REMPAR 1989).

No broadleaf vegetation was collected pre-operationally in 1988. Garden vegetables, although, were collected and analyzed during this year (REMPAR 1988). Pre-operationally and during this study, the REMP collected broadleaf foliage and other vegetation types. For this thesis research, the selection and sampling of pre-defined evergreen and broadleaf vegetation was required for consistency, quality control, and valid comparison of analytical results. The needed vegetation sites were located, identified, and samples collected.

As another means for correlating ^{137}Cs contents, samples of the soil beneath the vegetation sample sites were needed. Soil samples would allow for comparison of the ^{137}Cs specific activity between the soil and foliage at each sample station. In addition, soil samples would allow for the comparison of the ^{137}Cs activity concentrations between soils from different sample locations. Differences in ^{137}Cs content between individual sample sites and sample types could then be determined and interpreted to evaluate the research objective. Pre-operationally and operationally, the CPSES did not and does not routinely collect soils as part of its REMP, although, Squaw Creek Reservoir shoreline sediments are taken (REMPAR 1988, 1989; 1990). A pre-operational airborne survey of terrestrial radioactivity was conducted at the CPSES site as an aid to geologic mapping (FSAR 1988). Most of the stratigraphic units were too limited and could not be differentiated by the aerial survey. No specific references to terrestrial soil testing for radioactivity were found in CPSES related literature. For this thesis research, specific soil sample sites were located, identified, and samples collected.

Selection of Sample Stations

In 1990, broadleaf vegetation samples from three locations were collected under the REMP. Two locations were within the exclusion boundary and the other location was off-site. Figure 4 shows the CPSES exclusion boundary and the area confined by it. The off-site location was and still is used as the control station. These CPSES broadleaf sample stations are located in the north and southwest sectors (REMPAR 1990). The existing CPSES air monitoring station names were kept and used as reference points in this study. The REMP sample locations near the power station are designated as BL-1 (broadleaf no. 1) in the north sector and BL-2 in the southwest sector, at 2.3 and 1.6 kilometers, respectively. BL-1 is located alongside the CPSES air sampling station A1 in Squaw Creek Park within the CPSES exclusion zone. The park is on TU Electric property. BL-2 is located near CPSES air sampling station A5 at the exclusion zone fenceline. The control station, designated BL-3, is in the southwest sector 22 kilometers away from the nuclear reactor building (REMPAR 1990). If cow milk sampling cannot be performed at all required locations, then the CPSES Off-site Dose Calculation Manual (ODCM) requires the sampling of broadleaf vegetation in lieu of milk. The ODCM specifies that the broadleaf vegetation sampling be from two off-site locations that have the highest predicted annual average of radioactivity deposition (ODCM 1990). Since cow milk was unavailable for sampling at the pre-determined locations before and at commercial start up, broadleaf vegetation sampling was instituted by CPSES. During this thesis's research period (fall 1991 and spring 1992), CPSES had established two of its broadleaf sample stations along the nuclear power plant's exclusion boundary. The exception was the CPSES third broadleaf sample station. This one, as previously mentioned, was established for control purposes and is located 22 kilometers away in neighboring Erath County southwest of CPSES.

For this study, six sample stations were selected both on and off the CPSES site. Five of the stations were within the CPSES Exclusion Zone. The study's control station was located the farthest from the nuclear power plant. The control station was also upwind from the area's south-southeast prevailing wind. It was sited near the CPSES control station in Erath County (Fig. 10). This study's stations were named uniquely for identification purposes. The names of the established broadleaf and soil sample stations were developed by the author. Each station name was prefixed with *TAMU*, for Texas A&M University, and was followed with the general location name abbreviation of *SCP*, *PP*, or *CL*. *SCP* stands for Squaw Creek Park, *PP* stands for Power Plant, and *CL* means Control Location. The *SCP* station was situated within Squaw Creek Park, the *PP* stations were situated within the CPSES Exclusion Zone, and the *CL* station was situated southwest of CPSES in a rural area. In addition, each sample was identified with a *J*, *BL* or *Soil* label to differentiate and track the juniper, broadleaf or soil respective matrices. Each sample name ended with a number used to identify the order of collection from each sample location. For example, the respective sample labels for the juniper foliage and soil collected at Squaw Creek Park look like this: *TAMU SCP J-1* and *TAMU SCP Jsoil-1* (The reduced size of the "*soil*" lettering is intentional in the sample labels).

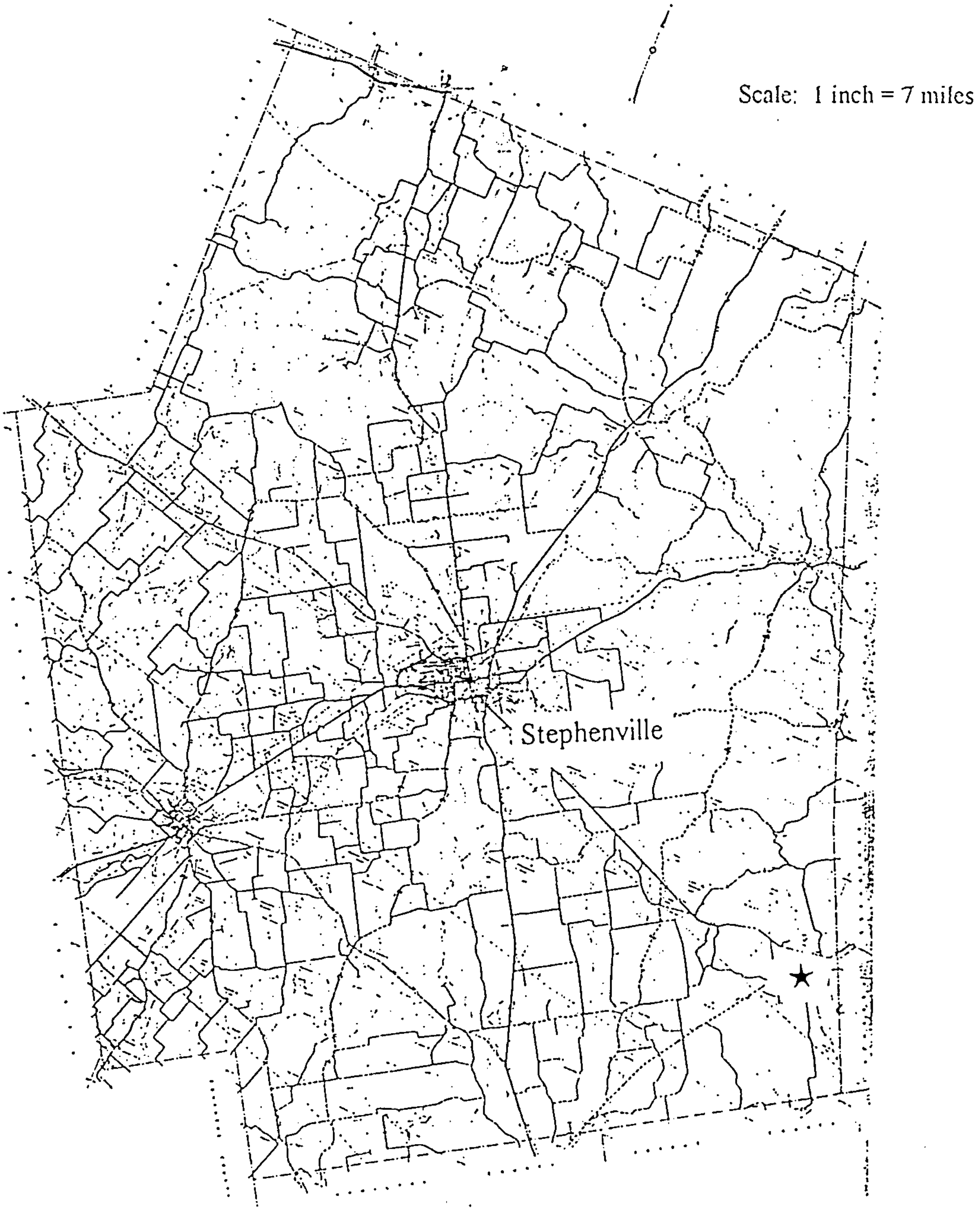


Fig. 10. Control Location (★) in Erath County (TSDHPT 1985)

Description of Sample Stations

The TAMU sample stations were selected to be representative of the CPSES site's deciduous and evergreen vegetation, duplicative of existing CPSES on-site and control broadleaf sample stations, and, in part, representative of the predicted CPSES radioactive airborne dispersion and deposition areas.

A total of 22 samples of tree leaves and soil were collected from the six study sample stations. The TAMU sample stations are described in the 16 compass sector standard format as shown in Fig. 5. This thesis adopted the same sectors as described in the CPSES 1988 FSAR and 1990 REMPAR. The center of the radial compass sectors is approximately between the Unit I and Unit II reactor buildings.

All of the study's sample stations were physically marked for easy identification and future reference. The individual trees selected as samples were marked conspicuously with orange vinyl flagging at diameter breast height (dbh.), which is approximately 1.4 meter above ground. In addition, a wooden stake (46 centimeters) labeled prominently with the sample name in indelible black ink was driven with a sledge hammer into the ground by each sample tree.

Sample Station No. 1 was located inside the Exclusion Zone and within Squaw Creek Park. The park is owned and operated by TU Electric. The park serves as a buffer to the nuclear power plant, but has a secondary benefit of providing recreation to the public. Squaw Creek Reservoir, which provides cooling water to the nuclear reactors, is the Park's main attraction. Station No. 1 is situated off of the park's main entrance road. The Station is approximately 46 meters east of the CPSES Air

Monitoring Station No. A1. The CPSES's Broadleaf Sampling Station No. 1 is adjacent to Air Monitoring Station A1 (REMPAR 1990). The first sample site of this study was co-located here and established as TAMU SCP BL-1. A broadleaf sample for TAMU SCP BL-1 was collected at this site. Since trees are sparse in the area, the juniper sample site (TAMU SCP J-1) was located 10 meters away from the broadleaf sample site (TAMU SCP BL-1). TAMU Station No. 1 is geographically located in the North Sector 2.3 kilometers from the nuclear power plant site center. TAMU Station No. 1 is on natural rolling limestone hills that slope towards the reservoir. As stated earlier, the dry limestone substrate is uninviting to deciduous trees. This area is dominated by One-seeded Juniper (*Juniperus monosperma*).

TAMU Sample Station No. 2 was located right next to Peninsula Road. This road is caliche-topped and parallels the southeast side of the Exclusion Zone. It is used for security patrols and terrestrial access to the dam. Station No. 2 was established approximately 1.0 kilometer northeast of the Exclusion Zone's southernmost corner boundary. The Station was placed on the road's north shoulder by three Eastern Cottonwoods (*Populus deltoides*). These tall cottonwoods were the only deciduous trees in the area and also readily accessible by the road. Also in the area was one of Squaw Creek Reservoir's finger coves reaching almost to the north side of Peninsula Road. One of the Eastern Cottonwoods was selected as the broadleaf sample (TAMU PP BL-2). The selected juniper sample tree (TAMU PP J-2) was on the lakeside of the road approximately 28 meters north of the broadleaf sample tree. This location is dominated by One-seeded Juniper (*Juniperus monosperma*). The juniper trees seemed larger in this area. The many juniper trees apparently were established before construction of Squaw Creek Reservoir and the adjacent moist soil may explain the favorable tree growing conditions. The only other deciduous tree in the area was an elm (*Ulmus sp.*) next to the cottonwoods. Peninsula Road was engineered to be flat and extend out in a straight line. The road almost runs in a northeast and southwest direction. The north side of the road gently slopes toward the lake.

TAMU Sample Station No. 3 was established between the Exclusion Zone fenceline and Peninsula Road approximately 1.5 kilometer northwest of the Exclusion Zone's southernmost corner boundary. This site is next to the chain gate on Peninsula Road. Also nearby is Park Road, which leads to the CPSES on-site employee recreation area. The Station No. 3 area was primarily composed of deciduous shrub and tree species. A Post Oak (*Quercus stellata*) was selected as the broadleaf sample tree (TAMU PP BL-3). A One-seeded Juniper (*Juniperus monosperma*) 6 meters away was chosen as the evergreen sample tree (TAMU PP J-3). Both trees were on the fenceline. TAMU Station No. 3 is just due northwest of CPSES Air Monitoring Station No. A-5. CPSES also has its No. 2 broadleaf sampling station in the area. It is located nearby just up (northwest) from TAMU Station No. 3 alongside Peninsula Road.

TAMU Sample Station No. 4 was established on the northwest side of Park Road by the entrance to the CPSES recreation area. The site was selected because of the heavy dust loading on the roadside vegetation. Park Road is very dusty due to its caliche cover and high vehicular usage. The vegetation on both sides of the road is blanketed by re-suspended soil. Station No. 4 is situated approximately 0.7 kilometer north of Peninsula Road. A Prairie Sumac (*Rhus lanceolata*) was designated the deciduous sample tree (TAMU PP BL-4). A large Eastern Red Cedar (*Juniperus virginiana*) was marked as the evergreen sample tree (TAMU PP J-4). The large Eastern Red Cedar towered over the surrounding numerous One-seeded Junipers.

TAMU Sample Station No. 5 was established in the vicinity of CPSES Air Monitoring Station No. A-8. A dirt road leads to the monitoring station. This air monitoring station is approximately 1.6 kilometer from the Unit I and II buildings. TAMU Station No. 5 was placed approximately 24 meters due east from A-8. The vegetation surrounding the Sample Station is dominated by One-seeded Juniper (*Juniperus monosperma*). Only a couple of deciduous trees were seen at a distance. No deciduous trees were immediately in the area. Because of the lack of deciduous trees, only an evergreen tree was selected for sampling. A young Eastern Red Cedar (*Juniperus virginiana*) was located, marked, and identified as TAMU PP J-5. This location was the only site of the study not sampled for both evergreen and deciduous foliage.

The last of the study's sample stations was the control. TAMU Sample Station No. 6 was established outside of the Exclusion Zone and Somervell County. TAMU Station No. 6 was co-located in Erath County in the vicinity of the CPSES Broadleaf Station No. 3 and Milk Station No. 4. Both Broadleaf Station No. 3 and Milk Station

No. 4 are CPSES controls. TAMU Sample Station No. 6 is approximately 22 kilometers southwest from the nuclear power plant. The Sample Station is just south of the Chalk Mountain community. It is on an unmarked caliche road 0.9 kilometer east of state highway 220. The caliche road is the first unpaved road encountered on state highway 220 southwest of the Chalk Mountain community and U.S. highway 67. The unmarked road runs east-west. TAMU Sample Station No. 6 was located on a fenceline on the north side of the caliche road. A producing dairy farm is just across the road of the Sample Station. The only trees available for sampling exist between the road shoulder and fence. A Red Mulberry (*Morus rubra*) was selected as the deciduous sample tree (TAMU CL BL-6). A One-seeded Juniper (*Juniperus monosperma*) located approximately 8 meters from the Red Mulberry was marked as the evergreen sample tree (TAMU CL J-6). The foliage and soil samples of TAMU Sample Station No. 6 were the only samples collected during a rain storm. The sample stations, foliage sample location names and associated plants are listed in Table 1.

TABLE 1. Vegetation Sample Stations

Sample Station	Sample Name	Plant Name
No. 1	TAMU SCP J-1	One-seeded Juniper
No. 1	TAMU SCP BL-1	Prairie Sumac
No. 2	TAMU PP J-2	One-seeded Juniper
No. 2	TAMU PP BL-2	Eastern Cottonwood
No. 3	TAMU PP J-3	One-seeded Juniper
No. 3	TAMU PP BL-3	Post Oak
No. 4	TAMU PP J-4	Eastern Red Cedar
No. 4	TAMU PP BL-4	Prairie Sumac
No. 5	TAMU PP J-5	Eastern Red Cedar
No. 6	TAMU CL J-6	One-seeded Juniper
No. 6	TAMU CL BL-6	Red Mulberry

Soil sample sites were established below each deciduous and evergreen sample tree. Each soil sample site was marked with a labeled stake. The 11 established soil sample sites were identified as TAMU SCP Jsoil-1, TAMU SCP BLsoil-1, TAMU PP Jsoil-2, TAMU PP BLsoil-2, TAMU PP Jsoil-3, TAMU PP BLsoil-3, TAMU PP Jsoil-4, TAMU PP BLsoil-4, TAMU PP Jsoil-5, TAMU CL Jsoil-6, and TAMU CL BLsoil-6. Table 2 lists the names of the sample stations, soil sample locations and plant names under which the soil samples were collected.

A map showing all the TAMU Sample Stations is presented in Fig. 11. The off-site control location in Erath County (Fig. 10) is shown relative to CPSES in Fig. 12. For comparison purposes, the CPSES's area air, radiological, milk and other monitoring stations are also shown on this figure.

Vegetation and Soils Collected

As previously stated, the purpose of the study was to compare ^{137}Cs concentrations in evergreen trees vis-à-vis deciduous trees. Samples were successfully collected from both plant categories by following the sampling procedure outlined in Appendix A. Broadleaf foliage was not collected at TAMU Sample Site No. 5 due to lack of deciduous vegetation in the area. Soil from the base of the tree sample sites was also collected as another means to measure and compare the tree types. The sampling procedure described in Appendix B was followed to collect the soil samples. A total of

TABLE 2. Soil Sample Stations

Sample Station	Sample Name	Soil Source
No. 1	TAMU SCP Jsoil-1	Base of One-seeded Juniper
No. 1	TAMU SCP BLsoil-1	Base of Prairie Sumac
No. 2	TAMU PP Jsoil-2	Base of One-seeded Juniper
No. 2	TAMU PP BLsoil-2	Base of Eastern Cottonwood
No. 3	TAMU PP Jsoil-3	Base of One-seeded Juniper
No. 3	TAMU PP BLsoil-3	Base of Post Oak
No. 4	TAMU PP Jsoil-4	Base of Eastern Red Cedar
No. 4	TAMU PP BLsoil-4	Base of Prairie Sumac
No. 5	TAMU PP Jsoil-5	Base of Eastern Red Cedar
No. 6	TAMU CL Jsoil-6	Base of One-seeded Juniper
No. 6	TAMU CL BLsoil-6	Base of Red Mulberry

22 plant and soil samples at six locations were collected during the field portion of this study.

All tree foliage was collected in clean clear commercial plastic bags. Collected soil was also stored in clean clear plastic bags. Detailed vegetation and soil sampling procedures are described in Appendices A and B.

At TAMU Sample Station No. 1 deciduous leaves were collected from Prairie Sumac (TAMU SCP BL-1) and evergreen leaves were collected from One-seeded Juniper (TAMU SCP J-1). The soil samples (TAMU SCP BLsoil-1 and TAMU SCP Jsoil-1) collected at the base of the sumac and juniper trees were similar in texture and color. The soil appeared to match the description and distribution of the Tarrant-Purves soil type.

For TAMU Sample Station No. 2 the deciduous leaves of Eastern Cottonwood (TAMU PP BL-2) were collected. One-seeded Juniper (TAMU PP J-2) contributed the evergreen sample leaves for this site. The soil sample (TAMU PP BLsoil-2) of the deciduous tree was calcareous in nature and essentially roadbed caliche due to the close proximity of Peninsula Road. The caliche road appears to have been put there in the early years of CPSES to access Squaw Creek dam construction. The soil sample (TAMU PP Jsoil-2) of the evergreen tree was dark and loamy with some limestone and more clay constituents. The evergreen soil sample appeared to belong to the Frio-Bosque soil group. The evergreen soil may have its origin from the nearby natural drainage that feeds the Squaw Creek Reservoir cove.

