RADON (RN-222) AND THORON (RN-220) EMANATION FRACTIONS FROM THREE SEPARATE FORMATIONS OF OIL FIELD PIPE SCALE

A Thesis

by

ERICH HAROLD FRUCHTNICHT

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

August 2004

Major Subject: Health Physics

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ABSTRACT

Radon (Rn-222) and Thoron (Rn-220) Emanation Fractions from Three Separate Formations of Oil Field Pipe Scale. (August 2004)

Erich Harold Fruchtnicht, B.S., Texas A&M University

Head of Advisory Committee: Dr. Ian S. Hamilton

Over the course of normal oil well operations, pipes used downhole in the oil and petroleum industry tend to accumulate a mineral deposit on their interior, which restricts the flow of oil. This deposit, termed scale, will eventually occlude the interior diameter of the pipe making removal from service and descaling a cost effective option. The pipes are sent to cleaning yards where they remain until descaling can be performed. This storage period can potentially create a health concern not only because of the external radiation exposure but also because of the radon gas emissions, both of which are due to the radioactive minerals contained in the scale. It was believed that the structure of the scale is formed tightly enough to prevent much of the radon from becoming airborne.

The goal of this research was to determine the emanation fractions for the rattled scale samples from three formations. A high purity germanium detector was used to measure the activities of the parents and progeny of radon, and electret ion chambers were used to measure the concentration of radon emanated from the scale. The emanation fractions of between 4.9×10^{-5} and 1.08×10^{-3} for radon were a factor of

approximately 100 smaller than previous research results. For thoron, the fractions were and 5.72×10^{-8} and 4.92×10^{-7} for thoron with no previous research to compare. However, information that pertains to the temperature dependence of emanation was included in this research and was not available for previous, similar research. Therefore, differences in the environment (e.g., temperature, humidity, etc.) in which the previous experiments were conducted, as well as differences in the scale formation types used, could account for the discrepancy.

In addition, measuring the emanation fractions of the rattled scale was a method of determining whether surface to volume ratio dependence existed. After acquiring the emanation fractions, insufficient evidence of any surface to volume ratio dependence could be found.

ACKNOWLEDGEMENTS

So many thanks are due Dr. Ian Hamilton for providing me with the opportunity to pursue a master's degree, and the guidance to see it to fruition. A special thanks is due my advisory committee. Dr. Poston, thank you for taking the time to trudge through the first few revisions of this paper. I always appreciate your constructive criticism. Dr. Marlow, thank you for taking the time out of your busy schedule to point me in the right direction on more than one occasion. Dr. McFarland, thank you for accepting the daunting task of checking over my procedure and proposal. They would not have turned out as well as they did without your input. Dr. Hartwig, thank you very much for donating your morning for my defense; you saved the day. I would like to state my immense appreciation for the all help that was provided me by my research partner Jason Cezeaux. Without him having laid so much of the groundwork needed for me to have even gotten started, I sincerely doubt that finishing in the proposed year would have even been possible. I also want to thank Robert Berry for being patient enough to let me bounce ideas off of him while I was trying to figure out how to practically approach this problem. Very special thanks to all of my friends who have been encouraging along the way; I wish the best for all of you. Lastly, but definitely not least, no acknowledgement could be complete without sending my deepest and sincerest thanks to my family for having faithfully kept me in their prayers throughout my entire adventure in college both undergraduate and graduate.

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INTRODUCTION

Formation of a mineral crust, known as pipe scale, on the interior of a pipe is a natural result of oil field-well operations. This scale results from the deposition of minerals present in the crude oil. Throughout the operational lifetime of the pipe the scale thickness increases and eventually begins to adversely affect the flow of the crude oil through the pipe, or tubular. At this point, it becomes cost effective to remove the tubular from operation and place it in storage until such time that the pipe can be descaled, if practical, and redeployed when needed. It is during these storage and cleaning processes that a radiation exposure concern arises. A portion of the minerals deposited in the scale is radioactive because of the presence of naturally occurring radioactive materials (NORM) in the earth's crust. Thus, there exists a potentially radioactive environment at pipe storage yards because of this radioactive scale within the pipes.

Primarily, radionuclides deposited as pipe scale are the progeny of the uranium and thorium decay series, starting with the isotope of radium characteristic of each chain. Radon, a progeny of radium in both decay series, is a concern not only because it is radioactive and produces radioactive progeny, but also because it is a monatomic, noble gas and, as such, is able to diffuse through nearly anything to become airborne very easily.

This thesis follows the style of Health Physics.