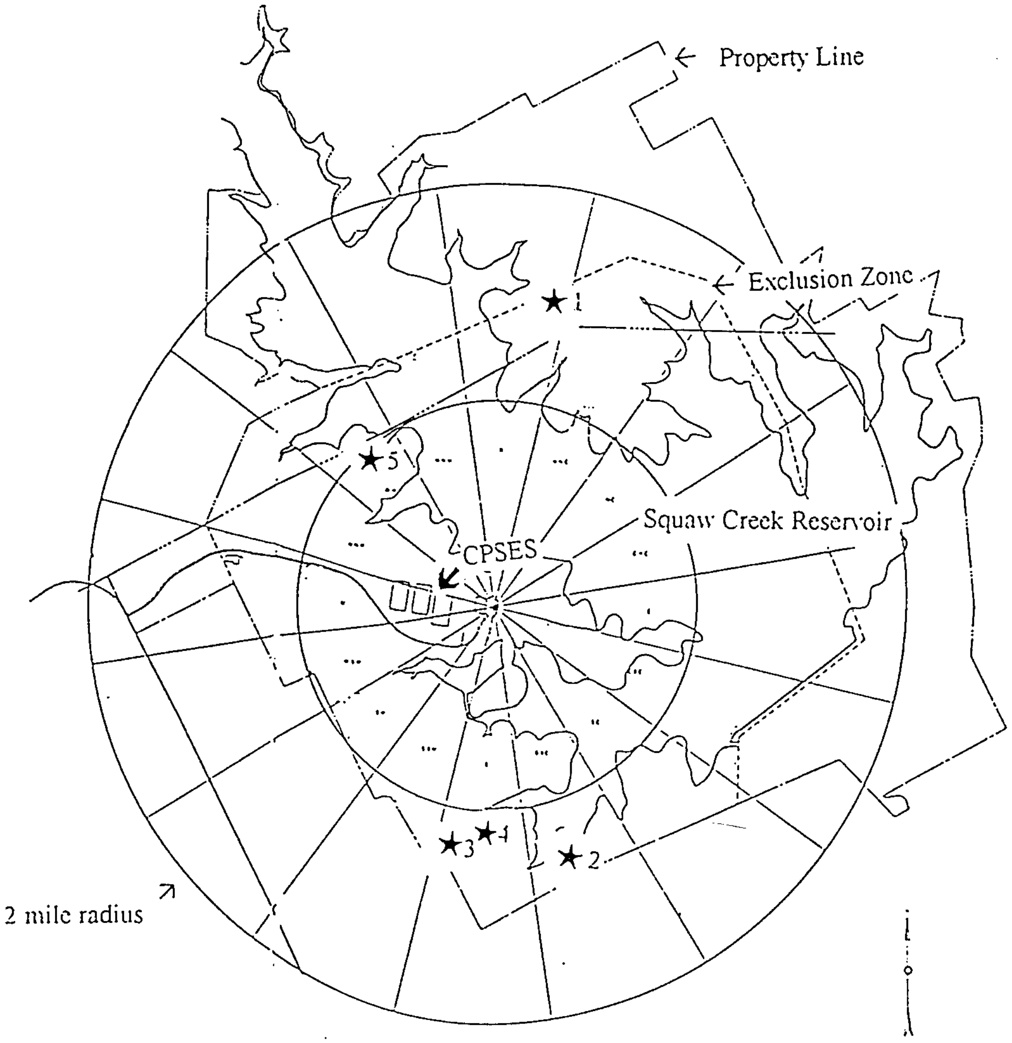


Fig. 11. TAMU Sample Stations (★) within 3.2 km (2 mi) of CPSES (REMPAR 1990)

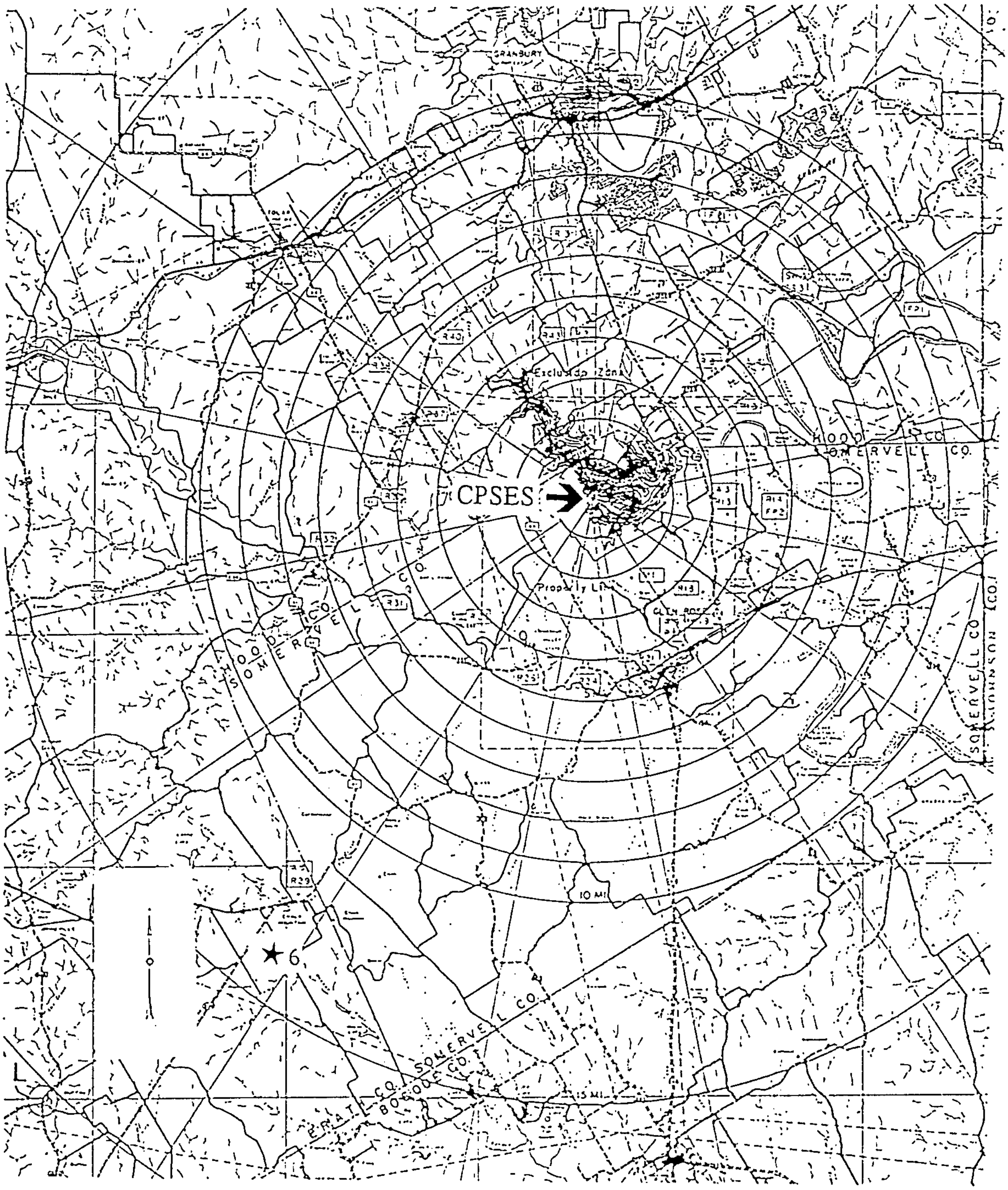


Fig. 12. CPSES Off-site TAMU Control Sample Station (★) (REMPAR 1990)

The TAMU Sample Station No. 3 deciduous and evergreen leaf samples were composed of Post Oak (TAMU PP BL-3) and One-seeded Juniper (TAMU PP J-3), respectively. The soil samples (TAMU PP BLsoil-3 and TAMU PP Jsoil-3) consisted of rich top soil and were of similar texture and color. These soil samples also appeared to meet the definition of the Frio-Bosque soil group.

At TAMU Sample Station No. 4 deciduous foliage was collected from Prairie Sumac (TAMU PP BL-4). The evergreen sample leaves were collected from a large Eastern Red Cedar (TAMU PP J-4). The soil sample (TAMU PP BLsoil-4) from the base of the Prairie Sumac was dry and hard. It was composed mainly of white caliche leachate from the adjacent road bed of Park Road. In contrast, the soil sample (TAMU PP Jsoil-4) from beneath the Eastern Red Cedar was dark in color, moist, and rich with humus. Although the Eastern Red Cedar was near the road, this old tree had developed the rich base soil over its long life. The natural soil of this area appear to belong to the Frio-Bosque soil group. The caliche was brought in as roadbed during the construction of the CPSES.

Only evergreen tree foliage was collected at TAMU Sample Station No. 5 because of the scarcity of deciduous trees in the area. Sample leaves were taken from a young Eastern Red Cedar (TAMU PP J-5). This sample area was in a forest of mostly One-seeded Juniper. The soil from this station was dark and clayey and may well also belong to the Frio-Bosque soil group.

A Red Mulberry tree (TAMU CL BL-6) was sampled for its deciduous leaves at TAMU Sample Station No. 6 out in Erath County. The evergreen foliage was collected from a nearby One-seeded Juniper (TAMU CL J-6) at this station. The soil samples (TAMU CL BLsoil-6 and TAMU CL Jsoil-6) collected from both evergreen and deciduous tree locations consisted mainly of caliche roadbed. The strip of land between the road and fence was narrow and occupied by a drainage ditch. The natural soil of this area is probably similar to the Tarrant-Purves soil group because of the few deep streams in the area. The names and characteristics of the vegetation collected as samples are presented in Table 3.

Each leaf and soil sample was placed in clean plastic Ziploc® bags at the time of collection to maintain sample integrity. Each bag was labeled with an indelible marker to identify the contents with the respective TAMU Sample Location and sample type.

TABLE 3. Vegetation Collected

Common Name	**Common Family Name**	**Scientific Name**	**Scientific Family Name**	**Leaf Characteristic**
One-seeded Juniper	Cypress	*Juniperus monosperma*	Cupressaceae	Evergreen
Eastern Red Cedar	Cypress	*Juniperus virginiana*	Cupressaceae	Evergreen
Prairie Sumac	Sumac	*Rhus lanceolata*	Anacardiaceae	Deciduous
Eastern Cottonwood	Willow	*Populus deltoides*	Salicaceae	Deciduous
Post Oak	Beech	*Quercus stellata*	Fagaceae	Deciduous
Red Mulberry	Mulberry	*Morus rubra*	Moraceae	Deciduous

ANALYTICAL PREPARATION

Once the CPSES foliage and soil samples were collected the next step was their preparation for analysis. The analytical sample preparation consisted of sample drying, homogenizing, quantification, and density determination. A standard soil and leaf geometry source set for efficiency calibration also had to be developed.

Sample Drying and Homogenizing

After field collection, the leaf and soil samples were transported to an environmental laboratory. The laboratory belongs to Texas A&M University in College Station, Texas. It is in the basement of the Zachry Engineering Center. The Department of Nuclear Engineering is also located in this building. The analytical preparation of all field samples was conducted in this environmental laboratory. The laboratory was kept closed and locked, and therefore had limited human access. The author routinely cleaned the laboratory tables. The minor human traffic and a low air flow helped to minimize the possibility of sample contamination.

At the laboratory, the leaf samples were transferred from their small plastic Ziploc® collection bags into large clean plastic commercial trash bags. The foliage samples were first partially dried in these open bags at room temperature before being fully dried in an oven. In order to keep them open, the trash bags were taped and hung from the edge of a laboratory counter. The soil samples were stored on a laboratory counter until time for oven drying. The soil samples were left in their field collection plastic bags. The soil samples dried at room temperature during the wait for oven drying. Detail of the sample drying procedure followed is described in Appendix C.

The leaf samples were first oven dried. An electric oven in the Department of Nuclear Engineering's radiochemistry laboratory was used to heat and dry the leaf and soil samples. The samples were heat dried at approximately 100° C in clean glass beakers for approximately 12 hours. As samples oven dried, the remaining field samples continued drying at room temperature. Only small volumes of samples could be dried at a time due to the small capacity of the oven. Because of this, it took weeks to dry all of the samples. The foliage and soil samples were oven dried at a constant temperature for six to twelve hours depending on the visible moisture content on the sample and glass sample container. After the leaf and soil samples were thoroughly dried, they were stored in clean sealed and labeled plastic bags.

The step after drying was the homogenizing of individual samples in a food blender. The purpose of physically breaking down the leaves and soil was to reduce the bulk sample volume. The blended homogenized leaf and soil samples could then better fill the counting containers (Marinelli Beaker). The correct volume and less air pockets in the containers would result in more representative samples for analysis. The dried foliage samples were first blended. The procedure followed for sample homogenizing and radioanalysis preparation is described in Appendix D. After homogenizing, the samples were quantitatively transferred into clean labeled 500 mL wide-mouth polyethylene Nalgene® bottles. The bottles were filled to the top. The homogenized samples were stored in these bottles until needed for further analytical preparation.

Sample Geometry Preparation and Quantification

A commercially available container with standardized geometry and volume was needed to properly analyze the leaf and soil samples. The Marinelli Beaker, because of its specific geometry and high counting efficiency, was chosen to hold the sample media during gamma-ray spectroscopy. The storage of sample media in 500 mL wide-mouth Nalgene® bottles facilitated its transfer into Marinelli Beakers. The manufacturer and model of the Marinelli Beaker and equipment used in this study are listed in Appendix L.

The next step consisted of volume and density determination of the homogenized leaf and soil samples. First the average weight of an empty 500 mL wide-mouth Nalgene® bottle was determined with the use of an electronic balance. The average weight was determined to be 68.6 g. The individual weights of 9 bottles and the average weight calculation are shown in Table 4. Then the 500 mL volume level of the bottle was determined by filling a clean graduated 1000 mL glass beaker to its 500 mL level with tap water. The 500 mL of water was poured into the bottle and the water level marked with indelible ink. This marked bottle was then used to calibrate the 500 mL level on all new bottles.

TABLE 4. 500 mL Nalgene® Bottle Average Weight

Bottle Number	**Weight (g)**
1.	68.0
2.	67.0
3.	67.0
4.	68.0
5.	67.0
6.	68.0
7.	68.0
8.	68.0
9.	68.0
Total Sum	**609.0**
Average Bottle Weight	**67.6**
Gummed Label Weight	**1.0**
Average Bottle & Label Weight	**68.6**

All of the homogenized leaf and soil samples were then quantitatively transferred into the calibrated Nalgene® bottles for storage. Each bottle was capped and properly labeled with the corresponding sample name. The bottles were lightly tapped on a table top to settle the contents. A clean plastic spoon was used to adjust the bottle contents to the 500 mL mark. A total of 22 leaf and soil samples were prepared in this manner.

To calculate the sample densities, each Nalgene® bottle with sample contents was weighed on an electronic balance. The individual weights of each leaf and soil sample were recorded. After subtracting for the average bottle weight, the density of each sample was calculated by dividing the sample weight by its bottle volume. From these individual sample densities, the average density for the deciduous and evergreen leaves, and soil was calculated. The calculated individual average bulk density for the leaf and soil samples are shown in Tables 5 and 6. The average leaf density was 0.44 gcm^{-3} and the average soil density was 1.37 gcm^{-3}.

TABLE 5. Average Leaf Density Determination

Sample	**Nalgene® Bottle & Content Weight (g)**	**Less Average Bottle Weight (g)**	**Equals Content Weight**	**Divided by Bottle Volume (cm^3)**	**Equals Density (gcm^{-3})**
TAMU SCP J-1	288.0	68.6	219.3	500	0.43
TAMU SCP BL-1	274.0	68.6	205.3	500	0.41
TAMU PP J-2	276.0	68.6	207.3	500	0.41
TAMU PP BL-2	314.0	68.6	245.3	500	0.49
TAMU PP J-3	258.0	68.6	189.3	500	0.37
TAMU PP BL-3	261.0	68.6	192.3	500	0.38
TAMU PP J-4	319.0	68.6	250.3	500	0.50
TAMU PP BL-4	271.0	68.6	202.3	500	0.40
TAMU PP J-5	297.0	68.6	228.3	500	0.45
TAMU CL J-6	282.0	68.6	213.3	500	0.42
TAMU CL BL-6	343.0	68.6	274.3	500	0.54

TABLE 5. Continued

Density Sum	**4.85**
Divided by no. of samples	**4.85/11**
Average Leaf Density	**0.44**

TABLE 6. Average Soil Density Determination

Sample	Nalgene® Bottle & Content Weight (g)	Less Average Bottle Weight (g)	Equals Content Weight	Divided by Bottle Volume (cm^3)	Equals Density (gcm^{-3})
TAMU SCP Jsoil-1	752.0	68.6	683.3	500	1.36
TAMU SCP BLsoil-1	724.0	68.6	655.3	500	1.31
TAMU PP Jsoil-2	717.0	68.6	648.3	500	1.29
TAMU PP BLsoil-2	801.0	68.6	732.3	500	1.46
TAMU PP Jsoil-3	752.0	68.6	683.3	500	1.36
TAMU PP BLsoil-3	792.0	68.6	723.3	500	1.44
TAMU PP Jsoil-4	631.0	68.6	562.3	500	1.12
TAMU PP BLsoil-4	737.0	68.6	668.3	500	1.33
TAMU PP Jsoil-5	782.0	68.6	713.3	500	1.42
TAMU CL Jsoil-6	853.0	68.6	784.3	500	1.56
TAMU CL BLsoil-6	784.0	68.6	715.3	500	1.43

TABLE 6. Continued

Density Sum	**15.11**
Divided by no. of samples	**15.11/11**
Average Soil Density	**1.37**

Standard Geometry Source Set Development

The method of choice to measure ^{137}Cs in the samples was gamma-ray spectroscopy. The standard geometry selected for the spectroscopy was a plastic 500 mL Marinelli Beaker with lid. This beaker design provided for more efficient sample counting because its wide uniform geometry approaches 4 π.

A radioactive source in this standard counting geometry was required for the efficiency calibration of the gamma-ray spectrometer. An efficiency calibration was also required for each sample type. Therefore, a composite of all leaf samples was chosen for the foliage efficiency calibration. The term *composite* is defined and used in this thesis as a predetermined volume (500 mL Marinelli Beaker) of evenly mixed sample media. Each sample contributes an equal volume fraction of its media to make up the composite volume. For example, each of the 11 leaf samples contributed 45.45 mL to make the 500 mL leaf composite. A composite of all the soil samples would likewise be used for the soil HPGe detector efficiency calibration. Appendix E describes in detail the procedure followed to develop a standard geometry source set. The use of composite leaf and soil samples for the calibration media were best because the composites closely matched the densities of the individual leaf and soil samples.

To produce the foliage and soil composite media, each leaf and soil sample had to contribute 1/11th of 500 mL to fill a 500 mL Marinelli Beaker. There were a total of 11 leaf samples and 11 soil samples in the study. The required 1/11th contribution was calculated to be 45.45 mL. The volume contribution was multiplied by each specific leaf and soil sample density value to establish the required weight contribution in grams. Then each sample's weight contribution was prepared using a sensitive micro-balance. To produce the standard source set, only one-half of a Marinelli Beaker volume was prepared at a time to allow for the introduction of the liquid ^{152}Eu standard. Therefore, the individual sample contributions summed for one-half of the Marinelli Beaker volume (500 mL) would equal 250 mL. The 250 mL of composite leaf media were put into a clean standard 1000 mL glass beaker. Only 250 mL of media was used at a time to allow for the addition and mixing of a standard liquid radioactive source. The rest of the composite sample (250 mL) would be added after introduction of the standard liquid radioactive source. The 250 mL of composite soil media was similarly measured out and put into a separate clean 1000 mL glass beaker. The individual weight fraction contribution of each leaf and soil sample for developing the foliage and soil standard source sets are presented in Tables 7 and 8.

A liquid ^{152}Eu radioactive source was used to make the efficiency calibration standard geometry source sets. The ^{152}Eu is a National Institute of Standards and Technology (NIST) Standard Reference Material. By using a disposable pipette, 1.0 mL of ^{152}Eu with a radioactivity of $7.26\text{x}10^2$ BqmL^{-1} ($1.93\text{x}10^{-8}$ CimL^{-1}) was quantitatively transferred onto the surface of the leaf composite in the 1000 mL glass beaker. Information on the NIST ^{152}Eu source is provided in Table 9 and in Appendix M. Care was taken not to touch the beaker sides with the pipette. Drops of the radioactive liquid were distributed over the composite media. The 250 mL of soil composite also received

TABLE 7. Leaf Contribution to Marinelli Beaker Standard Source Set

Sample	Density (gcm^{-3})	Multiplied by Volume Contribution (mL)	Equals Weight Contribution (g)
TAMU SCP J-1	0.43	45.45	**19.94**
TAMU SCP BL-1	0.41	45.45	**18.67**
TAMU PP J-2	0.41	45.45	**18.85**
TAMU PP BL-2	0.49	45.45	**22.30**
TAMU PP J-3	0.37	45.45	**17.21**
TAMU PP BL-3	0.38	45.45	**17.49**
TAMU PP J-4	0.50	45.45	**22.75**
TAMU PP BL-4	0.40	45.45	**18.39**
TAMU PP J-5	0.45	45.45	**20.76**
TAMU CL J-6	0.42	45.45	**19.39**
TAMU CL BL-6	0.54	45.45	**24.94**
Total Sum		500	**220.69**

TABLE 8. Soil Contribution to Marinelli Beaker Standard Source Set

Sample	**Density (gcm^{-3})**	**Multiplied by Volume Contribution (mL)**	**Equals Weight Contribution (g)**
TAMU SCP Jsoil-1	1.36	45.45	**67.12**
TAMU SCP BLsoil-1	1.31	45.45	**59.58**
TAMU PP Jsoil-2	1.29	45.45	**58.94**
TAMU PP BLsoil-2	1.46	45.45	**66.57**
TAMU PP Jsoil-3	1.36	45.45	**62.12**
TAMU PP BLsoil-3	1.44	45.45	**65.76**
TAMU PP Jsoil-4	1.12	45.45	**51.12**
TAMU PP BLsoil-4	1.33	45.45	**60.76**
TAMU PP Jsoil-5	1.42	45.45	**64.85**
TAMU CL Jsoil-6	1.56	45.45	**71.30**
TAMU CL BLsoil-6	1.43	45.45	**65.03**
Total Sum		500	**693.15**

1.0 mL of ^{152}Eu with the same quantity of radioactivity as the foliage composite. The glass beakers with the ^{152}Eu and sample composites were then put into the electric drying oven in the radiochemistry laboratory. Little if any ^{152}Eu was expected to be lost by evaporation since $EuCl_3$ solution is not volatile. After the liquid ^{152}Eu in the composites had dried, the beakers were removed from the oven and allowed to cool. The remaining 250 mL of composite leaf and soil media were then measured out and added to their respective 1000 mL beakers. Each glass beaker now contained the full volume of a Marinelli Beaker. The 500 mL of leaf composite was then stirred with a clean glass rod to mix and evenly distribute the ^{152}Eu in the media. Similarly, the 500 mL of soil composite was mixed with a glass rod. After mixing the radioactive source to satisfaction, the entire 500 mL of each leaf and soil composite was quantitatively transferred into two clean 500 mL Marinelli Beakers and sealed with a plastic lid. One beaker was labeled with radioactivity information and dated for use as the leaf sample efficiency calibration source set. The leaf composite without the beaker weighed 220 g, had an average density of 0.44 gmL^{-1}, and a volume of 498.4 mL. The other beaker was also labeled with pertinent information. It was identified as the soil sample efficiency calibration geometry source set. The soil composite without the Marinelli Beaker had a net weight of 692 g. The composite also had an average density of 1.37 gmL^{-1} and a volume of 503.5 mL.

TABLE 9. Decay Correction for ^{152}Eu NIST Standard

Original Activity (dps)	Assay Date	Efficiency Calibration Date	Elapsed Time (days)	Elapsed Time (years)	Half-Life (years)	Current Activity (dps)	Dilution by 100 mL
$9.39\text{x}10^4$ BqmL^{-1}	02/02/87	02/12/92	1836	5.02	13.55	$7.26\text{x}10^4$ BqmL^{-1}	**$7.26\text{x}10^2$ BqmL^{-1}**
							$1.93\text{x}10^{-8}$ CimL^{-1}

The activity was calculated using the following formula:

A = current activity

A_o = original activity

e = natural antilogarithm

0.693 = natural logarithm of 2

$T_{½}$ = half-life

t = elapsed time

$$A = A_0 e^{-\frac{0.693}{T_{½}} t}$$

$A_0 = 9.39\text{x}10^4$ BqmL^{-1}

$T_{½} = 13.55$ y

$t = 5.02$ y

$A = 7.26\text{x}10^4$ BqmL^{-1}

$A \div 100 = 7.26\text{x}10^2$ BqmL^{-1}

INSTRUMENTATION

The use of instrumentation in the analysis of the foliage and soil samples comprised a major part of the study. Data obtained from instruments were used to test the study's hypothesis.

Instrument Selection and Preparation

A gamma-ray spectroscopy system was chosen as the analytical method to measure gamma-rays from the ^{137}Cs in the leaf and soil samples. The instrumentation chosen for use was located in the counting laboratory of the TAMU's Department of Nuclear Engineering. These systems were composed of two high purity germanium (HPGe) detectors, liquid nitrogen dewar flasks, two Nuclear Data Inc. multi-channel analyzers (MCA), and associated NIM (nuclear instrument modules) bin of electronic hardware. The vertically-mounted HPGe detectors were surrounded by lead bricks in a manner to make a shielded sample well with a lead thickness of 10 cm. The wells had removable 10 cm thick lead covers. Marinelli Beakers are designed to fit over such vertically-mounted HPGe detectors. The counting geometry of the Marinelli Beaker design approaches 4 π and thus provides good counting efficiency and optimized count statistics.

The use of a germanium semiconductor detector is one of several ways to measure gamma-ray energies above several hundred keV. Use of a NaI scintillation detector is another way of detecting gamma-rays. The main component of a HPGe detector is the germanium present in solid crystalline form. HPGe detectors are manufactured such that impurity concentrations in the germanium crystal are extremely low. Gamma-rays interact in the detector crystal to produce secondary electrons. These secondary electrons are then collected at electrodes to produce pulses which are then translated as counts per unit time. The semiconductor nature of germanium assists in the electrical conduction of the interaction electrons. The electrical conductivity of the semiconductor changes when exposed to penetrating radiation (Hallenbeck 1994). Therefore, because of these properties, the HPGe detector is an excellent device to detect and measure gamma-ray radiation. In addition, the sensitivity of HPGe detectors results in high resolution of energy peaks.

Throughout the performance of theses spectroscopic analyses, the systems were routinely checked before use for instrument response, calibration, and general operability. A technician assigned to the counting laboratory kept the HPGe detectors operable at all times.

Energy Calibration

Energy calibrations of the gamma-ray spectrometers were required before their use. The process of determining the relationship between MCA channel number and incident gamma photon energy is called energy calibration. Energy calibration of the HPGe detectors was accomplished by following the procedure outlined in Appendix F. After confirming operability of the HPGe detector electronics, the calibration was performed using ^{57}Co and ^{60}Co sealed radioactive check sources. ^{57}Co and ^{60}Co were selected for calibration because their energies span the energy spectrum and their range contains the mid-point gamma-ray energy of ^{137}Cs (661.7 keV). After an acquisition period, the gamma-ray photopeaks of the check sources were identified on the MCA and assigned the left and right MCA video markers to define the desired region of interest (ROI). The 122.1 keV energy of ^{57}Co was assigned to the left marker at the lower energy range of the spectrum. Similarly, the 1332.5 keV energy of ^{60}Co was assigned to the right marker at the higher energy range of the spectrum. A successful energy calibration was verified by moving one of the MCA markers to the third and middle photopeak of the spectrum and noting the MCA corresponding energy readout as being 1173.2 keV. The lower energy gamma-ray of ^{60}Co is 1173.2 keV. The energy calibration was double checked by placing a ^{22}Na check source on the HPGe detectors, acquiring spectra, and correctly identifying the two photopeaks of 511 keV and 1274.5 keV. The energy calibration of the two HPGe detectors was periodically repeated to ensure the systems did not deviate from the calibration settings before, during, or after sample counting. The instruments' energy calibrations did not vary during the analytical portion of the study.

The energy calibration data for HPGe detectors Nos. 1 and 2 are shown in Tables 10 and 11. The energy calibration curves of these data are presented later in the Measurements section.

TABLE 10. HPGe Detector No. 1 Energy Calibration Data

E = mx + b for straight line. For energy calibration:

E = radioactive check source energy in keV

m = slope in keV/ch (0.4669)

x = x-intercept in ch (unknown)

b = y-intercept in keV (97.996)

Radionuclide	**Energy (keV)**	**Channel No.**
^{57}Co	122.1	52
^{60}Co	1173.5	2330
^{60}Co	1332.5	2644
^{22}Na	511.0	885
^{22}Na	1274.5	2520

TABLE 11. HPGe Detector No. 2 Energy Calibration Data

$E = mx + b$ for straight line. For energy calibration:

E = radioactive check source energy in keV

m = slope in keV/ch (0.4599)

x = x-intercept in ch (unknown)

b = y-intercept in keV (100.945)

Radionuclide	**Energy (keV)**	**Channel No.**
^{57}Co	122.1	46
^{60}Co	1173.5	2332
^{60}Co	1332.5	2678
^{22}Na	511.0	892
^{22}Na	1274.5	2552

Background Radiation Counting

To know the true radioactive content of the leaf and soil samples, the background radiation component had to first be determined. Background radiation was defined as the external penetrating radiation contributions from natural and man-made radioactive materials in the vicinity of the counting detectors. Of interest was the presence of ^{137}Cs in and around the laboratory. Background ^{137}Cs would be expected in the soils and plants outside the laboratory because of airborne deposition during the nuclear weapon atmospheric tests. Background ^{137}Cs could also possibly be present in the building materials of the laboratory. Therefore, the measurement of background radiation was important for determining the sample ^{137}Cs concentrations from CPSES. The net sample radiation was determined by subtracting the measured background radiation from the total measured sample radiation.

The background radiation contribution from natural, cosmic, man-made, and building material sources was determined by operating HPGe Detectors Nos. 1 and 2 with closed and empty counting wells for an acquisition live time of 48 hours. A long count time was required to help differentiate between the low radiation levels in the samples and detectors. The detectors were not disturbed during this counting period. After the lengthy count, a ten channel Region of Interest (ROI) at the MCA 661.5 keV photopeak was identified on the acquired spectra. The background radiation counts were measured and recorded for the ^{137}Cs photopeak. In addition, up to nine prominent background photopeaks were measured and recorded. The interior of Detector No. 1

shield was slightly contaminated with ^{152}Eu from a previous year mishap. The spectral data listed in Tables 33, 34, 36, 38 ,40, 42, 43, and 45 corroborate the ^{152}Eu contamination. Many ^{152}Eu gamma-ray energies were detected and identified from the sample data collected from Detector No. 1. This slight contamination did not influence the determination of the sample ^{137}Cs contents. The major photopeaks detected and measured for HPGe detectors Nos. 1 and 2 are listed in Tables 12 and 13.

Efficiency Calibration

Another step required before leaf and soil sample radioanalysis, was the determination of the HPGe detectors' counting efficiency. This efficiency was needed for the selected Marinelli Beaker geometry. Detector intrinsic efficiency is defined as the number of pulses recorded by the detector in some time interval divided by the number of emissions from a radioactive source incident on the detector during the same time interval (Knoll 1989). The HPGe detectors were calibrated for efficiency by following the procedure in Appendix G.

The efficiency calibration consisted of first performing an energy calibration, and a decay correction of the radioactive source standard. A NIST ^{152}Eu standard source which had been diluted to 100 mL was used to produce the foliage and soil Marinelli Beaker geometry standard source sets. The next step in efficiency calibration was the acquisition of gamma-ray spectra of the leaf and soil composites in Marinelli Beaker geometry. The ten major ^{152}Eu photopeaks were identified and collected on the MCA.

TABLE 12. Major Photopeaks of Background Spectrum for HPGe Detector No. 1*

(48 hours, ROI = 10 channels)

Radionuclide	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (48 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.63	41621	0.2409
^{152}Eu	244.7	244.44	8321	0.0482
^{152}Eu	344.3	343.91	20868	0.1208
^{152}Eu	411.1	410.69	1328	0.0077
^{152}Eu	444.0	443.37	1946	0.0113
^{137}Cs	**661.7**	**660.98**	**1166**	**0.0067**
^{152}Eu	778.9	778.66	3997	0.0231
^{152}Eu	964.0	963.58	3918	0.0227
^{152}Eu	1085.8	1085.47	2049	0.0119
^{152}Eu	1112.1	1111.62	2927	0.0169
^{152}Eu	1408.0	1407.68	2927	0.0169
^{40}K	1460.8	1460.45	1594	0.0092

* The HPGe Detector No. 1 sample well wall was contaminated with ^{152}Eu in 1991.

TABLE 13. Major Photopeaks of Background Spectrum for HPGe Detector No. 2

(48 hours, ROI = 10 channels)

Radionuclide	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (48 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.64	678	0.0039
^{235}U	143.8	143.71	1148	0.0066
^{235}U	185.7	185.56	3096	0.0179
^{212}Pb	238.6	238.44	1343	0.0077
^{152}Eu	344.3	344.22	745	0.0043
Annihilation Radiation		510.69	772	0.0045
unidentified		583.35	631	0.0037
^{214}Bi	609.3	609.11	643	0.0037
^{137}Cs	**661.7**	**661.53**	**836**	**0.0048**
^{228}Ac	911.1	911.25	419	0.0024
^{152}Eu	964.0	965.05	290	0.0017
^{234m}Pa	1001.0	1000.92	214	0.0012

TABLE 13. Continued

Radionuclide	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (48 hrs)**	**Net Count Rate (cps)**
^{214}Bi	1120.3	1120.49	238	0.0014
^{60}Co	1173.2	1172.92	321	0.0019
^{60}Co	1332.5	1332.96	382	0.0022
^{152}Eu	1408.0	1407.92	254	0.0015
^{40}K	1460.8	1461.26	1081	0.0063
^{214}Bi	1764.5	1764.78	315	0.0018

These data were recorded and are listed in Tables 14, 15, 16, and 17 for HPGe detectors Nos. 1 and 2. By using the acquired spectral data, photon intensity per decay, and the standard activity, the efficiency of the ten major ^{152}Eu photopeaks were calculated. These data on the efficiencies of the ten major ^{152}Eu are listed in Tables 18, 19, 20, and 21. The above energy calibration steps were performed for the two HPGe detectors used in analyzing the field samples. The calculated efficiencies of the ten ^{152}Eu photopeaks were then plotted against their energies in keV for each detector and each sample composite standard. The detector efficiency per sample media and geometry for the ^{137}Cs 661.5 keV energy were then determined from the graphs. The detector efficiency curves are presented in the Measurements Section.

The detector efficiencies for the ^{137}Cs photopeak were then used with a formula in Appendix J to calculate the activity of ^{137}Cs in each of the leaf and soil samples.

Estimated Lower Limit of Detection

An analysis was done of the background spectrum to determine the lower limit of detection (LLD) for ^{137}Cs. The lower limit of detection is the smallest quantity of radioactivity in a sample that will produce a net count with 95% confidence (USNRC c. 1976). Pasternack and Harley (1971) similarly define LLD as the smallest amount of sample activity that will yield a net count for which there is a predetermined confidence level that activity is present. The LLD is related directly to the characteristics of the instrumentation and the background radiation. Therefore the estimated LLD provides confidence that the measured sample activity is real.

TABLE 14. Composite Leaf Efficiency Calibration Photopeaks for HPGe Detector No. 1

(1 hour, ROI = 10 channels)

Radionuclide	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (1 hr)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.63	100573	27.93
^{152}Eu	244.7	243.98	17104	4.75
^{152}Eu	344.3	343.44	42382	11.77
^{152}Eu	411.1	410.69	2676	0.74
^{152}Eu	444.0	443.37	3503	0.97
^{137}Cs	**661.7**	**660.98**	**889**	**0.24**
^{152}Eu	778.9	777.73	7696	2.13
^{152}Eu	964.0	962.65	6618	1.83
^{152}Eu	1085.8	1084.53	4034	1.12
^{152}Eu	1112.1	1110.68	4870	1.35
^{152}Eu	1408.0	1406.28	5454	1.51

TABLE 15. Composite Soil Efficiency Calibration Photopeaks for HPGe Detector No. 1

(1 hour, ROI = 10 channels)

Radionuclide	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (1 hr)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.63	80023	26.22
^{152}Eu	244.7	244.44	14538	4.03
^{152}Eu	344.3	343.91	35123	9.75
^{152}Eu	411.1	410.69	2210	0.61
^{152}Eu	444.0	443.37	2939	0.81
^{137}Cs	**661.7**	**660.98**	**858**	**0.23**
^{152}Eu	778.9	778.66	5539	1.53
^{152}Eu	964.0	963.58	5507	1.52
^{152}Eu	1085.8	1085.47	2766	0.76
^{152}Eu	1112.1	1111.62	4350	1.20
^{152}Eu	1408.0	1407.68	4338	1.20

TABLE 16. Composite Leaf Efficiency Calibration Photopeaks for HPGe Detector No. 2

(1 hour, ROI = 10 channels)

Radionuclide	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (1 hr)	Net Count Rate (cps)
^{152}Eu	121.8	121.64	95976	26.66
^{152}Eu	244.7	244.42	17807	4.94
^{152}Eu	344.3	343.30	45816	12.72
^{152}Eu	411.1	410.90	2971	0.82
^{152}Eu	444.0	444.01	3950	1.09
^{137}Cs	**661.7**	**661.53**	**1106**	**0.30**
^{152}Eu	778.9	778.80	9776	2.71
^{152}Eu	964.0	963.67	8946	2.48
^{152}Eu	1085.8	1085.54	5706	1.58
^{152}Eu	1112.1	1111.75	7095	1.97
^{152}Eu	1408.0	1407.92	8819	2.44

TABLE 17. Composite Soil Efficiency Calibration Photopeaks for HPGe Detector No. 2

(1 hour, ROI = 10 channels)

Radionuclide	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (1 hr)**	**Net Count Rate (cps)**
^{152}Eu	121.8	*	86923	24.14
^{152}Eu	244.7	*	16371	4.54
^{152}Eu	344.3	*	43441	12.06
^{152}Eu	411.1	*	2928	0.81
^{152}Eu	444.0	*	3862	1.07
^{137}Cs	**661.7**	*	**1214**	**0.33**
^{152}Eu	778.9	*	9038	2.51
^{152}Eu	964.0	*	8557	2.37
^{152}Eu	1085.8	*	5503	1.52
^{152}Eu	1112.1	*	6935	1.92
^{152}Eu	1408.0	*	8647	2.40

* Data not documented.

TABLE 18. Composite Leaf Efficiency Calibration Data Sheet for HPGe Detector No. 1

(02/28/92)

^{152}Eu Photon Energy (keV)	Photon Intensity (ppd)	Net Count Rate (1 hour)	Net Count Rate (cps)*	Efficiency (cpp)
121.8	0.28	100573	27.69	1.34x10^{-1}
244.7	0.07	17104	4.70	8.62x10^{-2}
344.3	0.26	42382	11.65	6.03x10^{-2}
411.1	0.02	2676	0.73	4.53x10^{-2}
444.0	0.03	3503	0.96	4.24x10^{-2}
778.9	0.12	7696	2.11	2.24x10^{-2}
964.0	0.14	6618	1.81	1.71x10^{-2}
1085.8	0.10	4034	1.10	1.50x10^{-2}
1112.1	0.13	4870	1.33	1.3510^{-2}
1408.0	0.20	5454	1.49	9.87x10^{-3}

* ^{152}Eu background values (cps) from Table 12 subtracted out of each photon energy to account for detector ^{152}Eu contamination.

TABLE 19. Composite Soil Efficiency Calibration Data Sheet for HPGe Detector No. 1

(02/28/92)

^{152}Eu Photon Energy (keV)	Photon Intensity (ppd)	Net Count Rate (1 hour)	Net Count Rate (cps)*	Efficiency (cpp)
121.8	0.28	80023	21.98	1.06×10^{-1}
244.7	0.07	14538	3.98	7.31×10^{-2}
344.3	0.26	35123	9.63	4.99×10^{-2}
411.1	0.02	2210	0.60	3.73×10^{-2}
444.0	0.03	2939	0.80	3.55×10^{-2}
778.9	0.12	5539	1.51	1.61×10^{-2}
964.0	0.14	5507	1.50	1.41×10^{-2}
1085.8	0.10	2766	0.75	1.02×10^{-2}
1112.1	0.13	4350	1.19	1.20×10^{-2}
1408.0	0.20	4338	1.18	7.82×10^{-3}

* ^{152}Eu background values (cps) from Table 12 subtracted out of each photon energy to account for detector ^{152}Eu contamination.

TABLE 20. Composite Leaf Efficiency Calibration Data Sheet for HPGe Detector No. 2

(02/12/92)

^{152}Eu Photon Energy (keV)	Photon Intensity (ppd)	Net Count Rate (1 hour)	Net Count Rate (cps)	Efficiency (cpp)
121.8	0.28	95976	26.66	1.26×10^{-1}
244.7	0.07	17807	4.94	9.07×10^{-2}
344.3	0.26	45816	12.72	6.59×10^{-2}
411.1	0.02	2971	0.82	5.08×10^{-2}
444.0	0.03	3950	1.09	4.84×10^{-2}
778.9	0.12	9776	2.71	2.88×10^{-2}
964.0	0.14	8946	2.48	2.34×10^{-2}
1085.8	0.10	5706	1.58	2.14×10^{-2}
1112.1	0.13	7095	1.97	2.00×10^{-2}
1408.0	0.20	8819	2.44	1.61×10^{-2}

TABLE 21. Composite Soil Efficiency Calibration Data Sheet for HPGe Detector No. 2

(02/12/92)

^{152}Eu Photon Energy (keV)	**Photon Intensity (ppd)**	**Net Count Rate (1 hour)**	**Net Count Rate (cps)**	**Efficiency (cpp)**
121.8	0.28	86923	24.14	1.17x10^{-1}
244.7	0.07	16371	4.54	8.33x10^{-2}
344.3	0.26	43441	12.06	6.22x10^{-2}
411.1	0.02	2928	0.81	5.01x10^{-2}
444.0	0.03	3862	1.07	4.73x10^{-2}
778.9	0.12	9038	2.51	2.66x10^{-2}
964.0	0.14	8557	2.37	2.23x10^{-2}
1085.8	0.10	5503	1.52	2.07x10^{-2}
1112.1	0.13	6935	1.92	1.95x10^{-2}
1408.0	0.20	8647	2.40	1.58x10^{-2}

Knowledge of the background magnitude, detector counting efficiency, and sample volume were required to calculate the LLD. The LLD was calculated for the two HPGe detectors used in the study by following the procedure described in Appendix H. The calculated LLDs for HPGe detectors Nos. 1 and 2 are shown in Tables 22 and 23. The LLDs were calculated for both vegetation and soil samples. The LLD was important for comparing with the sample measurements because environmental samples, such as leaf and soil, normally have very low levels of radioactivity. The LLD was used as a guide in this capacity.

The measured foliage sample radioactivity values fell both above and below the LLDs, whereas the measured soil sample values were all well above the LLDs.

TABLE 22. HPGe Detector No. 1 Lower Limit of Detection

LLD (pCikg^{-1})	
Vegetation	5.28
Soil	2.01

TABLE 23. HPGe Detector No. 2 Lower Limit of Detection

	LLD (pCikg^{-1})
Vegetation	3.44
Soil	1.20

QUALITY ASSURANCE AND CONTROL

One definition of Quality Assurance (QA) is the summation of all programmed events imposed internally and externally in order to ensure that data being generated are meaningful (USEPA 1980). QA is the programmatic and systematic oversight of all activities involved in the making of a product that meets pre-defined standards of quality. A QA program includes planning, quality control, quality assessment, and quality improvement. Quality Control (QC) is the component of QA, usually a set of procedures, which addresses specific tasks. QC is designed to repetitively create products that consistently meet the same specifications. QA and QC were an important aspect of this study. Quality assurance, by definition, covered all of the study's activities. These activities ranged from sample field collection, standard source set development, and sample analysis. The goal of the study's QA was to maintain a strict adherence to field and laboratory procedures to assure end quality results. Quality control was composed of record keeping and procedures used to execute the study's activities. The study's QC was very important to the sample collection, pre-analysis preparation, and analysis, because of the repetitive nature of these tasks. Appendices A through K describe the QC procedures used in this study.

Sample Collection, Storage and Transfer

The collection of leaf and soil samples was performed in a methodical way for ease of sampling and procedure repetition. The methods reflected on the study's QC. As detailed in Appendices A and B, the sample collection consisted of a series of steps. The samples were collected after each location was selected and identified. At each sample location, the foliage was always collected first before the soil sample. Leaves and small tree branches with leaves were cut off with garden shears and put into clean plastic trash bags. The foliage was handled with clean utility gloves. For some samples, an extra bag was needed to collect extra small branches and leaves. The procedures in Appendices A and B called for the collection of enough leaves to perform the required radioanalysis. After foliage collection, the bags were closed, labeled, temporarily stored, and transported to the university laboratory.

The soil samples were always collected from the base of the sample tree. A predetermined volume of soil was collected at each sample site. Because soil is compact and more dense compared to foliage, less soil volume was required during collection. All soil samples were collected from a marked square area. The sample area was always marked off in a square with a standard 12 inch (31centimeter) ruler. The collection area measured 12 x 12 x 1 inches (31 x 31 x 2.5 cm). The soil was removed down to 1 inch (2.5 cm) with a clean garden trowel. The collected sample of soil was then transferred into clean plastic Ziploc® bags. As performed on the foliage samples, the soil samples bags were closed, labeled, and stored pending transport to the laboratory.