To determine the level of attention that should be given to the radon gas environment around and within a pipe storage yard, it is necessary to determine the amount of radon, if any, that is able to escape the structure of scale grains to become airborne. This quantity of escaped radon, when compared to the amount of radon that remains within the scale, is referred to as the "radon exhalation fraction" or the "radon escape fraction." Another popular term that has been used is the "radon emanation power," usually denoted by the greek letter epsilon, ε. The emanation power is synonymous with the radon emanation rate, and differs from the emanation fraction only in that the fraction is equivalent to 1-ε (Bossew 2003). The emanation power, or rate, could be determined from the results given in this report. However, the emanation power was not the desired result and was not computed. The desired end result of this research was to obtain the radon and thoron emanation fractions from each of three chosen formations of rattled pipe scale. These data aid in a determination of the health risks associated with working in and around stored petroleum tubulars.

Pipes from three separate formations in the southeastern US were used for this experiment. These formations types were referred to as "Lake Sand," "Mud Lake," and "West Delta." Of these formations, West Delta generated the highest detectable surface gamma exposure rate, while Lake Sand generated the lowest rate.

Pipes were descaled, also referred to as rattling, using a circa 1970s open-air rattling machine. The emanation fractions of ground up scale scattered by the rattling process were the desired results because they would help estimate the radon concentration in the work environment during that period. The 1970s work environment

was chosen for investigation because that is a time period during which the dry rattling process was used to descale tubulars.

BACKGROUND

PIPE SCALE FORMATION

During their operational lifetime, oil field pipes go through many cycles of use, occlusion, removal from service, storage, cleaning, and re-introduction to service. In each one of these cycles the same pattern repeats itself. In the first stage, the pipes are used to extract crude oils and gasses from deep within the earth's crust. It is during this stage that what is known as "pipe scale" forms on the interior, and sometimes the exterior, of the pipes because of the geochemical processes related to the water produced by the extraction. As the thickness of the scale increases the oil and gas flow is restricted more and more until a thickness is reached at which time it is more cost effective to remove the pipes from service and clean them. The pipe is removed from service once the pipe scale reaches a thickness that begins to occlude the flow of crude (see figure 1), and taken to a storage yard where it will remain until descaling can be performed.

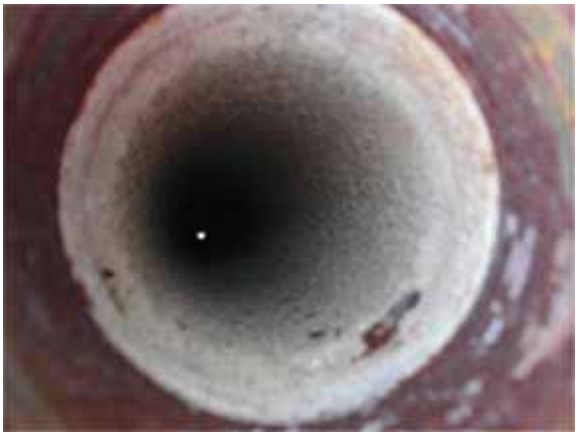

Fig 1 - Scale formation on the interior of an oil field tubular

The pipe, once descaled, may be returned to service in an oil well and the above cycle repeats until the pipe is no longer structurally sound.

Pipe scale is formed due to geochemical reactions that occur when water interacts with the rock formation around the subsurface oil reservoir. Water enters the subsurface oil reservoir either from injection well operations or through the surrounding rock due to the lower pressure in the reservoir from the oil being extracted. Injection well operations involve water that is injected into a reservoir to pressurize and float oil to the top of the subsurface cavity to make it easier to extract. Water can also seep through the surrounding rock formations, dissolving certain minerals and salts, because a negative pressure within the oil reservoir can draw it from the subsurface water table. In either case, the naturally occurring radium in the rock formation containing the oil can be dissolved by the water, which when coprecipitated with barium, strontium, and/or calcium sulfates, may form a hard mineral crust on the interior of any equipment involved in handling the extracted oil or the separated waste water (Smith et al. 1996). Radium is available for dissolution because of the presence of its precursors, uranium and thorium, which are in localized mineral deposits known as uranium provinces. The uranium and thorium in these mineral deposits are generally in an insoluble form as compared to radium. The radium progeny in the decay series, however, can be ejected into the oil reservoir when the parent nuclide decays, or they can be dissolved when they come into contact with either the waste or injected water (Hamilton et al. 2004).

NORM IN PIPE SCALE

A radioactive environment may exist at pipe storage yards because of the potentially large number of tubulars in storage. If each pipe is taken out of service because of the buildup of scale, and since the scale itself has a NORM component, there exists the possibility for a radiation level in the pipe yard that is above natural background (Bassignani et al. 1991). Another concern is that of exposure to an airborne radioactive element common to both the uranium and thorium decay series: radon. Radon is an intermediate product of the decay series of natural uranium, ^{238}U and ^{235}U, and natural thorium, and may be present wherever these radionuclides are present (see figure 2).