During the collection day, the samples were stored in the author's automobile. The samples were transported to the TAMU environmental laboratory on the same day of collection. Upon arrival at the laboratory, the field samples were placed in such a manner to enhance sample drying at room temperature.

The field samples were always identified, collected, recorded, stored, and transported following the same procedures in order to contribute to the QA of the study.

Laboratory Glass and Hardware

Care was taken when using glassware and instruments in the TAMU environmental and radiochemical laboratories. These items were used, handled, cleaned, and decontaminated following established QC procedures outlined in the Appendix I of this thesis. By following the laboratory procedures developed for the study, the equipment was always clean and available for use on individual field samples. Cross contamination from sample to sample or contamination from external sources was avoided by the QC procedures. The laboratory equipment employed in this study consisted of glass beakers, glass stir rods, glass pipettes, plastic Marinelli Beakers, plastic spoons, Nalgene® bottles, Solo® paper cups, paper towels, electric blender, small paint brush, utility gloves, electronic balance, manual micro-balance, electric drying oven, and plastic storage bags. Any equipment used more than once was washed, dried, and decontaminated before its next use. For example, several glass beakers were used many times to hold sample media during pre-analysis preparation. The beakers were always dried, cleaned, and decontaminated before use. After each use, the beakers were washed and rinsed under running tap water, and then dried with clean paper towels. After paper drying, the beakers were carefully washed on the inside with 200 proof anhydrous ethyl alcohol. The beakers were then set on clean paper towels on a laboratory counter to quickly air dry. The beakers were covered and stored if not immediately re-used.

The use of this same QC procedure (wash, rinse, decontaminate, and air dry) on all laboratory equipment that came into contact with sample media assured that no cross contamination took place.

Radioactivity Analysis

The radioactivity analysis consisted of sample preparation, standard source set development, and the actual HPGe detector spectrometry. Establishing and following good QA procedures was important to ensure the integrity of the samples and confidence in the detector measurements.

Methodical care was taken while handling the leaf and soil samples in the environmental and radiochemistry laboratories. The samples were always kept apart through the use of individual storage bags or bottles. All bags or Nalgene® bottles had labels identifying dates, names, and contents. During preparation for radioanalysis, the samples were always transferred into drying beakers with clean hands or gloves. The integrity of the samples was maintained by preparing media from one sample location at a time. For example, all of the leaves from one location were dried before drying other samples. All of the same sample leaves were dried regardless if multiple glass beakers and several oven drying cycles were required. This QC procedure minimized opportunities for cross contamination.

As previously mentioned, the cleanliness of laboratory ware was important in preparing the foliage and soil samples for radioanalysis. After oven drying, the sample media were transferred into storage bags with clean glass rods and plastic spoons. Likewise, clean decontaminated plastic spoons and small paint brush were used to transfer leaves and soil in and out of the electric blender. The homogenized leaf and soil samples were carefully and quantitatively transferred from the blender into clean Nalgene® bottles using the clean plastic spoons and paint brush. These labeled bottles contained individual sample media in prepared 500 mL volumes. Following the study's QC procedure thus resulted in the development of individually homogenized samples that were ready for gamma-ray spectroscopy.

The development of the standard geometry source set followed a strict QC procedure The procedure ensured the quantitative transfer and homogeneity of all the sample media to produce foliage and soil composite standards. The standard source sets of composite sample media were developed to fit in a 500 mL Marinelli Beaker with lid. As previously described in the section of standard source development, a contributing quantity was required from each homogenized leaf and soil sample. Each sample quantity was weighed using a sensitive micro-balance. Each sample contribution was quantitatively transferred into a clean 1000 mL glass beaker with a clean plastic spoon and a small paint brush. A clean new micro-pipette was used to quantitatively transfer the liquid ^{152}Eu radioactive standard source into a beaker with 250 mL of composite foliage sample, and another beaker with 250 mL of composite soil sample. As previously defined, a composite sample to fill a 500 mL Marinelli Beaker was made up of a fraction from each sample. For example, each leaf sample contributed a fraction of 500 mL to make the leaf composite. The same was done to produce the soil composite sample. The composite samples represented all of the samples of either leaf or soil, and therefore were good for determining the HPGe detector efficiency calibration for those media. After drying the composite media and radioactive source, an additional 250 mL of composite sample were carefully added to the respective composite beakers. Adding the ^{152}Eu to half of the composite sample allowed for better homogenization of the standard when the other 250 mL half was later added and mixed. This resulted in the required 500 mL quantity to make a source set for use in HPGe detector efficiency calibration. Following QC procedure, a clean glass rod was used to carefully mix the composite samples and the ^{152}Eu in the beakers. After a through mixing, the foliage and soil composites were quantitatively transferred by plastic spoon and small paint brush into their respective 500 mL Marinelli Beakers. The lids were placed on the Marinelli Beakers. By applying QC, valid foliage and soil standard geometry source sets were produced for instrument calibration.

The HPGe gamma-ray spectroscopy QC procedure required the counting of each individual field sample for the same time interval and using the same Marinelli Beaker geometry. Each sample was quantitatively transferred into a capped 500 mL Marinelli Beaker before counting. This step prevented sample contamination. The plastic Marinelli Beakers were washed and decontaminated after each use by following previously described QC procedures. The HPGe detector net counts were collected over a 12 hour period for each sample. As soon as one sample counting cycle was completed, another sample's analysis was begun. The radioanalytical counting of samples sometimes was done simultaneously with HPGe detectors No. 1 and 2. Both detectors were always QC checked for their energy vs. channel calibrations before use. The energy calibrations were never observed to change during the radioanalytical period. The steps involved in radioactivity analysis are outlined in Appendix J. All of the analytical measurement data were promptly recorded in a study logbook at the end of each counting cycle.

MEASUREMENTS

In order to test the hypothesis of the study, numerous measurements were made during sample processing. Data came from, for example, background radiation counting, standard geometry source set development, energy calibration, efficiency calibration, and gamma-ray spectrometry. The steps involved in these activities have already been described and are listed in the appendices. All of these activities involving data collection were important in their contribution to testing the study's hypothesis. Statistical analysis was applied to the spectroscopy data. The data used to test the hypothesis were the result of the preparation and results of the standard source set development, energy calibration, efficiency calibration, and gamma-ray spectrometry.

Standard Source Set

The development of composite leaf and soil source sets in 500 mL Marinelli Beaker geometry was required for HPGe detector efficiency calibrations. It was important to have the efficiency calibrations performed on media closely resembling the samples in order to assure good counting data. This was accomplished by having the composite standard set samples composed of the actual field leaf and soil samples. The composite samples represented an average media density closely matching each sample's density. The two standard source sets densities helped avoid uncompensated self-absorption of low-energy photons. In the production of the standard source sets, therefore, all of the leaf samples contributed a portion to the leaf composite, and the soil samples likewise to the soil composite. Careful measurements of each sample weight fraction were required in the development of each source set. For example, each contributing sample weight fraction to a source set was calculated. The leaf and soil fractions were also methodically weighed out in paper cups and collected into glass beakers to make the sample composites. Measurements involved in the source set development were carefully recorded. The fraction weights and other measurements made during the standard source set development were recorded and have been presented in Tables 4, 5, 6, 7, and 8.

Energy Calibration

The accurate measurement of the ^{137}Cs gamma-ray photopeak by the HPGe detectors was directly dependent on the quality of the energy calibration of the detectors. As previously described, energy calibration consisted of acquiring a gamma-ray energy spectrum from known standard radioactive sources. The calibration required the careful adjustment of the MCA to match the measured gamma-ray photopeaks of ^{57}Co, ^{60}Co and ^{22}Na. The calibration was deemed successful when the acquired and measured energies reflected by the instrumentation agreed with the known energies of the standard check sources. The energy calibration gamma-ray check source information is listed in Appendix L. In addition, the typical energy calibration curves produced by HPGe detector Nos. 1 and 2 are illustrated in Figures 13 and 14.

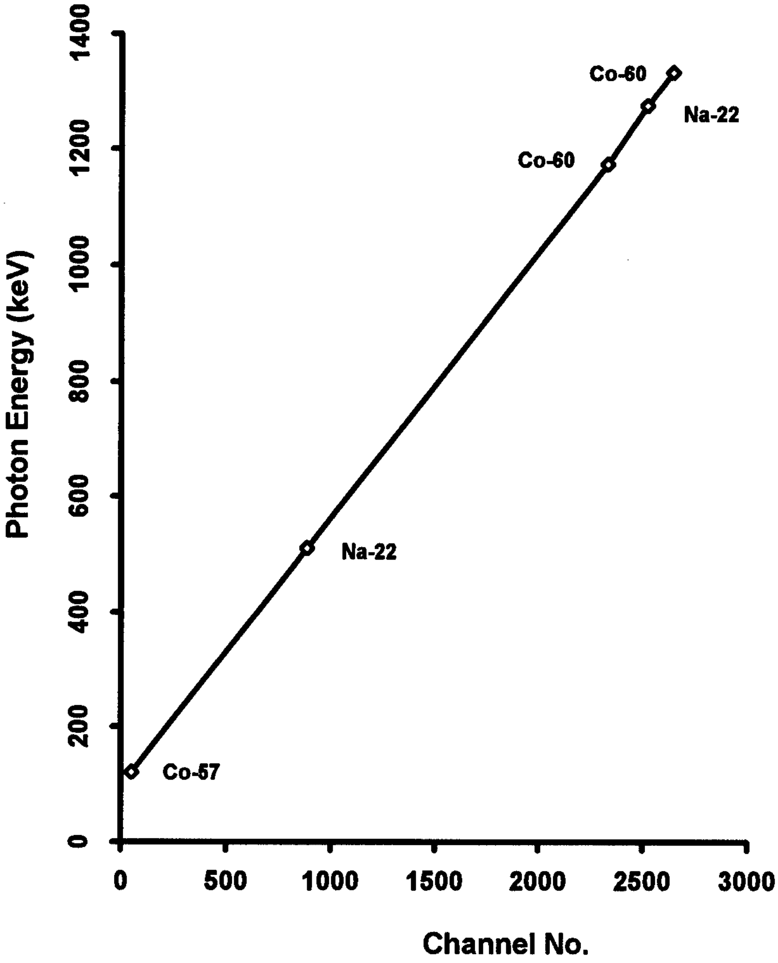


Fig. 13. Energy Calibration Curve for HPGe Detector No. 1

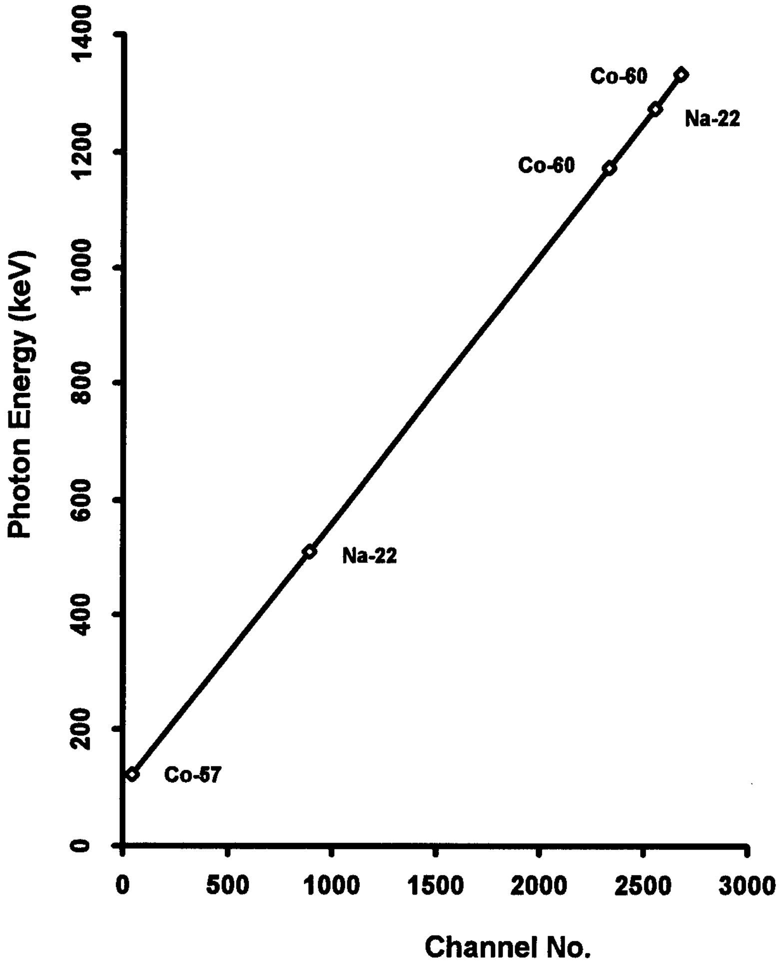


Fig. 14. Energy Calibration Curve for HPGe Detector No. 2

Efficiency Calibration

The measurements in the efficiency calibration were very important because by determining the counting efficiencies of the two HPGe detectors, the radioactivity of each sample could therefore be calculated. Because of individual sensitivity characteristics, an efficiency calibration curve was generated for each gamma-ray detector. In order to calculate the detector efficiencies, many measurements were required. The development of an efficiency curve depended on knowing the energies of ten prominent photons of the ^{152}Eu standard used in the composite sample source sets. The calculation of the efficiency in counts per photon for each of the ^{152}Eu photons was also necessary to produce the curve. The photon intensities, net count rate, and radioactivity of the standard were other parameters needed to calculate the photon efficiencies. The measured background radiation was first subtracted from the ^{152}Eu standard net count rates before calculating the counts per photon values. An efficiency curve was plotted from the ten known ^{152}Eu photon energies and then the counting efficiency for the ^{137}Cs 661.7 keV photon was interpolated from it. These efficiency calibration measurements were made for the ^{152}Eu spiked foliage composite and soil composite standard sets. The efficiency calibration measurements were documented and have been presented in Tables 18, 19, 20, and 21. These data were also charted to assist in determining the efficiencies for each detector. The efficiency calibration curves of the leaf and soil composites for HPGe Detectors Nos. 1 and 2 are shown in Figures 15, 16, 17, and 18.

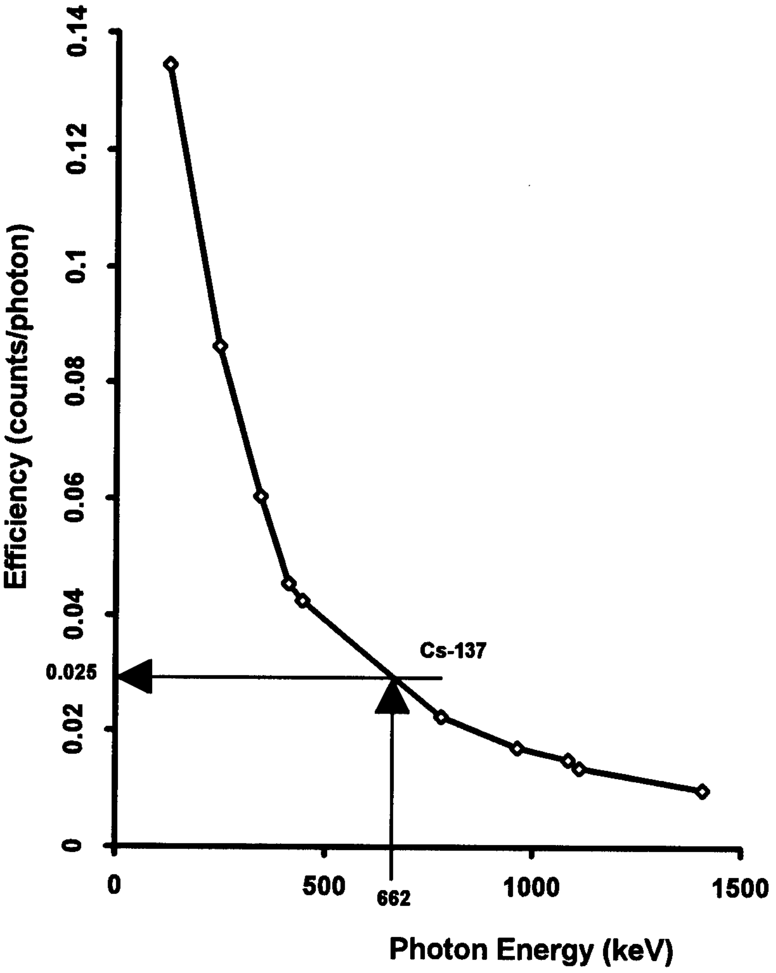


Fig. 15. Composite Leaf Efficiency Calibration Curve for HPGe Detector No. 1

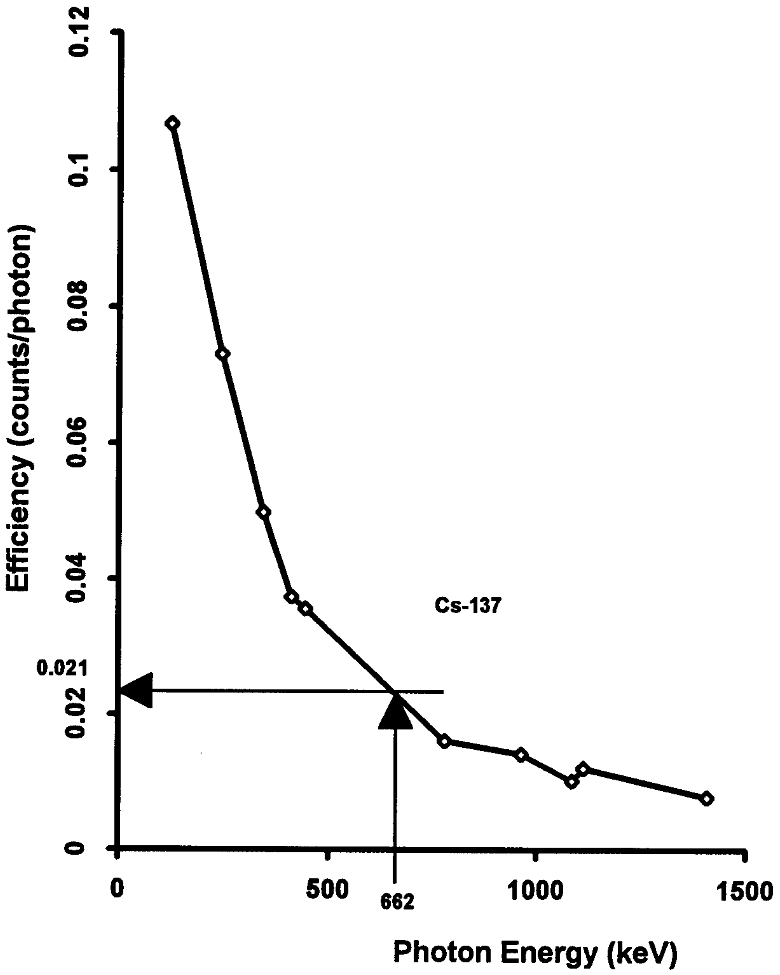


Fig. 16. Composite Soil Efficiency Calibration Curve for HPGe Detector No. 1

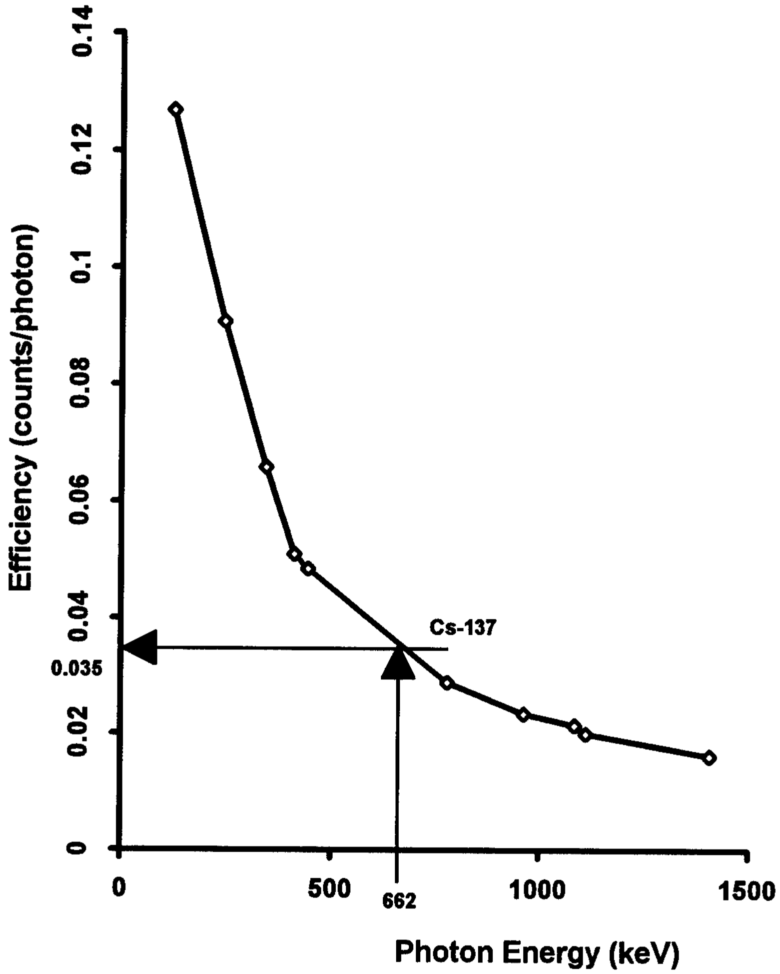


Fig. 17. Composite Leaf Efficiency Calibration Curve for HPGe Detector No. 2

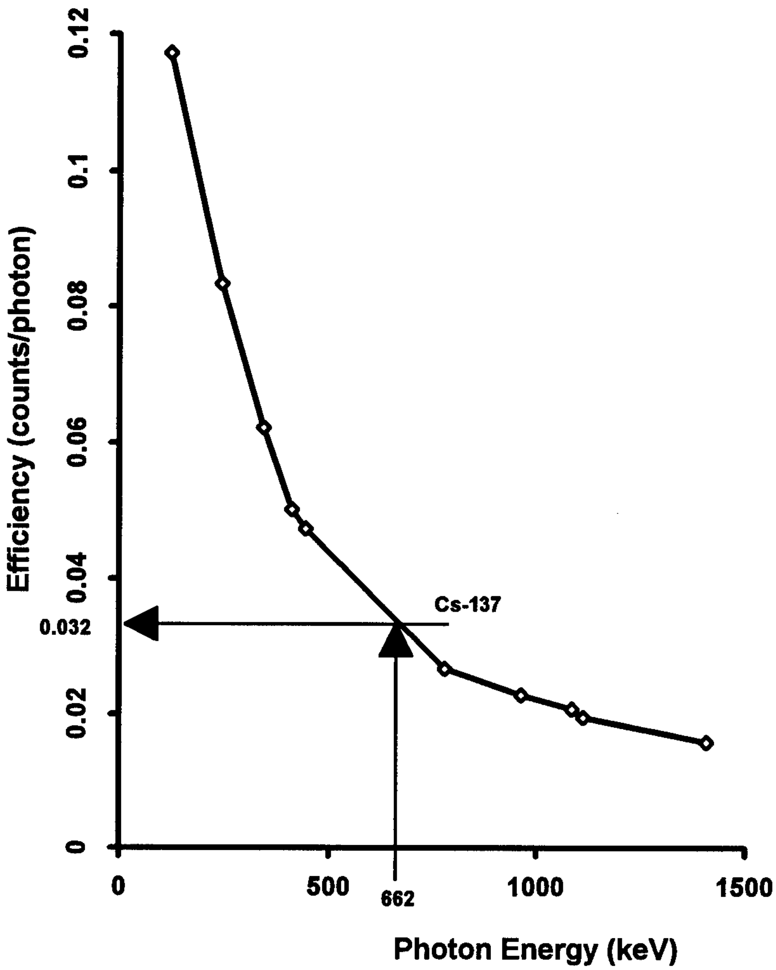


Fig. 18. Composite Soil Efficiency Calibration Curve for HPGe Detector No. 2

Spectrometry

Another crucial step in testing the study's hypothesis was sample analysis with the HPGe detectors. Sample spectrometry provided counting data used to calculate the ^{137}Cs radioactivity of each sample. The HPGe detector measurements consisted of acquiring a 12 hour spectrum for each leaf and soil sample. First, a Marinelli Beaker filled with distilled water was counted for 12 hours in each detector to check for presence of ^{137}Cs in the vicinity of the detectors. No ^{137}Cs in significant quantities was detected by using the distilled water. The distilled water spectral data for HPGe detectors Nos. 1 and 2 are presented in Tables 24 and 25. After each sample counting, multiple prominent gamma-ray photopeaks were distinguished from the data and identified where possible. Among the photopeaks on the MCA, the ^{137}Cs photopeak was located, identified, and its net count rate recorded. These measurements were then used to calculate each sample's ^{137}Cs radioactivity. The absolute ^{137}Cs radioactivity of each sample was determined as the means to compare the environmental radioactivity at each CPSES sample location. Calculation of radioactivity was performed by using the formula shown in Appendix J. All the measurements involved in gamma-ray counting were recorded. These spectral data for each individual leaf and soil sample are presented in the following Tables 26 through 47. Additional measurements, such as the sample net counting rate and the net counting rate standard deviation, were used to calculate each sample's ^{137}Cs radioactivity. These data are shown in Tables 48, 49, 50, and 51. The ^{137}Cs radioactivity data calculated for each leaf and soil sample are listed in Tables 52 and 53. These ^{137}Cs radioactivity data were charted to compare the concentrations between the samples and between the foliage and soil populations. These charts with one-standard error of the mean error bars are shown in Figures 19, 20, and 21.

TABLE 24. Distilled Water Spectral Data for HPGe Detector No. 1

(500 mL Marinelli Beaker)

Radionuclide	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{137}Cs	661.7	661.467	316	0.007

TABLE 25. Distilled Water Spectral Data for HPGe Detector No. 2

(500 mL Marinelli Beaker)

Radionuclide	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{137}Cs	661.7	661.537	184	0.004

Statistics

Statistics were applied after calculating each sample's ^{137}Cs radioactivity concentration. Statistical measurements, such as number of points in data set, sample mean, sample standard deviation, sum of samples, and the sum of the samples squared, were made with the sample data. The procedure described in Appendix K was followed to calculate these statistical data. These types of measurements were used to compare leaf to leaf samples, soil to soil samples, and leaf population to soil population.

The statistical measurements from the samples were used to test the Null Hypothesis for the study. The Null Hypothesis compared the true means of the leaf and soil sample populations. Statistical tests were applied on the sample means to determine if significant differences existed in foliage and soil sample ^{137}Cs concentration. The tests compared the population means between the evergreen juniper leaves and the deciduous broadleaves, between soils from juniper and broadleaf sample sites, and between the foliage and soil populations. The Modified Student's *t*-test was used because it is designed for comparing the means of sets with few samples. The Student's *t*-test assumed the unknown sample variances to be equal and the sample distribution to be

TABLE 26. TAMU SCP Jsoil-1 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{235}U	185.7	186.02	1771	0.041
^{228}Ac	209.3	209.01	518	0.012
^{212}Pb	238.6	238.44	4050	0.093
^{214}Pb	295.2	295.01	1427	0.033
^{223}Ra	338.3	338.24	856	0.002
^{214}Pb	315.9	351.57	2418	0.056
Annihilation Radiation	511.0	510.69	615	0.014
unidentified		582.89	1299	0.030
^{214}Bi	609.3	609.11	1623	0.037
^{137}Cs	**661.7**	**661.53**	**3499**	**0.081**
^{228}Ac	727.0	726.84	278	0.006
unidentified		776.76	115	0.002
^{228}Ac	794.7	794.90	117	0.002
unidentified		860.20	195	0.004

TABLE 26. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{228}Ac	911.1	910.79	840	0.019
^{228}Ac	964.6	964.13	428	0.009
^{152}Eu	969.1	968.73	161	0.003
^{214}Bi	1120.3	1120.03	350	0.008
^{214}Bi	1238.1	1237.76	166	0.003
^{40}K	1460.8	1460.34	2478	0.057

TABLE 27. TAMU SCP J-1 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.64	407	0.009
^{235}U	143.8	143.71	13	0.000
^{235}U	185.7	185.56	701	0.016
^{212}Pb	238.6	238.44	287	0.006
^{152}Eu	344.3	344.22	124	0.002
^{214}Pb	351.9	352.03	210	0.004
unidentified		477.58	224	0.005
Annihilation Radiation	511.0	510.23	209	0.004
unidentified		582.89	148	0.003
^{214}Bi	609.3	609.11	178	0.004
^{137}Cs	**661.7**	**661.53**	**149**	**0.003**
unidentified		778.34	39	0.000
^{228}Ac	911.1	910.79	78	0.001
unidentified		963.67	64	0.001

TABLE 27. Continued

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	969.1	968.73	99	0.002
^{60}Co	1173.2	1172.92	112	0.002
^{40}K	1460.8	1460.34	1085	0.025

TABLE 28. TAMU SCP BLsoil-1 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{235}U	185.7	186.02	1366	0.031
^{228}Ac	209.3	209.01	290	0.006
^{212}Pb	238.6	238.44	3903	0.090
^{214}Pb	295.2	295.01	1582	0.036
^{223}Ra	338.3	338.24	729	0.016
^{214}Pb	351.9	352.03	2319	0.053
Annihilation Radiation	511.0	510.69	593	0.013
unidentified		582.89	1249	0.028
^{214}Bi	609.3	609.11	1821	0.042
^{137}Cs	**661.7**	**661.53**	**3939**	**0.091**
^{228}Ac	727.0	726.84	209	0.004
^{228}Ac	794.7	794.90	105	0.002
unidentified		860.20	125	0.002
^{228}Ac	911.1	910.79	723	0.016

TABLE 28. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{152}Eu	969.1	968.73	436	0.010
^{214}Bi	1120.3	1120.03	342	0.007
^{214}Bi	1238.1	1237.76	169	0.003
^{40}K	1460.8	1460.34	2476	0.057

TABLE 29. TAMU SCP BL-1 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.64	290	0.006
^{235}U	185.7	185.56	914	0.021
^{152}Eu	244.7	243.04	260	0.006
^{214}Pb	351.9	351.57	268	0.006
Annihilation Radiation	511.0	510.23	144	0.003
^{214}Bi	609.3	609.11	165	0.003
^{137}Cs	**661.7**	**661.53**	**205**	**0.004**
^{60}Co	1173.2	1172.92	110	0.002
^{40}K	1460.8	1459.88	1432	0.033

TABLE 30. TAMU PP J-2 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	120.26	224	0.005
^{235}U	143.8	143.71	332	0.007
unidentified		164.86	325	0.007
^{235}U	185.7	185.56	659	0.015
^{212}Pb	238.6	238.44	264	0.006
^{214}Pb	351.9	351.57	199	0.004
Annihilation Radiation	511.0	510.69	157	0.003
unidentified		582.89	188	0.004
^{214}Bi	609.3	609.11	192	0.004
^{137}Cs	**661.7**	**661.53**	**219**	**0.005**
^{228}Ac	911.1	910.79	97	0.002
^{60}Co	1173.2	1172.46	35	0.000
^{60}Co	1332.5	1332.04	95	0.002
^{40}K	1460.8	1459.88	723	0.016

TABLE 31. TAMU PP BL-2 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{152}Eu	121.8	120.26	241	0.005
^{235}U	185.7	185.56	719	0.016
^{212}Pb	238.6	238.44	409	0.009
^{214}Pb	295.2	295.01	167	0.003
^{152}Eu	344.3	344.22	185	0.004
^{214}Pb	351.9	351.57	228	0.005
Annihilation Radiation	511.0	510.23	193	0.004
^{214}Bi	609.3	609.11	139	0.003
^{137}Cs	**661.7**	**661.53**	**160**	**0.003**
^{60}Co	1173.2	1172.00	154	0.003
^{40}K	1460.8	1460.34	1413	0.032

TABLE 32. TAMU PP J-3 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.64	380	0.008
^{235}U	185.7	185.56	778	0.018
^{212}Pb	238.6	238.44	356	0.008
^{152}Eu	344.3	344.22	143	0.003
^{214}Pb	351.9	351.57	156	0.003
Annihilation Radiation	511.0	510.69	160	0.003
^{214}Bi	609.3	608.65	175	0.004
^{137}Cs	**661.7**	**661.53**	**158**	**0.003**
^{228}Ac	911.1	910.33	125	0.002
^{60}Co	1173.2	1172.46	78	0.001
^{40}K	1460.8	1459.88	1011	0.023

TABLE 33. TAMU PP BL-3 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.74	8642	0.200
^{212}Pb	238.6	238.56	426	0.009
^{152}Eu	244.7	244.64	1862	0.043
^{214}Pb	295.2	295.11	249	0.005
^{152}Eu	344.3	344.17	4596	0.106
unidentified		356.32	436	0.010
^{228}Ac	409.5	410.99	223	0.005
^{223}Ra	445.0	444.17	403	0.009
Annihilation Radiation	511.0	510.99	287	0.006
^{214}Bi	609.3	609.59	416	0.009
^{137}Cs	**661.7**	**661.46**	**293**	**0.006**
^{152}Eu	778.9	779.22	987	0.022
^{228}Ac	911.1	964.27	967	0.022
^{152}Eu	1085.8	1086.23	520	0.012

TABLE 33. Continued

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	1112.0	1112.87	600	0.013
^{152}Eu	1408.0	1409.13	700	0.016
^{40}K	1460.8	1461.94	925	0.021

TABLE 34. TAMU PP J-4 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.27	9089	0.210
^{152}Eu	244.7	244.64	1815	0.042
^{152}Eu	344.3	344.17	4573	0.105
unidentified		367.54	238	0.005
^{228}Ac	409.5	410.99	137	0.003
^{223}Ra	445.0	444.17	405	0.009
Annihilation Radiation	511.0	510.99	279	0.006
unidentified		582.96	197	0.004
^{214}Bi	609.3	609.13	332	0.007
^{137}Cs	**661.7**	**661.46**	**266**	**0.006**
^{152}Eu	778.9	779.22	1011	0.023
unidentified		867.54	257	0.005
^{228}Ac	964.6	964.27	861	0.019
^{152}Eu	1085.8	1086.23	514	0.011

TABLE 34. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{152}Eu	1112.0	1112.40	673	0.015
^{152}Eu	1408.0	1408.66	853	0.019
^{40}K	1460.8	1461.47	844	0.019

TABLE 35. TAMU PP Jsoil-2 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{228}Ac	129.1	128.99	509	0.011
^{235}U	185.7	186.02	1609	0.037
^{228}Ac	209.3	209.01	673	0.015
^{212}Pb	238.6	238.44	4199	0.097
^{223}Ra	269.5	270.18	281	0.006
^{214}Pb	295.2	295.01	1428	0.033
^{223}Ra	338.3	338.24	930	0.021
^{214}Pb	351.9	352.03	2203	0.051
^{228}Ac	463.0	462.87	277	0.006
Annihilation Radiation	511.0	510.69	595	0.013
unidentified		582.89	1396	0.032
^{214}Bi	609.3	609.11	1628	0.037
^{137}Cs	**661.7**	**661.53**	**4840**	**0.112**
^{228}Ac	727.0	726.84	298	0.006

TABLE 35. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{228}Ac	911.1	910.79	827	0.019
^{152}Eu	969.1	968.73	560	0.013
^{214}Bi	1120.3	1120.03	339	0.007
^{40}K	1460.8	1460.34	2533	0.058
^{214}Bi	1764.5	1763.86	254	0.005

TABLE 36. TAMU PP BL-4 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.27	8512	0.197
^{152}Eu	244.7	244.64	1747	0.040
^{152}Eu	344.3	344.17	4719	0.109
^{228}Ac	409.5	410.99	431	0.010
unidentified		443.70	412	0.009
^{214}Bi	609.3	609.59	472	0.010
^{137}Cs	**661.7**	**661.46**	**402**	**0.009**
^{152}Eu	778.9	778.75	998	0.023
unidentified		867.54	311	0.007
^{152}Eu	964.0	964.27	754	0.017
^{152}Eu	1085.8	1085.76	571	0.013
^{152}Eu	1112.0	1111.93	767	0.017
unidentified		1413.34	849	0.019
^{40}K	1460.8	1461.47	888	0.020

TABLE 37. TAMU PP BLsoil-2 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{235}U	163.4	163.02	409	0.009
^{235}U	185.7	185.56	1422	0.032
^{228}Ac	209.3	209.47	267	0.006
^{212}Pb	238.6	238.44	3691	0.085
^{223}Ra	269.5	270.18	406	0.009
^{214}Pb	295.2	295.01	1572	0.036
^{223}Ra	338.3	338.24	798	0.018
^{214}Pb	351.9	351.57	2590	0.060
Annihilation Radiation	511.0	510.69	545	0.012
unidentified		582.89	1205	0.027
^{214}Bi	609.3	609.11	1950	0.045
^{137}Cs	**661.7**	**661.53**	**320**	**0.007**
^{228}Ac	911.1	910.79	702	0.016
^{152}Eu	969.1	968.27	386	0.008

TABLE 37. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{40}K	1460.8	1459.88	1923	0.044

TABLE 38. TAMU PP J-5 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.27	9084	0.210
^{152}Eu	244.7	244.64	1698	0.039
^{152}Eu	344.3	344.17	4460	0.103
^{214}Pb	351.9	352.11	391	0.009
^{228}Ac	409.5	411.46	230	0.005
unidentified		443.70	550	0.012
^{214}Bi	609.3	609.13	473	0.010
^{137}Cs	**661.7**	**661.46**	**267**	**0.006**
^{152}Eu	778.9	779.75	932	0.021
unidentified		867.54	307	0.007
^{152}Eu	964.0	964.27	962	0.022
^{152}Eu	1085.8	1086.23	503	0.011
^{152}Eu	1112.0	1112.40	695	0.016
^{152}Eu	1408.0	1408.20	800	0.018
^{40}K	1460.8	1461.47	775	0.017

TABLE 39. TAMU CL J-6 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{235}U	185.7	185.56	958	0.022
^{212}Pb	238.6	238.44	410	0.009
^{214}Pb	295.2	295.01	200	0.004
^{152}Eu	344.3	344.22	127	0.002
^{214}Pb	351.9	352.03	253	0.005
Annihilation Radiation	511.0	510.69	199	0.004
^{214}Bi	609.3	609.11	249	0.005
^{137}Cs	**661.7**	**661.53**	**224**	**0.005**
^{40}K	1460.8	1460.34	850	0.019

TABLE 40. TAMU PP Jsoil-3 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.27	7207	0.166
^{235}U	185.7	185.76	553	0.012
^{228}Ac	209.3	209.59	425	0.009
^{212}Pb	238.6	238.56	2190	0.050
^{152}Eu	244.7	244.64	1120	0.025
^{214}Pb	295.2	295.11	966	0.022
^{152}Eu	344.3	344.17	3926	0.090
^{214}Pb	351.9	351.65	1619	0.037
^{228}Ac	409.5	410.99	403	0.009
Annihilation Radiation	511.0	510.99	384	0.008
unidentified		582.96	880	0.020
^{214}Bi	609.3	609.13	1222	0.028
^{137}Cs	**661.7**	**661.46**	**3021**	**0.069**
^{152}Eu	778.9	779.22	845	0.019

TABLE 40. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{228}Ac	911.1	911.00	462	0.010
^{228}Ac	964.6	964.74	748	0.017
^{152}Eu	1085.8	1086.23	533	0.012
^{152}Eu	1112.0	1112.40	676	0.015
^{152}Eu	1408.0	1409.13	769	0.017
^{40}K	1460.8	1461.94	1231	0.028

TABLE 41. TAMU CL BL-6 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{235}U	185.7	185.56	662	0.015
^{212}Pb	238.6	238.44	394	0.009
^{214}Pb	295.2	295.01	295	0.006
^{214}Pb	351.9	351.57	288	0.006
unidentified		477.58	339	0.007
Annihilation Radiation	511.0	510.69	165	0.003
^{214}Bi	609.3	609.11	252	0.005
^{137}Cs	**661.7**	**661.53**	**251**	**0.005**
^{40}K	1460.8	1460.34	2055	0.047

TABLE 42. TAMU PP BLsoil-3 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{152}Eu	121.8	121.27	7131	0.165
^{235}U	185.7	185.76	514	0.011
^{212}Pb	238.6	238.56	2514	0.058
^{152}Eu	244.7	244.64	736	0.017
^{214}Pb	295.2	295.11	1088	0.025
^{152}Eu	344.3	344.17	3728	0.086
^{214}Pb	351.9	351.65	1830	0.042
^{228}Ac	409.5	410.53	268	0.006
^{223}Ra	445.0	444.17	448	0.010
^{228}Ac	463.0	462.86	284	0.006
Annihilation Radiation	511.0	510.53	413	0.009
unidentified		583.42	776	0.018
^{214}Bi	609.3	609.59	1263	0.029
^{137}Cs	**661.7**	**661.46**	**2831**	**0.065**

TABLE 42. Continued

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	778.9	779.22	789	0.018
^{228}Ac	911.1	911.46	526	0.012
^{228}Ac	964.6	964.74	831	0.019
^{152}Eu	1085.8	1086.70	442	0.010
^{152}Eu	1112.0	1112.87	631	0.014
^{152}Eu	1408.0	1409.13	738	0.017
^{40}K	1460.8	1461.94	1556	0.036

TABLE 43. TAMU PP BLsoil-4 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.27	7107	0.164
^{235}U	185.7	185.76	1395	0.032
^{228}Ac	209.3	209.12	261	0.006
^{212}Pb	238.6	238.56	2739	0.063
^{152}Eu	244.7	244.64	698	0.016
^{214}Pb	295.2	295.11	2024	0.046
^{223}Ra	338.3	338.10	635	0.014
^{152}Eu	344.3	344.17	4016	0.093
^{214}Pb	351.9	351.65	3188	0.073
^{223}Ra	445.0	444.17	414	0.009
Annihilation Radiation	511.0	510.53	553	0.012
unidentified		583.42	815	0.018
^{214}Bi	609.3	609.59	2104	0.048
^{137}Cs	**661.7**	**661.46**	**2312**	**0.053**

TABLE 43. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{152}Eu	778.9	779.22	928	0.021
^{228}Ac	911.1	911.93	587	0.013
^{228}Ac	964.6	964.74	814	0.018
^{152}Eu	1085.8	1086.23	487	0.011
^{152}Eu	1112.0	1112.87	580	0.013
^{152}Eu	1408.0	1409.13	832	0.019
^{40}K	1460.8	1461.94	1286	0.029

TABLE 44. TAMU PP Jsoil-4 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{235}U	185.7	185.56	1399	0.032
^{228}Ac	209.3	209.01	530	0.012
^{212}Pb	238.6	238.44	4287	0.099
^{223}Ra	269.5	270.18	462	0.010
^{214}Pb	295.2	295.01	1328	0.030
^{223}Ra	338.3	338.24	951	0.022
^{214}Pb	351.9	351.57	2395	0.055
Annihilation Radiation	511.0	510.69	554	0.012
unidentified		582.89	1200	0.027
^{214}Bi	609.3	609.11	1600	0.037
^{137}Cs	**661.7**	**661.53**	**8310**	**0.192**
^{228}Ac	911.1	910.79	759	0.017
^{40}K	1460.8	1460.34	2294	0.053