Radon is of particular interest because it is a monatomic gas and it can very easily diffuse throughout the environment in which it is present. Radon has a high affinity for water and can be readily absorbed by any ambient moisture, making transport relatively easy. It is the potential for inhalation of gaseous radon and more so its solid, radioactive progeny (i.e., bismuth, polonium, and lead) that fostered additional concerns about possible personnel doses that could result from working in and around pipe storage yards.

The presence of thorium series nuclides in the pipe scale means that ^{222}Rn would not be the only isotope of radon that should be considered. This created the need to measure the concentration of ^{220}Rn, as well as ^{222}Rn, for a more complete analysis of the ability of the radon to escape the scale formation (see figure 2). ^{219}Rn, also known as

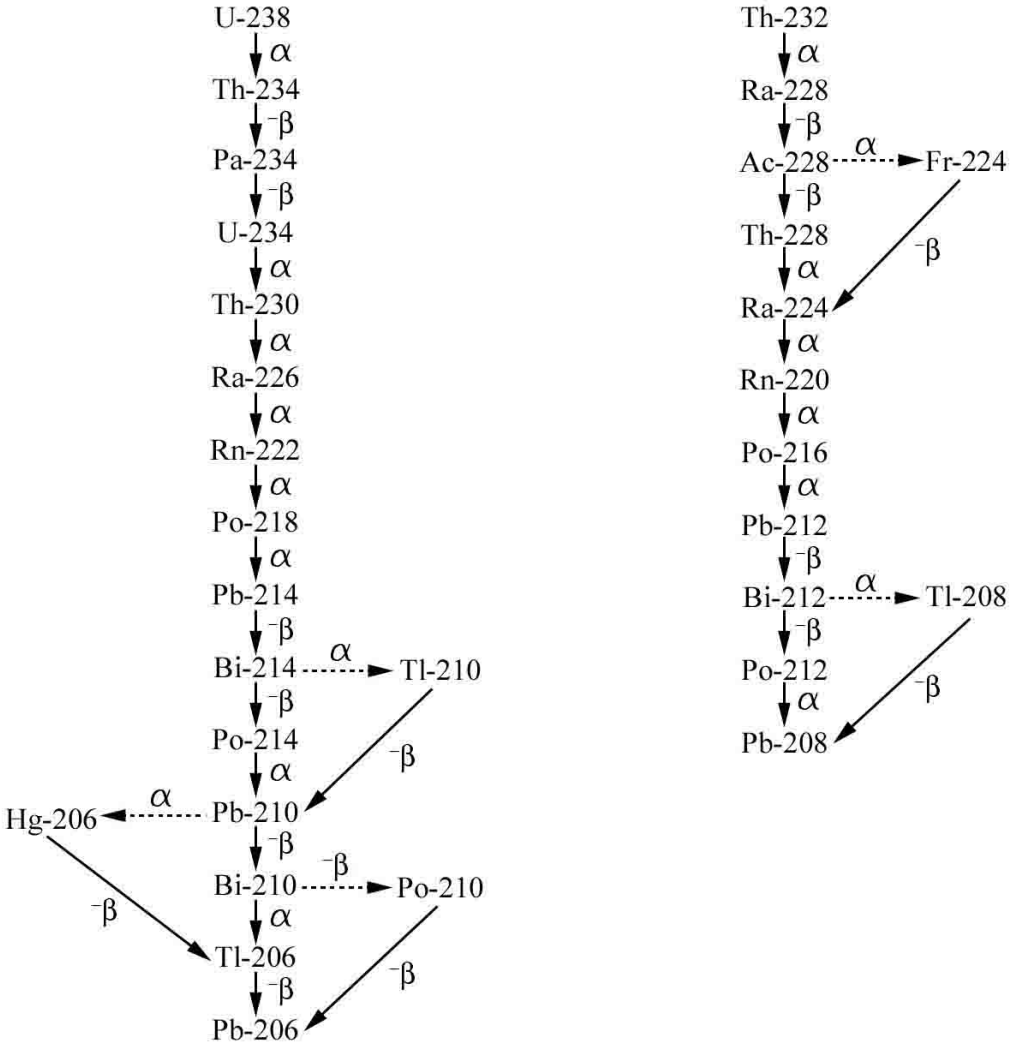

Fig 2 - Uranium and thorium decay series and decay methods

(Dotted lines indicate those decay modes that occur with lower yields)

actinon, and a product of the ^{235}U series, was not considered because its half-life is 3.96 seconds; therefore, it would decay too quickly to be a significant contributor to the total radon exhalation rate.