TABLE 45. TAMU PP Jsoil-5 Spectral Data for HPGe Detector No. 1

Radionuclide Identified	**Photon Energy (keV)**	**MCA Energy (keV)**	**Net Count Rate (12 hrs)**	**Net Count Rate (cps)**
^{152}Eu	121.8	121.27	6973	0.161
^{235}U	185.7	185.76	1561	0.036
^{228}Ac	209.3	209.12	428	0.009
^{212}Pb	238.6	238.56	5194	0.120
^{152}Eu	244.7	244.64	479	0.011
^{223}Ra	269.5	269.87	673	0.015
^{214}Pb	295.2	295.11	2129	0.0493
^{223}Ra	338.3	338.10	1219	0.028
^{152}Eu	344.3	344.17	4051	0.093
^{214}Pb	351.9	351.65	3557	0.082
Annihilation Radiation	511.0	510.99	764	0.017
unidentified		583.42	1517	0.035
^{214}Bi	609.3	609.59	2262	0.052
^{137}Cs	**661.7**	**661.46**	**4437**	**0.102**

TABLE 45. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{152}Eu	778.9	779.22	897	0.020
^{228}Ac	911.1	911.93	989	0.022
^{228}Ac	964.6	964.74	898	0.020
^{152}Eu	1085.8	1086.70	505	0.011
^{152}Eu	1112.0	1118.01	506	0.011
^{152}Eu	1408.0	1409.13	802	0.018
^{40}K	1460.8	1461.94	1997	0.046

TABLE 46. TAMU CL Jsoil-6 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{235}U	143.8	143.71	450	0.010
^{235}U	185.7	186.02	1899	0.044
^{212}Pb	238.6	238.44	2617	0.060
unidentified		246.72	1246	0.028
^{223}Ra	269.5	270.18	453	0.010
^{214}Pb	295.2	295.01	2324	0.053
^{223}Ra	338.3	338.24	513	0.011
^{214}Pb	351.9	352.03	4250	0.098
Annihilation Radiation	511.0	510.69	479	0.011
unidentified		582.89	854	0.019
^{214}Bi	609.3	609.11	2749	0.063
^{137}Cs	**661.7**	**661.46**	**4437**	**0.102**
^{228}Ac	911.1	911.25	531	0.012
^{152}Eu	969.1	968.73	390	0.009

TABLE 46. Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{214}Bi	1120.3	1120.03	537	0.012
^{40}K	1460.8	1460.34	893	0.020
unidentified		1759.72	421	0.009

TABLE 47. TAMU CL BLsoil-6 Spectral Data for HPGe Detector No. 2

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{228}Ac	129.1	128.99	363	0.008
^{235}U	185.7	186.02	2263	0.052
^{212}Pb	238.6	238.44	3485	0.080
unidentified		242.12	1403	0.032
^{223}Ra	269.5	270.18	498	0.011
^{214}Pb	295.2	295.01	2499	0.057
^{223}Ra	338.3	338.24	676	0.015
^{214}Pb	351.9	352.03	4233	0.098
Annihilation Radiation	511.0	510.69	528	0.012
unidentified		582.89	1242	0.028
^{214}Bi	609.3	609.11	3024	0.070
^{137}Cs	**661.7**	**661.53**	**820**	**0.019**
^{228}Ac	911.1	911.25	651	0.015
^{152}Eu	969.1	968.73	400	0.009

TABLE 47 Continued

Radionuclide Identified	Photon Energy (keV)	MCA Energy (keV)	Net Count Rate (12 hrs)	Net Count Rate (cps)
^{214}Bi	1120.3	1120.03	600	0.013
^{40}K	1460.8	1460.34	1329	0.030
^{214}Bi	1764.5	1764.32	421	0.009

TABLE 48. Vegetation Sample Net Counting Rate

Sample Name	**Plant Name**	**Net Counting ^{137}Cs Rate (r_n) (cps500mL^{-1})**
TAMU SCP J-1	One-seeded Juniper	-0.0014
TAMU SCP BL-1	Prairie Sumac	-0.0001
TAMU PP J-2	One-seeded Juniper	0.0003
TAMU PP BL-2	Eastern Cottonwood	-0.0011
TAMU PP J-3	One-seeded Juniper	-0.0011
TAMU PP BL-3	Post Oak	0.0001
TAMU PP J-4	Eastern Red Cedar	-0.0005
TAMU PP BL-4	Prairie Sumac	0.0026
TAMU PP J-5	Eastern Red Cedar	-0.0005
TAMU CL J-6	One-seeded Juniper	0.0004
TAMU CL BL-6	Red Mulberry	0.0010

TABLE 49. Soil Sample Net Counting Rate

Sample Name	**Soil Source**	**Net Counting ^{137}Cs Rate (r_n) (cps500mL^{-1})**
TAMU SCP Jsoil-1	Base of One-seeded Juniper	0.0761
TAMU SCP BLsoil-1	Base of Prairie Sumac	0.0863
TAMU PP Jsoil-2	Base of One-seeded Juniper	0.1072
TAMU PP BLsoil-2	Base of Eastern Cottonwood	0.0026
TAMU PP Jsoil-3	Base of One-seeded Juniper	0.0632
TAMU PP BLsoil-3	Base of Post Oak	0.0588
TAMU PP Jsoil-4	Base of Eastern Red Cedar	0.1876
TAMU PP BLsoil-4	Base of Prairie Sumac	0.0468
TAMU PP Jsoil-5	Base of Eastern Red Cedar	0.0960
TAMU CL Jsoil-6	Base of One-seeded Juniper	0.0078
TAMU CL BLsoil-6	Base of Red Mulberry	0.0142

TABLE 50. Vegetation Standard Deviation of the Net Counting Rate

Sample Name	**Plant Name**	**^{137}Cs Standard Deviation of Net Counting Rate (σ_n)**
TAMU SCP J-1	One-seeded Juniper	0.0003
TAMU SCP BL-1	Prairie Sumac	0.0004
TAMU PP J-2	One-seeded Juniper	0.0004
TAMU PP BL-2	Eastern Cottonwood	0.0003
TAMU PP J-3	One-seeded Juniper	0.0003
TAMU PP BL-3	Post Oak	0.0004
TAMU PP J-4	Eastern Red Cedar	0.0004
TAMU PP BL-4	Prairie Sumac	0.0005
TAMU PP J-5	Eastern Red Cedar	0.0004
TAMU CL J-6	One-seeded Juniper	0.0004
TAMU CL BL-6	Red Mulberry	0.0004

TABLE 51. Soil Standard Deviation of the Net Counting Rate

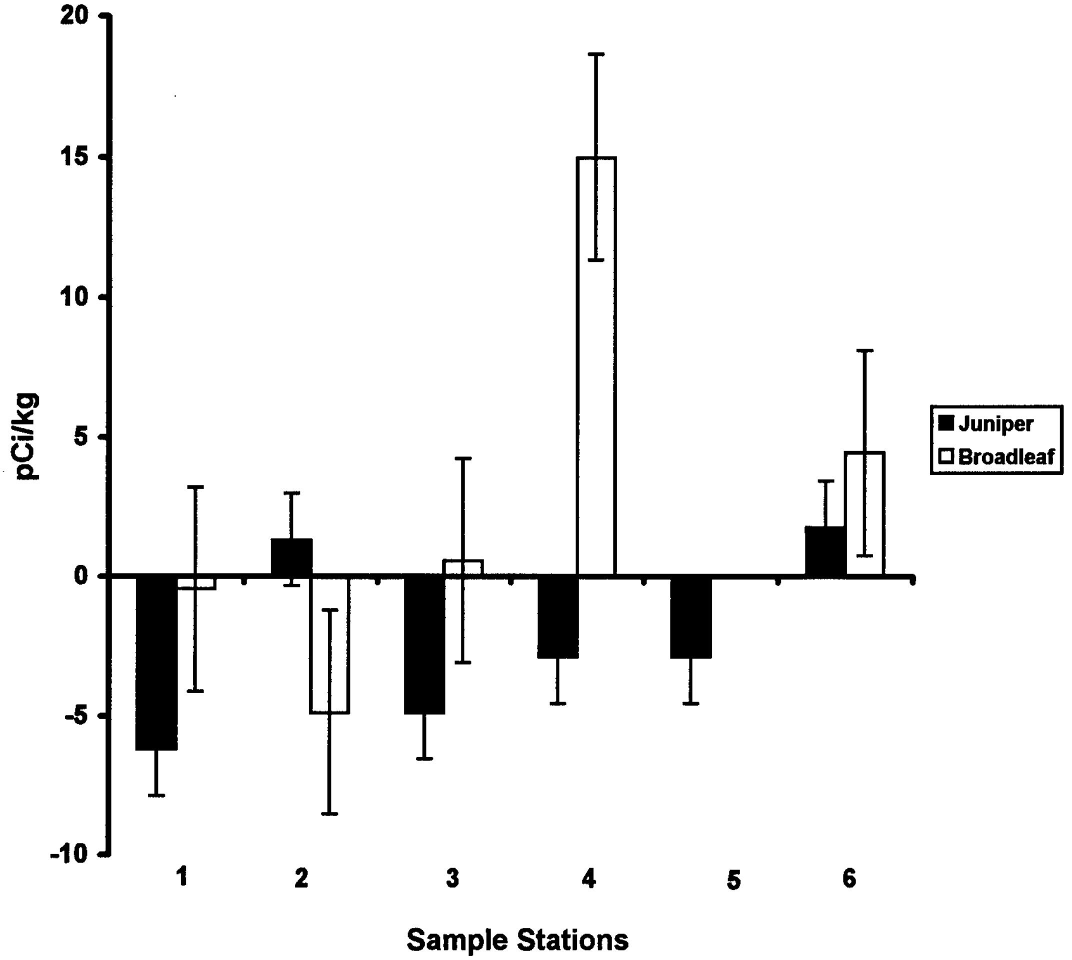
Sample Name	**Soil Source**	**^{137}Cs Standard Deviation of Net Counting Rate (σ_n)**
TAMU SCP Jsoil-1	Base of One-seeded Juniper	0.0014
TAMU SCP BLsoil-1	Base of Prairie Sumac	0.0015
TAMU PP Jsoil-2	Base of One-seeded Juniper	0.0016
TAMU PP BLsoil-2	Base of Eastern Cottonwood	0.0004
TAMU PP Jsoil-3	Base of One-seeded Juniper	0.0013
TAMU PP BLsoil-3	Base of Post Oak	0.0012
TAMU PP Jsoil-4	Base of Eastern Red Cedar	0.0021
TAMU PP BLsoil-4	Base of Prairie Sumac	0.0011
TAMU PP Jsoil-5	Base of Eastern Red Cedar	0.0016
TAMU CL Jsoil-6	Base of One-seeded Juniper	0.0006
TAMU CL BLsoil-6	Base of Red Mulberry	0.0007

TABLE 52. Vegetation Sample ^{137}Cs Concentrations

Sample Name	**Plant Name**	**^{137}Cs Concentration (pCikg^{-1})**
TAMU SCP J-1	One-seeded Juniper	-6.20
TAMU SCP BL-1	Prairie Sumac	-0.44
TAMU PP J-2	One-seeded Juniper	1.33
TAMU PP BL-2	Eastern Cottonwood	-4.87
TAMU PP J-3	One-seeded Juniper	-4.87
TAMU PP BL-3	Post Oak	0.57
TAMU PP J-4	Eastern Red Cedar	-2.88
TAMU PP BL-4	Prairie Sumac	14.98
TAMU PP J-5	Eastern Red Cedar	-2.88
TAMU CL J-6	One-seeded Juniper	1.77
TAMU CL BL-6	Red Mulberry	4.43

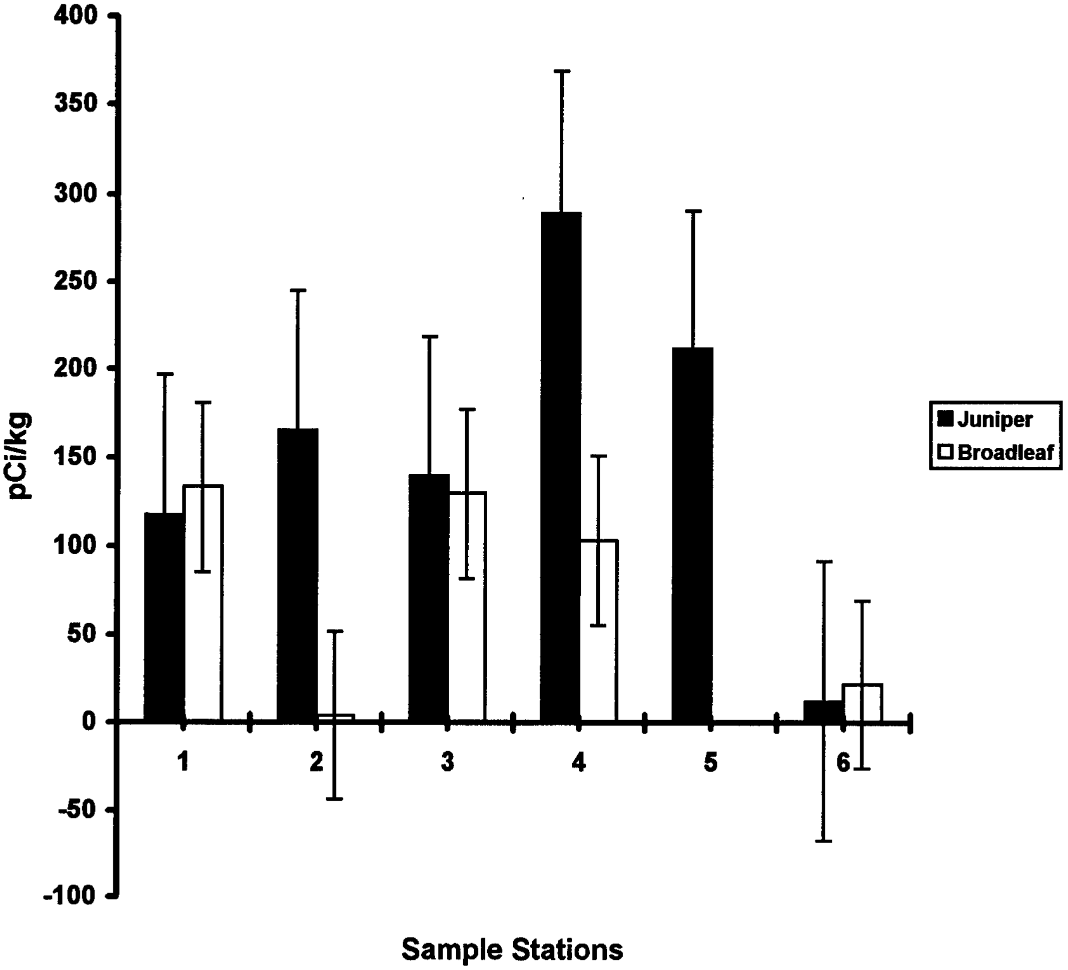
TABLE 53. Soil Sample ^{137}Cs Concentrations

Sample Name	**Soil Source**	**^{137}Cs Concentration (pCikg^{-1})**
TAMU SCP Jsoil-1	Base of One-seeded Juniper	117.38
TAMU SCP BLsoil-1	Base of Prairie Sumac	133.12
TAMU PP Jsoil-2	Base of One-seeded Juniper	165.36
TAMU PP BLsoil-2	Base of Eastern Cottonwood	4.01
TAMU PP Jsoil-3	Base of One-seeded Juniper	139.27
TAMU PP BLsoil-3	Base of Post Oak	129.57
TAMU PP Jsoil-4	Base of Eastern Red Cedar	289.38
TAMU PP BLsoil-4	Base of Prairie Sumac	103.13
TAMU PP Jsoil-5	Base of Eastern Red Cedar	211.54
TAMU CL Jsoil-6	Base of One-seeded Juniper	12.03
TAMU CL BLsoil-6	Base of Red Mulberry	21.90



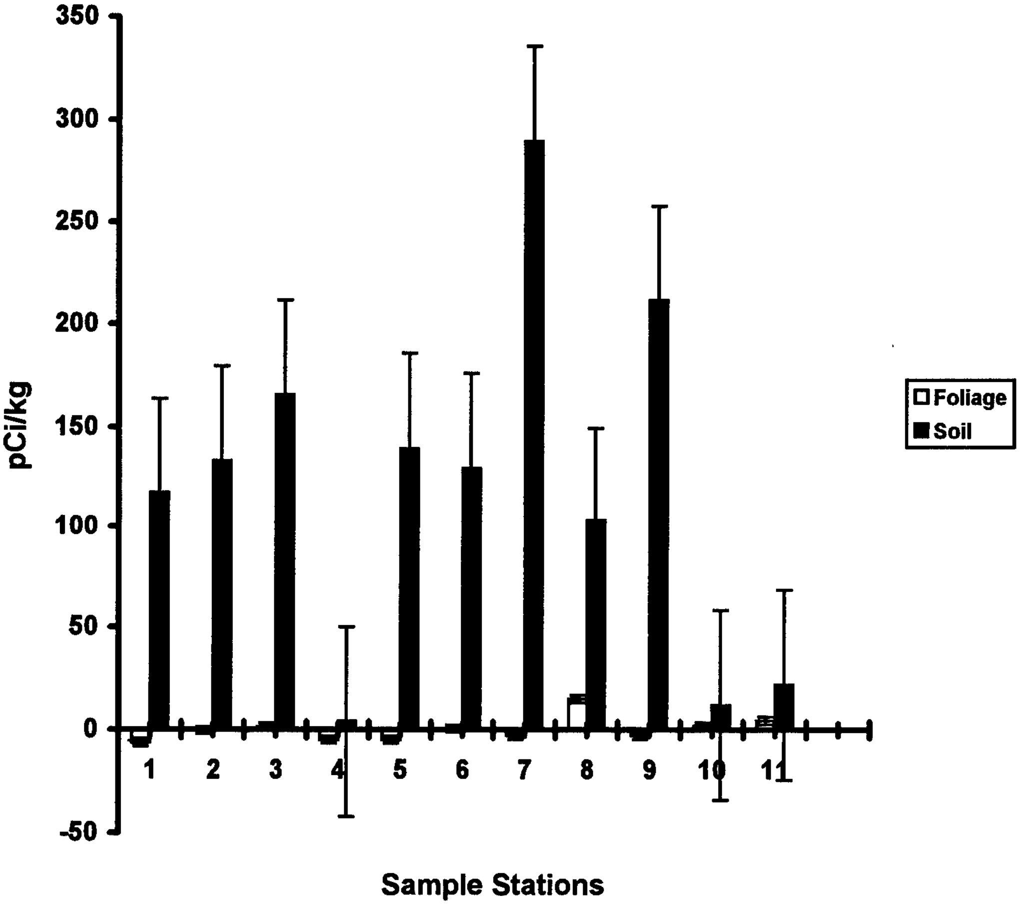
Note: Error bars represent one standard error of the mean.

Fig. 19. Foliage Sample Concentrations



Note: Error bars represent one standard error of the mean.

Fig. 20. Soil Sample Concentrations



Note: Error bars represent one standard error of the mean.

Fig. 21. Foliage vs. Soil Sample Concentrations

Gaussian. Statistical measurements needed to apply the Modified Student's *t*-tests to the Null hypothesis are shown in Tables 54, 55, and 56.

TABLE 54. Vegetation Sample *t*-test Results

(Evergreen vis-à-vis Deciduous)

	Juniper	**Broadleaf**
Number of points in data set (n)	6	5
Sample standard deviation (s_{n-1})	3.23	7.50
Sum of measures (Σx) [pCi/kg]	-13.74	14.67
Sum of squares (Σx^2)	83.79	268.44
Sample mean ($\bar{x}$)	-2.29	2.93
Standard Error of Mean ($s_{\bar{x}}$)	2.23	6.07

Standard deviation estimate based on both samples jointly (s)	5.55
Alpha level of significance (α)	0.05
Degrees of freedom [$n_1 + n_2 - 2$] (df)	9

TABLE 54. Continued

***t* probability for one-tailed test (P)**	1.83
Student's *t* statistic (|*t*|)	1.55

Null hypothesis	H_o: $\mu_1 = \mu_2$ Evergreen = Deciduous
Alternate hypothesis	H_1: $\mu_1 \neq \mu_2$ Evergreen ≠ Deciduous

1.553 < 1.833	**Therefore, H_o: $\mu_1 = \mu_2$ stands**

TABLE 55. Soil Sample *t*-test Results

(Evergreen vis-à-vis Deciduous)

	Juniper	**Broadleaf**
Number of points in data set (n)	6	5
Sample standard deviation (s_{n-1})	93.23	61.13
Sum of measures (Σx) [pCi/kg]	934.98	391.74
Sum of squares (Σx^2)	189160.02	45642.55
Sample mean ($\bar{x}$)	155.83	78.34
Standard Error of Mean ($s_{\bar{x}}$)	64.321	49.45

Standard deviation estimate based on both samples jointly (s)	80.56
Alpha level of significance (α)	0.05
Degrees of freedom [$n_1 + n_2 - 2$] (df)	9

TABLE 55. Continued

***t* probability for one-tailed test (P)**	1.83
Student's *t* statistic (|*t*|)	1.58

Null hypothesis	H_o: $\mu_1 = \mu_2$ Evergreen = Deciduous
Alternate hypothesis	H_1: $\mu_1 \neq \mu_2$ Evergreen ≠ Deciduous

$1.588 < 1.833$	**Therefore, H_o: $\mu_1 = \mu_2$ stands**

TABLE 56. Vegetation Sample vs. Soil Sample *t*-test Results

(Foliage Population vis-à-vis Soil Population)

	All Foliage	**All Soil**
Number of points in data set (n)	11	11
Sample standard deviation (s_{n-1})	5.93	86.47
Sum of measures (Σx) [pCi/kg]	0.93	1326.72
Sum of squares (Σx^2)	352.24	234802.58
Sample mean ($\bar{x}$)	0.085	120.61
Standard Error of Mean ($s_{\bar{x}}$)	2.56	37.32

Standard deviation estimate based on both samples jointly (s)	61.29
Alpha level of significance (α)	0.05
Degrees of freedom [$n_1 + n_2 - 2$] (df)	20

TABLE 56. Continued

***t* probability for one-tailed test (P)**	1.72
Student's *t* statistic (|*t*|)	4.61

Null hypothesis	H_o: $\mu_1 = \mu_2$ Foliage = Soil
Alternate hypothesis	H_1: $\mu_1 \neq \mu_2$ Foliage ≠ Soil

4.612 > 1.725	**Therefore, H_1: $\mu_1 \neq \mu_2$ stands**

RESULTS

The study's vegetation and soil survey resulted in the selection of 11 sample locations in and around the CPSES. From these 11 locations, representative evergreen and deciduous foliage samples (Table 1) were collected. Corresponding soil samples were also collected at each foliage sample site (Table 2).

After collection and drying, the foliage and soil samples were homogenized and used to develop the standard geometry source sets. Composite source sets, important for the successful efficiency calibration of the counting instrumentation, were prepared according to plan. The source sets were used for the efficiency calibrations. The HPGe detectors were also properly calibrated to specific photon energies by the use of commercial standard gamma-ray check sources. Using properly calibrated HPGe detectors and properly prepared samples, ^{137}Cs concentrations in each leaf and soil sample were obtained (Tables 52 and 53).

All of the study's field and laboratory preparations resulted in the successful measurement of ^{137}Cs radioactivity in each sample. These ^{137}Cs concentrations of the sample population means were statistically analyzed to determine if the measured sample means were significantly different. A one-tailed Modified Student's *t*-test for small samples was used to test the study's Null Hypothesis. The purpose of the *t*-test was to compare the means of two small sample sets. The test assumed that the unknown sample variances were equal (Bailey 1981; Downie and Health 1974). Modified Student's *t*-tests were applied to the juniper and broadleaf foliage sample data, and to the juniper and broadleaf soil sample data. In addition, the foliage population sample data were tested against the soil population sample data. The purpose of testing the sample data sets was to determine if the sample means belonged to the same population. In other words, the Null Hypothesis was tested. The Null Hypothesis states that the true means of each data set were equal.

The *t*-test was applied at the 95% confidence interval for each sample data set. The statistical test results are shown in Tables 54, 55, and 56. The means of the juniper and broadleaf foliage sample data sets were found not to be significantly different. Also, there was no significant difference found between the juniper and broadleaf soil sample data sets. The tested means of the foliage population and soil population sample sets, however, were found to be significantly different.

All measured ^{137}Cs concentrations are reported including some negative values. In gamma spectroscopy, a small net count of a nuclide relative to the background count can lead to large uncertainties and values below the LLD. These negative values are real measurements and are important in statistical analysis. The measured value is the best estimate of the true value. The measured value includes its own random error. The random error has a normal distribution with a mean of zero. Thus negative random error can also account for negative measurements. Not reporting negative ^{137}Cs concentrations would result in censored data and a truncated data distribution that would not show the reality of the measured radioactivity being close to background.

CONCLUSION

The Null Hypothesis that states each individual sample of this study is from the same statistical population regardless of location origin is supported by the results of Modified Student's *t*-tests. The *t*-tests were conducted on CPSES evergreen, deciduous, and soil samples on an individual and population basis. The three *t*-test results show that the evergreen and deciduous leaf samples are from the same population, and the associated soil samples are from another distinct population. No significant statistical difference was found between the evergreen leaf and deciduous leaf compared means, and the evergreen soil and deciduous soil compared means. In contrast, the *t*-tests show that the foliage population is different from the soil population. The means of these two populations are statistically different. Based on the statistical testing, it is concluded that each sample ^{137}Cs radioactivity concentration is also from the same respective foliage or soil population.

The statistical test results also support this study's research objective, which was to quantitatively determine if ^{137}Cs was present in significantly differing concentrations in the local evergreen and deciduous plant species about the CPSES site. The study's results show that the ^{137}Cs concentrations in the two plant categories are not significantly different. Therefore, the evergreen and deciduous trees are from the same statistical population. A conclusion from these results is that deciduous trees at CPSES are not better environmental collectors of air deposited radionuclides vis-à-vis evergreen (junipers) trees. Because the ^{137}Cs concentrations are from the same statistical population, then the evergreen trees collect at least the same quantity of environmental airborne radionuclides as the deciduous species. This was shown to be true only for ^{137}Cs. By being in the same statistical population, evergreen foliage may then be substituted for deciduous foliage during routine environmental sampling of the CPSES REMP.

It is the conclusion of this study that the ^{137}Cs concentration in and around the CPSES at the time of sampling was distributed differentially in the plant and soil populations. The environmental concentrations of ^{137}Cs are statistically the same in the evergreen and deciduous foliage in the CPSES area. Therefore, the foliage of both evergreen and deciduous shrub and tree species at the CPSES may be used to sample and measure environmental concentrations of ^{137}Cs. It is logical to assume that any radioactive environmental contamination of the CPSES site would come from the CPSES facility and/or atmospheric nuclear weapons deposition. This theoretical radioactive contamination should be from the same statistical population. Therefore, any airborne radioactive contamination originating from this population would be deposited evenly on the evergreen and deciduous vegetation of the area. This scenario of even deposition would be true only in calm local wind conditions. The presence of strong winds would result in differential deposition. The ^{137}Cs deposited at the CPSES in the 1950's and 1960's by atmospheric nuclear weapon testing, however, seems to be more evenly distributed than not according to the results of this thesis study.

These conclusions are based on a small field sample set and very low ^{137}Cs concentrations. A larger number of field samples would provide a better statistical distribution. A larger data set may be needed to validate the conclusions of this study.

Based on this study's statistical tests, it is logical to conclude by extension that other airborne deposited radionuclides behaving like ^{137}Cs in the CPSES site could be sampled from the environment by the collection of either evergreen or deciduous foliage. Since no statistical difference would be expected in the radionuclide concentrations of the foliage types, the type of tree or shrub leaves collected would not matter. With respect to the CPSES REMP and the USNRC environmental sampling requirements, this study's results support the substitution of juniper evergreen leaves for deciduous leaves during routine environmental sampling at the CPSES site.

By collecting juniper evergreen foliage as a supplement to deciduous foliage sampling, the CPSES's REMP would be enhanced and thus better satisfy USNRC regulatory requirements. Regulatory compliance would be easily met in those seasons of deciduous foliage scarcity because of the availability of juniper leaves. As previously stated, juniper trees are widely present at CPSES; and by being evergreen their leaves are available for collection year-round as opposed to the leaves of the few deciduous tree species.

As an added measure to fulfill regulatory compliance, the CPSES may use the conclusions of this study to petition the USNRC for permission to change the REMP to allow for the routine collection and analysis of evergreen foliage along with deciduous foliage.

FUTURE WORK

Historical environmental data for analysis and trending can be obtained through the careful planning for a long term project at the CPSES. Such a long term research project can be accomplished by establishing a schedule for collecting field samples from the same sample locations of this study. The field samples should be a close replication of this study's samples. Sampled evergreen and deciduous foliage, and soil should be analyzed for ^{137}Cs and other airborne deposited radionuclides. Radionuclides with the potential for routine or accidental release from the CPSES should be selected for analysis.

By routinely collecting and analyzing environmental foliage and soil samples from the same locations as this study's, the CPSES can establish a good database for developing a variety of reports and charts. For example, charts showing radionuclide patterns, airborne radionuclide deposition, and radionuclide concentrations over time could be made. Future trends of environmental parameters could also be established by such a database. Annual measurements could be done at the field sites for the life time of the CPSES and even into its decontamination and decommissioning phase. A near life time of environmental data from a nuclear power plant could be developed and studied, if such an endeavor is undertaken. The study and analysis of these data could lead to useful important conclusions. These conclusions could be used in the development and implementation of future environmental monitoring plans for nuclear power facilities.

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APPENDIX A

VEGETATION SAMPLING PROCEDURE

Introduction:

Field collection of vegetation samples was performed both on and near the Comanche Steam Electric Station (CPSES). Samples of deciduous and evergreen trees were central to the objective of this study. The vegetation samples were collected by following this procedure.

Equipment needed:

1. Garden shears,
2. utility gloves,
3. clear Ziploc® plastic collection bags
4. 46 centimeter wooden stakes,
5. sledge hammer,
6. indelible black ink marker,
7. orange vinyl flagging,
8. camera,
9. notebook, and
10. pen.

Steps to collect samples:

1. Locate an area with juniper and deciduous trees.
2. Tag selected juniper tree at diameter breast height (dbh) (1.4 meter) with orange vinyl flagging.
3. Label location name on wooden stake with marker.
4. Drive stake into ground at base of sample tree with sledge hammer.
5. Put on utility gloves.
6. Prune small leaf bearing branches from juniper tree with garden shears.
7. Place branches and leaves into plastic collection bags.
8. Collect enough foliage to fill four 1000 mL glass beakers.
9. Label collection bags with sample name, location, and date.
10. Take field notes of identified sample tree.
11. Photograph sample tree and surroundings.
12. Repeat Steps 2 through 10 for nearby selected deciduous tree.
13. Transport samples to environmental laboratory.
14. Repeat Steps 1 through 13 for each identified sample location.

APPENDIX B

SOIL SAMPLING PROCEDURE

Introduction:

Field collection of soil samples was performed both on and near the Comanche Steam Electric Station (CPSES). These samples were needed to compare ^{137}Cs radioactivity of soils at the different sample locations. The soil samples were collected by following this procedure.

Equipment needed:

1. Garden trowel,
2. utility gloves,
3. clear Ziploc® plastic collection bags,
4. inch ruler,
5. camera,
6. notebook, and
7. pen.

Steps to collect samples:

1. Locate an identified sample site.
2. Select flagged juniper tree.
3. Put on utility gloves.
4. Clear leaf litter from the base of the juniper sample tree.
5. Mark a 31 cm by 31 cm square area with ruler and garden trowel edge.
6. Remove soil from marked area to a depth of 2.5 cm (1 in) with ruled garden trowel.
7. Place soil into plastic collection bags.
8. Collect enough soil to fill four 1000 mL glass beakers.
9. Label collection bags with sample name, location, and date.
10. Take field notes of identified soil sample site.
11. Photograph soil sample site and surroundings.
12. Repeat Steps 2 through 10 for nearby flagged deciduous sample tree.
13. Transport samples to environmental laboratory.
14. Repeat Steps 1 through 13 for each identified sample location.

APPENDIX C

SAMPLE DRYING PROCEDURE

Introduction:

Drying of vegetation and soil samples was performed in preparation for radioanalysis. The field samples were dried in a two step process. First the samples were air dried at room temperature and then oven dried with heat.

Equipment needed:

1. Utility gloves,
2. large clear plastic garbage bags,
3. masking tape,
4. black marker,
5. Pyrex ® 1000 and 500 mL glass beakers,
6. Pyrex ® glass stirring rod,
7. clear Ziploc® plastic collection bags,
8. camera,
9. notebook, and
10. pen.

Steps to dry foliage samples:

1. Put on utility gloves.
2. Transfer individual field vegetation sample into large clear plastic garbage bag.
3. Tape full garbage bag onto environmental laboratory counter with masking tape.
4. Label masking tape with sample name and tape on laboratory counter above garbage bag.
5. Leave garbage bag open.
6. Leave vegetation sample in garbage bag for several days to air dry.
7. Turn electric drying oven on and leave on with thermostat set for approximately 100 °C.
8. Transfer air dried tree leaves into corresponding field sample collection bag.
9. Carry sample bag to the radiochemistry laboratory.
10. With utility gloves on, transfer air dried tree leaves into four 1000 mL and one 600 mL clean glass beakers.
11. Use clean glass stirring rod to pack leaves in beakers.
12. Put the five beakers into electric drying oven.
13. Leave beakers in oven for approximately 12 hours.
14. With utility gloves, remove hot beakers from oven.
15. Transfer hot dry leaves into corresponding sample bag.
16. Return bag with leaves to environmental laboratory for cooling and storage.
17. Photograph steps of procedure.

18. Take notes of procedure process.
19. Repeat Steps 1 through 18 until all leaves of a sample are dry.
20. Repeat Steps 1 through 19 for each foliage sample.

Steps to dry soil samples:

1. Leave soil sample in properly labeled field collection bag.
2. Place field collection bag on environmental laboratory counter.
3. Open the soil sample bag.
4. Leave soil bag open for days to air dry while foliage samples are oven dried.
5. Turn electric drying oven on and leave on with thermostat set for approximately 100 °C.
6. Carry sample bag to the radiochemistry laboratory.
7. With utility gloves on, transfer air dried soil into four 1000 mL and one 600 mL clean glass beakers.
8. Put the five beakers into electric drying oven.
9. Leave beakers in oven for approximately 12 hours.
10. With utility gloves, remove hot beakers from oven.
11. Transfer hot dry soil into corresponding sample bag.
12. Return bag with soil to environmental laboratory for cooling and storage.
13. Photograph steps of procedure.
14. Take notes of procedure process.

15. Repeat Steps 1 through 14 until all soil of a sample is dry.

16. Repeat Steps 1 through 15 for each soil sample.

APPENDIX D

RADIOANALYSIS PREPARATION PROCEDURE

Introduction:

In order to analyze the foliage and soil samples by the High Purity Germanium (HPGe) detector, the media needed to be homogenized to fill a standard geometry container. Each leaf and soil sample was stored for analysis after being individually homogenized.

Equipment needed:

1. Electric blender,
2. plastic spoon,
3. dust mask,
4. 1.3 cm paint brush,
5. Pyrex ® 1000 mL glass beaker,
6. 500 mL wide-mouth polyethylene Nalgene® bottles,
7. Ziploc® plastic bag,
8. camera,
9. notebook, and
10. pen.

Steps to homogenize foliage samples:

1. Wash and dry hands.
2. Manually crush dry sample leaves from the outside of the Ziploc® bags.
3. Transfer leaves into clean electric blender.
4. Fill blender vessel to approximately one-quarter mark.
5. Remove any twigs with a plastic spoon.
6. Put on a dust mask.
7. Set blender to "Lo" and "Chop".
8. Turn on blender and chop leaf samples for approximately 1 minute.
9. Tilt the blender to allow blades to chop the leaves quickly and evenly.
10. Repeat Steps 8 and 9 until leaves are homogenized to a granular form.
11. Use a clean plastic spoon to transfer the homogenized leaf sample into a clean Pyrex ® 1000 mL glass beaker.
12. Use a clean 1.3 cm paint brush to remove residue from blender vessel.
13. Pour the homogenized leaves from the beaker to the 500 mL mark of two clean wide-mouth polyethylene Nalgene® bottles.
14. Label the Nalgene® bottle with the sample name.
15. Transfer any sample remainder into a clean labeled Ziploc® plastic bag.
16. Photograph steps of procedure.
17. Take notes of procedure process.
18. Repeat Steps 1 through 17 for each foliage sample.

Steps to homogenize soil samples:

1. Wash and dry hands.
2. Transfer dry soil into clean electric blender.
3. Fill blender vessel to approximately one-quarter mark.
4. Remove any pebbles with a plastic spoon.
5. Put on a dust mask.
6. Set blender to "Lo" and "Stir".
7. Turn on blender and chop soil samples for approximately 1 minute.
8. Tilt the blender to allow blades to chop the soil quickly and evenly.
9. Repeat Steps 7 and 8 until soil is homogenized to a granular form.
10. Use a clean plastic spoon to transfer the homogenized soil sample into a clean Pyrex ® 1000 mL glass beaker.
11. Use a clean 1.3 cm paint brush to remove residue from blender vessel.
12. Pour the homogenized soil from the beaker to the 500 mL mark of two clean wide-mouth polyethylene Nalgene® bottles.
13. Label the Nalgene® bottle with the sample name.
14. Transfer any sample remainder into a clean labeled Ziploc® plastic bag.
15. Photograph steps of procedure.
16. Take notes of procedure process.
17. Repeat Steps 1 through 16 for each soil sample.

APPENDIX E

STANDARD GEOMETRY SOURCE SET DEVELOPMENT PROCEDURE

Introduction:

A radioactive source in the standard geometry of a 500 mL Marinelli Beaker was required for the efficiency calibration of the High Purity Germanium (HPGe) detectors. An efficiency calibration was needed for each type of sample media. Therefore, a 500 mL composite of all leaf samples was made for the foliage efficiency calibration A 500 mL composite of all the soil samples for use in the soil efficiency calibration was also made.

Equipment needed:

1. Electronic balance,
2. manual micro-balance,
3. calculator,
4. 500 mL wide-mouth polyethylene Nalgene® bottles,
5. Pyrex ® 1000 mL glass beakers,
6. plastic 500 mL Marinelli Beakers with lids,
7. small Solo® paper cups,
8. plastic spoons,

9. Pyrex ® glass stirring rods,
10. 1 mL glass pipettes with bulb syringe,
11. camera,
12. notebook, and
13. pen.

Steps to determine leaf composite sample weight fractions:

1. Weigh 9 new empty 500 mL Nalgene® bottles on the electronic balance.
2. Sum the bottle weights and divide by 9 to determine the average bottle weight in grams.
3. Fill a clean Pyrex ® 1000 mL glass beaker with tap water to the 500 mL mark.
4. Pour the 500 mL of tap water into a clean Nalgene® bottle.
5. Mark the 500 mL level on the neck of the Nalgene® bottle.
6. Empty the water from the Nalgene® bottle and allow bottle to air dry.
7. Weigh a Nalgene® bottle filled with 500 mL of homogenized leaf sample on the electronic balance.
8. Subtract the average Nalgene® bottle weight from the gross weight to determine the content weight.
9. Divide the sample content weight by the Nalgene® bottle volume (500 mL) to determine the density (gcm^{-3}) of the leaf sample.
10. Repeat Steps 7 through 9 for each foliage sample.

11. Sum all the leaf sample densities and divide by the total number of leaf samples (11) to determine the average leaf density.
12. Divide 500 mL volume by the total number of foliage samples (11) to determine the individual sample fraction (45.45 mL) of 500 mL.
13. Multiply the leaf sample density (gcm^{-3}) by 45.45 mL to determine the sample weight fraction (grams) contribution needed to equal 500 mL.
14. Repeat Step 13 for each foliage sample.
15. Photograph steps of procedure.
16. Take notes of procedure process.

Steps to determine soil composite sample weight fractions:

1. Weigh a Nalgene® bottle filled with 500 mL of homogenized soil sample on the electronic balance.
2. Subtract the average Nalgene® bottle weight from the gross weight to determine the content weight.
3. Divide the sample content weight by the Nalgene® bottle volume (500 mL) to determine the density (gcm^{-3}) of the soil sample.
4. Repeat Steps 1 through 3 for each soil sample.
5. Sum all the soil sample densities and divide by the total number of soil samples (11) to determine the average soil density.

6. Divide 500 mL volume by the total number of soil samples (11) to determine the individual sample fraction (45.45 mL) of 500 mL.
7. Multiply the soil sample density (gcm^{-3}) by 45.45 mL to determine the sample weight fraction (grams) contribution needed to equal 500 mL.
8. Repeat Step 7 for each soil sample.
9. Photograph steps of procedure.
10. Take notes of procedure process.

Steps to produce foliage composite sample:

1. Divide in half the weight fraction contribution (grams) of a leaf sample.
2. Zero the manual micro-balance.
3. Weigh an clean empty Solo® paper drinking cup (grams) on the micro-balance.
4. Leave the clean empty Solo® paper cup on the micro-balance.
5. Use a clean plastic spoon to transfer a homogenized leaf sample from a 500 mL Nalgene® bottle into the paper cup.
6. Weigh out the weight fraction contribution (grams) of the leaf sample after accounting for the paper cup weight.
7. Use the plastic spoon to add or remove sample media to obtain the required weight fraction.
8. Pour the leaf sample weight fraction from the paper cup into a clean Pyrex ® 1000 mL glass beaker.

9. Repeat Steps 1 through 8 for each foliage sample to result in 250 mL of leaf composite sample in the glass beaker.
10. Mix the 250 mL of composite leaf sample with a clean Pyrex ® glass stirring rod.
11. Under a laboratory vent hood fill a clean glass pipette with 1 mL of NIST ^{152}Eu standard liquid solution.
12. Without contacting the beaker sides, spot the 1 mL of ^{152}Eu solution onto the 250 mL of leaf composite sample in the glass beaker.
13. Turn the electric drying oven on and set thermostat for a temperature of approximately 100 °C.
14. Place the glass beaker with 250 mL of leaf composite sample and ^{152}Eu into the drying oven.
15. Dry the leaf composite sample in the oven for 24 hours.
16. Remove the beaker from the electric drying oven.
17. Repeat Steps 2 through 7 to weigh out the remaining half of the foliage sample composite fraction contribution.
18. Pour the leaf sample weight fraction into the 1000 mL glass beaker holding the 250 mL of dry leaf composite sample and ^{152}Eu.
19. Repeat Step 18 for each foliage sample to result in a total of 500 mL of leaf composite sample in the glass beaker.
20. Mix the 500 mL of composite leaf sample with a clean Pyrex ® glass stirring rod.
21. Pour the 500 mL of composite leaf sample into a clean Marinelli Beaker.

22. Label a lid with media and radioactive source information and attach it to the Marinelli Beaker.
23. Set the composite leaf sample aside for efficiency calibration use.
24. Photograph steps of procedure.
25. Take notes of procedure process.