Historically, ^{220}Rn was referred to as thoron since it results from the thorium decay series while ^{222}Rn has been referred to as radon. Similarly, ^{219}Rn was referred to as actinon since it is a member of the ^{235}U decay series; the historical name for ^{235}U was actinouranium (Columbia Encyclopedia 2003). In this thesis the word "thoron" will henceforth be used to refer to ^{220}Rn and "radon" to ^{222}Rn.

To create the ^{222}Rn and ^{220}Rn gas environment, the ^{222}Rn and ^{220}Rn must first escape the structure of the scale and become airborne. The density of pipe scale, usually around 2.6 g cm^{-3}, is such that the amount of radon able to escape through the pore spaces is generally very low (Smith et al. 1996). Past research has reported very low emanation fractions of ^{222}Rn and ^{220}Rn: in the range 0.02 to 0.063 (Rood et al. 1998). However, a different method was employed to acquire those values. Activated carbon filters were used along with a moisture saturated nitrogen wash to collect all emanated radon. Although there were differences in the collection method, in accordance with the previous research, it is still expected that the emanation fractions of ^{222}Rn and ^{220}Rn will be very small. This would imply that the potential for any equivalent dose related to radon and thoron inhalation would be minute.

THEORY

ELECTRET ION CHAMBERS

This entire experiment relied on the passive radiation detection system known as the electret ion chamber (EIC). The EIC is comprised of two elements: a positively charged Teflon® plate mounted on a conducting plastic disk (see figure 3), called an electret, and the electrically conductive plastic ion chamber into which the electret is mounted.

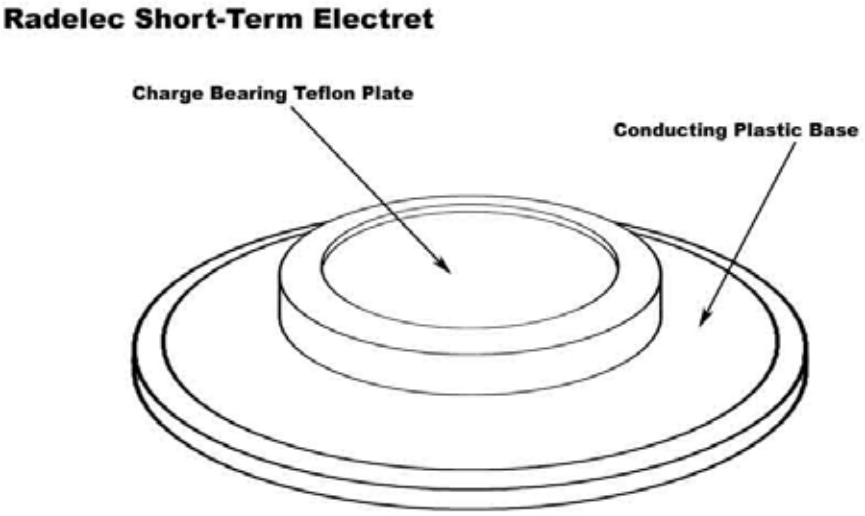

Fig 3 - Electret schematic

An electret is a piece of Teflon® that was heated in the presence of an electric field and cooled rapidly to preserve the orientation of the dipoles in the material. This process can create voltage differences between the two sides of the Teflon® plate with magnitudes up to 1000 V. When the electret is inserted into the ion chamber its positive

charge will create an electric field throughout the chamber volume because of the voltage difference between the electret and the walls of the chamber. The electric field in the chamber will draw negative ions from within the chamber toward the Teflon® plate (electret) thus discharging it slightly and reducing the aforementioned voltage difference (Knoll 1999).

As mentioned above, the electret ion chamber works on the principle that governs charged-particle interactions. Alpha particles emitted by the decay of radon atoms within the chamber are not detected directly. Rather, their presence is detected indirectly by sensing the electrons that are stripped from the atoms in the air molecules as they pass by (DOE 2000). These electrons are the charged particles that are responsible for the neutralization of the positive charge on the electret, and the neutralization (voltage drop) is proportional to the radon concentration in the EIC environment (see figure 4).