Steps to produce soil composite sample:

1. Divide in half the weight fraction contribution (grams) of a soil sample.
2. Zero the manual micro-balance.
3. Weigh an clean empty Solo® paper drinking cup (grams) on the micro-balance.
4. Leave the clean empty Solo® paper cup on the micro-balance.
5. Use a clean plastic spoon to transfer a homogenized soil sample from a 500 mL Nalgene® bottle into the paper cup.
6. Weigh out the weight fraction contribution (grams) of the soil sample after accounting for the paper cup weight.
7. Use the plastic spoon to add or remove sample media to obtain the required weight fraction.
8. Pour the soil sample weight fraction from the paper cup into a clean Pyrex ® 1000 mL glass beaker.
9. Repeat Steps 1 through 8 for each soil sample to result in 250 mL of soil composite sample in the glass beaker.

10. Mix the 250 mL of composite soil sample with a clean Pyrex ® glass stirring rod.
11. Under a laboratory vent hood fill a clean glass pipette with 1 mL of NIST traceable ^{152}Eu standard liquid solution.
12. Without contacting the beaker sides, spot the 1 mL of ^{152}Eu solution onto the 250 mL of soil composite sample in the glass beaker.
13. Turn the electric drying oven on and set thermostat for a temperature of approximately 100 °C.
14. Place the glass beaker with 250 mL of soil composite sample and ^{152}Eu into the drying oven.
15. Dry the soil composite sample in the oven for 24 hours.
16. Remove the beaker from the electric drying oven.
17. Repeat Steps 2 through 7 to weigh out the remaining half of the soil sample composite fraction contribution.
18. Pour the soil sample weight fraction into the 1000 mL glass beaker holding the 250 mL of dry soil composite sample and ^{152}Eu.
19. Repeat Step 18 for each soil sample to result in a total of 500 mL of soil composite sample in the glass beaker.
20. Mix the 500 mL of composite soil sample with a clean Pyrex ® glass stirring rod.
21. Pour the 500 mL of composite soil sample into a clean Marinelli Beaker.
22. Label a lid with media and radioactive source information and attach it to the Marinelli Beaker.

23. Set the composite soil sample aside for efficiency calibration use.
24. Photograph steps of procedure.
25. Take notes of procedure process.

APPENDIX F

HIGH PURITY GERMANIUM DETECTOR ENERGY CALIBRATION PROCEDURE

Introduction:

The High Purity Germanium (HPGe) detectors used to analyzed the leaf and soil samples were first calibrated to a gamma-ray energy range that included the 661.7 keV photon of ^{137}Cs. Commercial radioactive check sources with low and high gamma-ray energy were used to develop the needed energy range.

Equipment needed:

1. HPGe well detector systems,
2. ^{57}Co check source,
3. ^{60}Co check source,
4. ^{22}Na check source,
5. camera,
6. notebook, and
7. pen.

Steps to energy calibrate HPGe detector:

1. Verify that HPGe detector and associated electronic equipment are on.
2. Verify that HPGe detector electronics are properly connected.
3. Verify that the high voltage is properly set at 3.5 KV.
4. Verify that the amplifier pulse shaping time is set at 6 μsec.
5. Verify that the Multi-channel Analyzer (MCA) conversion gain is set to 4096.
6. Set the live time to 60 seconds.
7. Place a ^{57}Co and a ^{60}Co gamma-ray check source on top f the detector in a shielded well. (NOTE: ^{57}Co has a 122.1 keV photon and ^{60}Co has 1173.5 and 1332.5 keV photons.)
8. Acquire a spectrum.
9. Adjust the vertical scale so that the photopeaks are easily distinguished.
10. Set the photopeak Region Of Interest (ROI) to 10 channels.
11. Place the left MCA marker on the ^{57}Co photopeak.
12. Enter 122.1 keV into the MCA and assign the energy to the ^{57}Co photopeak.
13. Place the right MCA marker on the higher energy photopeak of ^{60}Co.
14. Enter 1332.5 keV into the MCA and assign the energy to the higher energy photopeak of ^{60}Co.
15. Move a MCA marker to the lower energy photopeak of ^{60}Co and verify calibration by checking MCA energy reading as 1173.2 keV.

16. Double check energy calibration by placing a ^{22}Na check source on the detector and acquiring a spectrum for 60 seconds.
17. The energy calibration is successful if the MCA correctly identifies the ^{22}Na photopeaks as 511.0 and 1274.5 keV.
18. If calibration is not successful, repeat Steps 1 through 17 until photopeaks are correctly identified.
19. Photograph steps of procedure.
20. Take notes of procedure process.

APPENDIX G

HIGH PURITY GERMANIUM DETECTOR EFFICIENCY CALIBRATION PROCEDURE

Introduction:

The efficiency calibration of the High Purity Germanium (HPGe) detector system was important to determine the radioactive emissions from the leaf and soil samples. The counting yield of the detector was dependent on the radioactive sources and the counting geometry, which was a 500 mL Marinelli Beaker.

Equipment needed:

1. HPGe well detector systems,
2. composite samples with ^{152}Eu standard,
3. plastic 500 mL Marinelli Beaker with lid,
4. calculator,
5. computer graph application,
6. camera,
7. notebook, and
8. pen.

Steps to efficiency calibrate HPGe detector:

1. Perform an energy calibration of the HPGe detector systems.
2. Using the exponential decay equation, calculate the current activity of the ^{152}Eu NIST standard:

$$A = A_0 e^{-\frac{0.693}{T_{1/2}} t}$$

A = activity amount (dps) left after time t

A_0 = initial quantity of activity (dps)

e = base of the system of natural logarithms

0.693 = ln 2

$T_{1/2}$ = half-life (years)

t = elapsed time (years)

3. Record the ^{152}Eu activity in disintegrations per second.
4. Set the live time to 3600 seconds.
5. Place the composite sample with ^{152}Eu standard in 500 mL Marinelli Beaker geometry on top of the detector in a shielded well.
6. Acquire a spectrum.
7. Adjust the vertical scale so that the photopeaks are easily distinguished.
8. Set the photopeak Region Of Interest (ROI) to 10 channels.
9. Determine the net counts of the following ^{152}Eu gamma-ray photopeaks: 121.8, 244.7, 344.3, 411.1, 444.0, 778.9, 964.0, 1085.8, 1112.1, and 1408.0 keV.

10. Calculate the net counts per second for each photopeak.

11. Calculate the efficiency for each photon energy using the following equation:

$$\varepsilon_{\lambda} = \frac{R_{net}}{A I_{\lambda}}$$

ε_{λ} = efficiency in counts per photon

R_{net} = net counts per second

A = activity of standard in dps

I_{λ} = gamma-ray intensity in photons per disintegration

12. Plot the values of ε_{λ} versus photon energy on log-log scale.

13. From the graph interpolate the ε_{λ} for the 661.7 keV photon of ^{137}Cs.

14. Repeat Steps 1 through 13 for the leaf and soil composite samples mixed with ^{152}Eu standard for HPGe Detectors No. 1 and 2.

15. Tabulate the data.

16. Photograph steps of procedure.

17. Take notes of procedure process.

APPENDIX H

ESTIMATION OF LOWER LIMIT OF DETECTION

Introduction:

The lower limit of detection (LLD) of ^{137}Cs was calculated to determine, with confidence, the smallest concentration of radioactive material a leaf or soil sample could have and still be above High Purity Germanium (HPGe) detector background. A background count rate for each HPGe detector used was required to determine the LLD. The HPGe detector efficiencies for the ^{137}Cs photopeaks of the composite leaf and soil samples were also needed for calculating the LLD.

Equipment needed:

1. HPGe well detector systems,
2. calculator,
3. camera,
4. notebook, and
5. pen.

Steps to measure HPGe detector background radiation:

1. Perform an energy calibration of the HPGe detector system.
2. Set the live time to 48 hours (2880 minutes).
3. Check that HPGe detector well is empty.
4. Close lid to detector well.
5. Acquire a spectrum.
6. Adjust the vertical scale so that the photopeaks are easily distinguished.
7. Set the photopeak ROI to 10 channels.
8. Determine the net counts of the ^{137}Cs and major gamma-ray photopeaks.
9. Calculate the net counts per second for the photopeaks.
10. Repeat Steps 1 through 9 for each HPGe detector (Nos. 1 and 2) used.
11. Photograph steps of procedure.
12. Take notes of procedure process.

Steps to calculate Lower Limit of Detection:

1. Calculate the LLD using the following equation:

$$LLD = \frac{4.66 S_b}{EV 2.22 Y e^{-\lambda \Delta t}}$$

$$S_b = \sqrt{\frac{bkgcountrate}{T}}$$

LLD = lower limit of detection

S_b = standard deviation of the background counting rate (cpm)

E = counting efficiency (cpd)

V = sample size (volume in mL)

2.22 = number of disintegrations per minute per pCi

Y = fractional radiochemical yield

λ = radioactive decay constant of ^{137}Cs

Δt = elapsed time between sample collection and counting

bkgcountrate = background count rate

T = acquisition time in minutes

2. Obtain background counting rate of HPGe Detector No. 1.
3. Use Steps 1 and 2 to calculate LLD for the composite leaf sample.
4. Use Steps 1 and 2 to calculate LLD for the composite soil sample.
5. Obtain background counting rate of HPGe Detector No. 2.
6. Use Steps 1 and 5 to calculate LLD for the composite leaf sample.
7. Use Steps 1 and 5 to calculate LLD for the composite soil sample.
8. Take notes of procedure process.

APPENDIX I

LABORATORY EQUIPMENT CLEANING PROCEDURE

Introduction:

The proper handling and cleaning of laboratory equipment and ware was crucial to prevent cross contamination between field samples. All laboratory equipment that had multiple contact with the leaf and soil samples was cleaned, washed, decontaminated, and dried before each use.

Equipment needed:

1. Sink with hot and cold running water,
2. clean commercial paper towels,
3. 200 proof ethyl anhydrous alcohol,
4. 10 mL glass pipette,
5. laboratory counter top,
6. camera, and
7. notebook.

Steps to clean and decontaminate laboratory ware and equipment:

1. Wash and dry hands.
2. Wash laboratory ware in sink with hot water to remove residue.
3. Dry laboratory ware with clean paper towels.
4. Place clean paper towels on laboratory counter top.
5. Set ware on laboratory counter.
6. Fill glass pipette with 10 mL of ethyl anhydrous alcohol.
7. Rinse laboratory ware with the alcohol.
8. Swirl alcohol on all surfaces that contact leaf and soil samples.
9. Set laboratory ware on paper towels on counter to air dry.
10. Dry residual alcohol in or on ware with clean paper towels as needed.
11. Photograph steps of procedure.
12. Take notes of procedure process.
13. Repeat Steps 1 through 12 for all glass and plastic ware.
14. For the laboratory counter tops and weigh balance top, wash with wet paper towel, dry with paper towel, decontaminate with ethyl anhydrous alcohol on paper towel, and allow to air dry.

APPENDIX J

RADIOACTIVITY ANALYSIS PROCEDURE

Introduction:

The measurement of ^{137}Cs radioactivity in each leaf and soil sample was important to this study. The radioactivity in each sample was needed to determine if there is a significant difference between deciduous and evergreen foliage in the Comanche Steam Electric Station (CPSES) area. Each sample's gamma-ray emissions were measured in two HPGe detector systems. The sample spectra were analyzed for the ^{137}Cs and other major photopeaks.

Equipment needed:

1. HPGe well detector systems,
2. homogenized field leaf and soil samples in 500 mL Nalgene® bottles,
3. plastic 500 mL Marinelli Beakers with lids,
4. plastic funnel,
5. plastic spoons,
6. dust mask,
7. 1.3 cm (½ in) paint brush,
8. calculator,

9. camera,
10. computer,
11. computer graph application,
12. notebook, and
13. pen.

Steps to radioanalyze field samples:

1. Put on a dust mask.
2. Use a clean plastic spoon and a clean plastic funnel to transfer 500 mL of homogenized sample from Nalgene® bottle into a clean Marinelli Beaker.
3. Use a clean 1.3 cm (½ in) paint brush to transfer residue from the Nalgene® bottle.
4. Put a clean plastic lid on the Marinelli Beaker.
5. Perform an energy calibration of the HPGe detector systems.
6. Set the live time to 12 hours (720 minutes).
7. Place Marinelli Beaker with sample in the HPGe detector well.
8. Close lid to detector well.
9. Acquire a spectrum.
10. Adjust the vertical scale so that the photopeaks are easily distinguished.
11. Set the photopeak Region Of Interest (ROI to 10 channels).
12. Determine the net counts of the ^{137}Cs and major gamma-ray photopeaks.

13. Calculate the net counts per second for the photopeaks.
14. Repeat Steps 1 through 13 for each leaf and soil field sample using HPGe detectors Nos. 1 and 2.
15. Tabulate the data.
16. Photograph steps of procedure.
17. Take notes of procedure process.

Steps to calculate field sample net counting rate and standard deviation of the net counting rate:

1. Calculate the net counting rate using the following equation:

$$r_n = \frac{c_g}{t_g} - \frac{c_{bg}}{t_{bg}}$$

r_n = net counting rate

c_g = gross count

c_{bg} = background count

t_g = time during which gross count was made

t_{bg} = time during which background count was made

2. Repeat Step 1 for each leaf and soil sample using the respective ^{137}Cs radioanalytical data and HPGe detector background counting data.
3. Tabulate the data.

4. Calculate the standard deviation of the net counting rate using the following equation:

$$\sigma_n = \sqrt{\frac{r_g}{t_g} + \frac{r_{bg}}{t_{bg}}}$$

σ_n = standard deviation of the net counting rate

r_g = gross counting rate

r_{bg} = background counting rate

5. Tabulate the data.
6. Repeat Step 4 for each leaf and soil sample using the results from Step 1.
7. Take notes of procedure process.

Steps to calculate field sample ^{137}Cs radioactivity:

1. Calculate the concentration for the ^{137}Cs photon using the following equation:

$$A = \{[\left(\frac{R_{net}}{\varepsilon_\lambda \mathrm{I}_\lambda}\right) \times 27.027] \times DCF\} \times \frac{1}{2}$$

A = activity concentration (pCikg^{-1})

R_{net} = net counts per second in photopeak (cps 500 mL^{-1})

ε_λ = HPGe detector efficiency in counts per photon

I_λ = gamma-ray intensity in photons per disintegration (85% for ^{137}Cs 661.7 keV).

27.027 = conversion factor to pCi from cps.

DCF = density conversion factor (cm^3g^{-1}) from average composite leaf and soil densities.

$\frac{1}{2}$ = conversion of $pCi500g^{-1}$ to $pCikg^{-1}$

2. Repeat Step 1 for each leaf and soil sample using the radioanalytical data and respective HPGe detector counting efficiency.
3. Tabulate the data.
4. Plot the activity concentrations for each sample using a computer and graph software.
5. Take notes of procedure process.

APPENDIX K

STATISTICAL ANALYSIS PROCEDURE

Introduction:

After calculating the ^{137}Cs radioactivity of each leaf and soil sample, the activities were statistically compared. The sample mean, sample standard deviation, sum of samples, and the sum of the samples squared are some of the statistical measurements made with the sample data. The Modified Student's *t*-test was applied to compare the means between the foliage samples, between the soil samples, and between the foliage and soil samples. For the *t*-test, the sample variances were assumed to be equal and the sample distribution to be Gaussian.

Equipment needed:

1. Scientific calculator.

Steps to statistically analyze samples:

1. Calculate $|t|$ using the following equations of the Modified Student's *t*-test:

$$|t| = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$s^2 = \frac{1}{(n_1+n_2)-2}\left\{\left[\Sigma_1 x^2 - \frac{(\Sigma_1 x)^2}{n_1}\right] + \left[\Sigma_2 x^2 - \frac{(\Sigma_2 x)^2}{n_2}\right]\right\}$$

$|t|$ = Student's t statistic (absolute value)

$\bar{x}_1$ = Mean of first sample

$\bar{x}_2$ = Mean of second sample

s = Standard deviation estimate based on both samples jointly

n = Number of points in data set

s^2 = Variance

$\Sigma_1 x$ = Sum of measures of first sample

$\Sigma_2 x$ = Sum of measures of second sample

$\Sigma_1 x^2$ = Sum of the squares of first sample

$\Sigma_2 x^2$ = Sum of the squares of second sample

2. Compare the means of two small sample sets (unknown variances assumed equal) by setting a Null hypothesis and an alternate hypothesis.

$$H_0: \mu_1 = \mu_2$$

$$H_1: \mu_1 \neq \mu_2$$

H_0 = Null hypothesis

H_1 = Alternate hypothesis

μ_1 = Population mean or true mean, e.g. juniper

μ_2 = Population mean or true mean, e.g. broadleaf

3. Set the α to 5%, determine the df, and lookup the P in a *t* distribution table (one-tailed test) for the assigned α.

   α = Level of significance

   df = Degrees of freedom ($n_1 + n_2 - 2$)

   P = *t* probability for one-tailed test

4. Test the hypotheses by comparing the calculated $|t|$ to the P.

   If $|t| < P$, then H_0: $\mu_1 = \mu_2$ is tenable and the hypothesis is accepted.

   If $|t| > P$, then H_1: $\mu_1 \neq \mu_2$ is tenable and the hypothesis is rejected.

5. Tabulate the data.

6. Repeat Steps 1 through 5 for broadleaf vs. juniper samples, broadleaf soil vs. juniper soil samples, and all foliage samples vs. all soil samples.

7. Take notes of procedure process.

APPENDIX L

EQUIPMENT SPECIFICATIONS

The equipment and associated ware used in this study are listed below:

1. Marinelli Beakers with lids:

   GA-MA Associates
   Model no. 530G-E
   500 mL volume

2. Detector No. 1:

   EG&G Ortec® coaxial HPGe [relative efficiency of 10% vis-à-vis 3 x 3 NaI(Tl) crystal]
   Canberra Nuclear® NIM-BIN model 1400

3. Detector No. 2:

   Canberra Nuclear® coaxial HPGe [relative efficiency of 10% vis-à-vis 3 x 3 NaI(Tl) crystal]
   Canberra Nuclear® NIM-BIN model 1400

4. Canberra Nuclear® NIM-BIN model 1400 components:

   Canberra Nuclear® Amplifier 2011
   Canberra Nuclear® LN_2 Monitor 1786
   Canberra Nuclear® H.V. Power Supply 3105
   Nuclear Data Inc.® MCA No. 62

5. Precision Scientific Co.® electric drying oven:

   Serial No. 16M-3797
   Cat. No. 1475
   Temperature range up to 180 °C (356 °F)

6. Oster® Osterizer® 14 Speed Heavy Duty Blender

7. Sartorius® electronic weigh scale:

   Type F1355
   Serial No. 36090050
   Capacity range up to 60 kg (132 lb)

8. Sartorius® sensitive weigh scale:

   Capacity range up to 250 g (0.55 lb)

9. The Nucleus Company sealed gamma-ray check sources:

   Nominal 1 µCi ^{22}Na green disk
   Nominal 1 µCi ^{60}Co orange disk
   Nominal 1 µCi ^{57}Co orange disk

APPENDIX M

^{152}Eu STANDARD INFORMATION

Information from the National Institute of Standards and Technology (NIST) radioactivity solution standard certificate on the ^{152}Eu standard used in this study is listed below:

1. Radionuclide--------------------------------Europium-152
2. Source Identification ----------------------4370C
3. Source Description ------------------------Liquid in 5-mL flame-sealed glass ampoule
4. Source Mass--------------------------------5.0338±0.0019 grams
5. Solution Composition ---------------------277 μg Eu per gram of 1 M HCl
6. Radioactivity Concentration --------------9.390x10^{4} Bq g^{-1}
7. Reference Time ----------------------------1200 EST February 2, 1987
8. Overall Uncertainty------------------------1.1 percent
9. Photon-emitting impurities----------------^{154}Eu/^{152}Eu: (2.9±0.3)x10^{-3}
10. Half-Life -------------------------------------13.55±0.06 years
11. Solution Dilution---------------------------100 mL dilute HCl

APPENDIX N

ACRONYMS

The acronyms and their meanings used in this thesis are listed below:

ALARA	As Low As Reasonably Achievable
BL	Broadleaf
β	Beta-ray
Bq	Becquerel
CFR	Code of Federal Regulations
CL	Control Location
cm	Centimeter
cpd	Counts per Disintegration
cpm	Counts per Minute
cpp	Counts per Photon
cps	Counts per Second
CPSES	Comanche Peak Steam Electric Station
dbh	Diameter Breast Height
DCF	Density Conversion Factor
DOE	U.S. Department of Energy
dps	Disintegrations per Second
FSAR	Final Safety Analysis Report
γ	Gamma-ray
g	Gram
HPGe	High Purity Germanium
hrs	Hours
HS-4	Health Physics Measurement Group
H.V.	High Voltage
in	Inch
J	Juniper
kCi	Kilo-curies
keV	Kilo-electron Volts
km	Kilometer
KV	Kilo-volt
LANL	Los Alamos National Laboratory

LLD	Lower Limit of Detection
LN_2	Liquid Nitrogen
MCA	Multi-Channel Analyzer
MCi	Mega-curies
MeV	Mega-electron Volt
mi	Mile
MWe	Mega-watt electrical
MWt	Mega-watt thermal
mL	Milliliter
µsec	Microsecond
NIM	Nuclear Instrument Modules
NIST	National Institute of Standards and Technology
No.	Number
ODCM	Off-site Dose Calculation Manual
PP	Power Plant
ppd	Probability Per Decay
PWR	Pressurized Water Reactor
QA	Quality Assurance
QC	Quality Control
REMP	Radiological Environmental Monitoring Program
REMPAR	Radiological Environmental Monitoring Program Annual Report
ROI	Region Of Interest
SCP	Squaw Creek Park
TAMU	Texas A&M University
TU	Texas Utilities
USNRC	U.S. Nuclear Regulatory Commission
y	Year

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