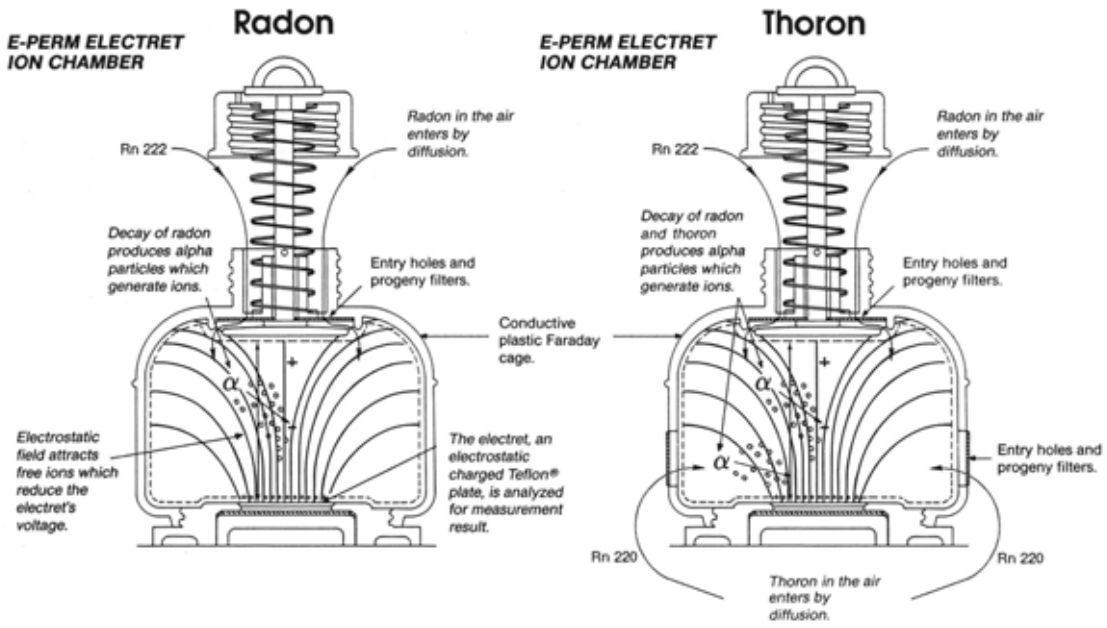

Fig 4 - Radon and thoron chamber schematic

The emitted alpha particles have a high specific ionization and will ionize large numbers of atoms along their paths through the ion chamber. The alpha particle will interact with many atoms before it collides with the ion chamber wall or acquires two electrons and becomes a stable helium atom.

Data are collected from the electrets using of a non-contact voltage reader. The electret voltage is measured before deployment and again after retrieval. The resulting voltage change determines how much of the initial charge was neutralized by ions created by the alphas particles emitted within the chamber volume.

Not all electrons are generated within the sensitive volume of the chamber. However, there is an established relationship to account for these lost ionizations by Rad Elec and NIST.

Since the experiment involved detection of two separate isotopes of radon, there were two distinct ion chamber types employed. The Rad Elec Radon standard or "S"-chamber, and the Rad Elec Thoron "S"-chamber (see figure 4) were chosen because of their effectiveness and ease of use. Both ion chambers employ a special filtration material that prevents large particulate, radioactive progeny from entering the chamber. However, isotopes of gaseous radon and thoron may enter the internal air volume. This special material, known as Tyvek®, is

> made from very fine, high-density polyethylene fibers, Tyvek® brand protective material offers all the best characteristics of paper, film and fabric in one material. This unique balance of properties, which cannot be found in any other material, makes Tyvek® lightweight yet strong; vapor-permeable, yet water-, chemical-, puncture-, tear- and abrasion-resistant. Tyvek® is also low-linting, smooth and opaque. (DuPont 2004)

Radelec has modified the Tyvek® filter material by adding a carbon coating which, "allows passive entry of both radon and thoron into the chamber (Rad Elec 2004)," while still providing a barrier to any other particles that might enter the ion chamber volume and cause inaccuracies in the measurements.

The major difference between the two chambers pictured above is the addition of entry ports and progeny filters, carbon coated Tyvek®, around the side of the thoron chamber. These extra entry ports allow the shorter-lived thoron to enter the chamber at a lower altitude in the jar. The reasoning behind the side entry ports is that the ^{222}Rn has a long enough half-life, 3.823 days, that it will have sufficient time to diffuse throughout the sample chamber and into the radon S-chamber, which consequently has only one entry port on top, while the ^{220}Rn, with a half-life of 55.6 seconds, may have decayed

away long before having diffused enough to have reached the top entry port. With the side ports, however, the ^{220}Rn has a higher probability of entering the chamber volume and decaying within the chamber while the radon response remains unaffected. Therefore, to obtain the emanation fractions for both ^{222}Rn and ^{220}Rn, one must employ both the radon and thoron S-chambers. A simple subtraction of the total voltage drop on the radon chamber electret from the voltage drop on the thoron chamber electret will result in the voltage reduction due solely to thoron decay.

SECULAR EQUILIBRIUM IN THE SCALE

It was necessary to know how much of the generated ^{222}Rn and ^{220}Rn remained within the structure of the scale to determine the emanation fractions for the ^{222}Rn and ^{220}Rn. To acquire the fraction of ^{222}Rn and ^{220}Rn that remained trapped in the scale, a high purity germanium (HPGe) detector was employed. The HPGe detector was used to determine the activities of the parent isotopes of radium present within each scale sample.

Determining the activities of the parent radium allows the activities of the generated ^{222}Rn and ^{220}Rn to be determined. This can be accomplished because secular equilibrium existed between the nuclides in the decay series. Proving that secular equilibrium existed was useful because, by the definition of secular equilibrium, it could be said that the progeny, ^{222}Rn and ^{220}Rn, were of equal activities to their parents, ^{226}Ra and ^{228}Th. To prove that secular equilibrium existed, the following equations were used (Attix 1986):

$$t = \frac{\ln(\lambda_2/\lambda_1)}{\lambda_2 - \lambda_1} = t_m, \quad \textbf{(1)}$$

and

$$\frac{\lambda_2 N_2}{\lambda_1 N_1} = \frac{\lambda_2}{\lambda_2 - \lambda_1}, \quad \textbf{(2)}$$

where:

$\lambda_2 N_2$ – activity of the daughter nuclide;

$\lambda_1 N_1$ – activity of the parent nuclide;

λ_2 – decay constant of the progeny in days^{-1};

λ_1 – decay constant of the parent in days^{-1};

t – time in days; and

t_m – time in days at which the progeny activity is at a maximum.

Both activities should be stated in the same units and the units of time should reflect the units used in the decay constants (e.g., if λ – [d^{-1}] then t – [d]). These equations were used for both the uranium and thorium decay series. In both series, the decay of the radium parent, ^{226}Ra or ^{224}Ra, results in only one progeny, ^{222}Rn from ^{226}Ra and ^{220}Rn from ^{224}Ra. Equation (1) was used to determine the time at which a state of secular equilibrium began. By using equation (1), it was determined that a state of secular equilibrium would occur after 65.87 days for the ^{226}Ra to ^{222}Rn decay and after 11.56 minutes for the ^{224}Ra to ^{220}Rn decay. When equation (2) was applied, secular

equilibrium was found to occur within an accuracy of 0.0007% for the decay of ^{226}Ra to ^{222}Rn (radon), and to within 0.0176% for the decay of ^{224}Ra to ^{220}Rn (thoron). In other words, the activities of the ^{222}Rn and ^{220}Rn were found to vary from their parent activities by only 0.0007% and 0.0176%, respectively. This served to confirm that the state of equilibrium would exist. Since the scale was present in the pipes for several months to years before any experimental work was performed, it could be said with confidence that secular equilibrium existed within the pipes.

RADON PROGENY EQUILIBRATION

Having established that secular equilibrium existed within the pipes themselves did not, however, imply that equilibrium existed within the individual samples taken from the pipes. The equations listed above make the assumption that there is no nuclide present at the start time other than the parent, which of course could not be so since the samples came from the pipes in which a great deal of the parent, radium, and its subsequent progeny would have already decayed.

The original plan for carrying out this experiment involved following a United States Air Force radiochemistry procedure. This procedure made the assumption that there was a preexisting concentration of progeny present within each sample. This procedure, employed by personnel at Brooks Air Force Base Armstrong Laboratory, recommended allowing the individual samples to remain sealed for a period of twenty-eight days to allow for secular equilibrium to be re-established within each sample (Galarza 2003). However, due to scheduling set backs and problems with the

availability of equipment, the samples remained sealed in individual jars for a period much longer than 65.87 days. The jars were sealed on 21 January 2004 and not opened until 26 May 2004, a total of 121 days. Therefore, there was no doubt that secular equilibrium was established between the radium parents and their progeny.

VIRTUAL EFFICIENCY CALIBRATION USING LabSOCS

It was advantageous to use the HPGe detector because the activities of the ^{222}Rn and ^{220}Rn could be determined by measuring the activities of the parent nuclides and the ^{222}Rn and ^{220}Rn progeny by detecting their characteristic gamma-ray emissions. However, the activity could be determined accurately only when an efficiency calibration could be performed on the HPGe detector using a known standard of the exact geometry, density, and atomic composition of the samples. This led to the use of a program known as LabSOCS, which is a detector-simulation program designed to create virtual standards and perform a virtual efficiency calibration with an accuracy equivalent to having a real standard of the needed characteristics. This virtual standard was necessary because of the non-standard shape of the jars relative to other counting geometries in which the samples were sealed, and the density and composition of the scale.

The elemental composition of the scale and the jars themselves was required to create the virtual standard of the sample jars. X-ray Fluoroscopy (XRF) was used to determine the composition of the jar lids and to acquire an approximate composition of the scale itself. The composition of the glass in the jar was taken to be soda-lime glass

since that type makes up over 90% of all commercially used glass (www.glassonweb.com 2004). The LabSOCS software included a preset composition for common glass, which was verified to be soda-lime glass by comparing the compositions in the software materials editor.

PROCEDURE

SAFETY AND LABORATORY CONSIDERATIONS

The following materials, instrumentation, and methods were used to collect data for the determination of the fractions of generated ^{222}Rn and ^{220}Rn that escaped the pipe scale samples.

As with the handling of any radioactive material, there were safety issues that were addressed prior to beginning the experiment. It was recommended that everyone involved in the experiment have at least a basic understanding of radioactive materials and the risks associated with handling them. To this end, there were certain requirements to be met when selecting a laboratory in which to conduct the experiment.

A large lab with a high air-change rate was strongly recommended to prevent airborne concentrations of the ground-up pipe scale samples, or ^{222}Rn and ^{220}Rn and their progeny, from reaching potentially hazardous levels when air washing the samples. A large lab bench on which to work was of paramount importance because of the large size of the equipment and the large number of EICs used in this experiment.

There were also important considerations regarding the lab equipment. Each component was checked for radioactive contamination before beginning the experiment since some of the equipment had been used previously. It was important to check the equipment because any radioactive contamination could alter the final results. Since the entire experiment relied on natural gaseous diffusion to take place, it was critical that the

equipment be disturbed as little as possible during use so as not to alter the gas distribution.

In this experiment, there was special concern as to the size of the ground-up pipe scale particles and the depth to which they could be inhaled into the respiratory system. Therefore, care was taken to ensure that the ground-up scale samples remained sealed until use. Remaining sealed also prevented any radionuclides from becoming airborne due to self-dispersion. The samples also were prevented from becoming airborne when in use by taking care not to pour them out too vigorously as some grain sizes were conducive to deep respiratory inhalation and may have been a chemical hazard.

MATERIALS AND INSTRUMENTATION

Specialized equipment was required to accurately determine the emanation fractions of both ^{222}Rn and ^{220}Rn. To conduct the experiment efficiently, twelve Rad Elec 4-liter glass, sealable jars were procured (one for each of the grain sizes of each formation). Twenty-two radon standard ("S") chambers, twenty-two thoron "S" chambers, and an accompanying forty-four short-term electrets were obtained so that all samples could be run simultaneously. Short-term electrets were used because of their increased sensitivity and the small deployment times involved in this experiment. Two NIST 5 Bq ^{226}Ra/^{222}Rn emanation sources (see Appendix H) were acquired to allow two sets of electret calibrations to be run concurrently. Additionally, twelve 2 oz. re-sealable jars were used to store each of the separated samples for the equilibration process.

String was used to tie two “S” chambers together so that one would hang below the other, but not rest on the bottom of the jar (see figure 5).

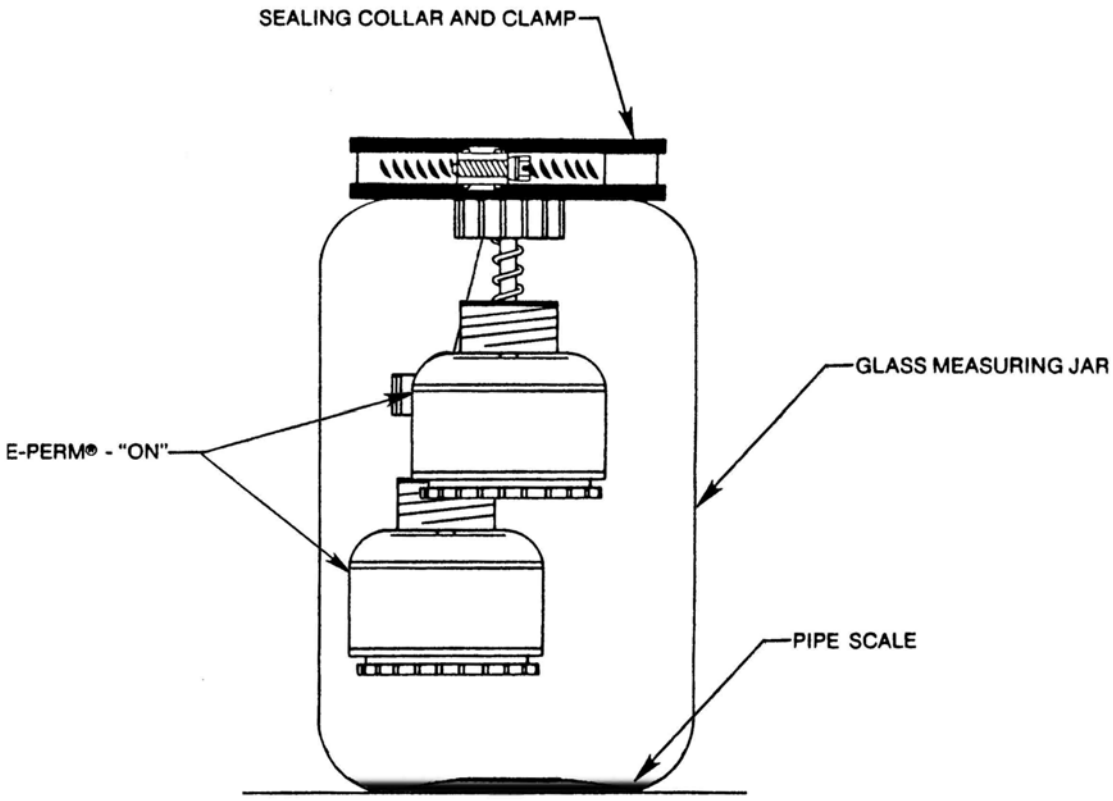

Fig 5 - Schematic of EICs in 4-liter jar

A 0.5-liter marinelli beaker radiation standard was needed to acquire an energy calibration for the HPGe detector and to be used for comparing an actual efficiency calibration to the virtual LabSOCS calibration.

The following instrumentation was used in the analysis and calibration procedures involved in this experiment. A portable hygrometer was acquired for determining the relative humidity of the laboratory as well as the outdoor humidity. To

read the initial and final electret voltages, a calibrated electret reader was acquired from Rad Elec. A computer with a Pentium II processor and Windows 98SE, Canberra GENIE PC 2000 spectroscopic software, and LabSOCS virtual calibration software was needed to operate the HPGe detector and its accompanying Canberra Inspector portable multi-channel analyzer (MCA). Finally, a laboratory balance accurate to one one-hundredth of a gram was needed to measure the mass of each individual scale sample.

It was important to keep the environment that the scale was exposed to as similar as possible to that of the storage yard in which the pipes would be stored since this experiment was intended to determine the emanation fractions of pipe scale when at the yard. Therefore, it was imperative to store the scale in sealed containers at all times to prevent the scale from drying out any more than it would have if it were outside at the storage yard. Keeping the scale sealed ensures that moisture content of the air, and by default the moisture content of the scale, inside the container would not change over the equilibration period, which would allow the emanation fractions to reflect the proper emanation environment.

SETUP

The first step taken in the sample preparation was to divide the scale according to grain size and formation type. A trial-and-error approach was used to determine the mass of each sample. A thin layer of scale just able to cover the bottom surface of the 4-liter glass jars was desired because that would reduce the probability of radon escaping from its scale grain only to get trapped by the other grains piled on top. Therefore,

differing quantities of scale were measured and poured into the 4-liter jars until the desired thinness of the scale layer was found. This quantity of scale was then rounded to 10.00 grams for ease and consistency of measurement.

Particle sizes greater than 297 microns, between 297 and 105 microns, less than 105 microns, and mixed, or general bucket, were chosen because those grain sizes were the most convenient to use having already been separated by sieving. None of the scale was ground up into smaller grain sizes. The sieving only separated those size particles that had been created by the descaling process (see figure 6).

Fig 6 – Descaling process with scale being ejected by rattling machine

Differing scale sizes than those employed here could also have been used without any modification of this procedure. A grain size distribution was established because there was interest in determining whether or not there was any variation of emanation fraction with surface to volume ratio.

RADON PROGENY EQUILIBRATION AND MEASUREMENT

With the intent of keeping equipment costs to a minimum while also providing a geometry that would fit within the HPGe detection cell used later on, 2oz. re-sealable glass jars were used as the containers in which the separated scale samples were stored for equilibration (see figure 7).

Fig 7 - Scale samples sealed for equilibration

Although the nuclides within the scale had reached a state of secular equilibrium within the pipe, the effect of rattling the scale may have disrupted the localized equilibria. Therefore, each individual scale sample had to be allowed to re-equilibrate before an accurate determination of the nuclide activities could be acquired. After the re-equilibration, or in-growth period, the radium, ^{222}Rn and ^{220}Rn, and their progeny should have re-established the equilibrium relationship between them. As discussed previously,

the original intent was to use the procedure for ^{222}Rn sample re-equilibration of storing the sample in a sealed container for 28-30 days as established by the Brooks Air Force Base procedure. However, the jars were sealed for far longer than the required 65.87 days. Thus, secular equilibrium was guaranteed to exist.

Once the in-growth procedure was completed each jar was placed in the HPGe detection cell for nuclide and isotope characterization. The 0.5-liter marinelli standard was used to acquire an energy calibration prior to counting the samples. The energy calibration was re-acquired after counting every two samples to ensure any effect of gain-drift in the detection system was minimized. The Canberra GENIE PC 2000 software package for isotopic characterization was used with an HPGe detector to generate an energy spectrum from which the nuclides present in the scale were determined. A 12-hour count time optimized the nuclide identification with the standard and, therefore, 12-hour count times were used throughout the sample counting procedure. Each generated spectrum was saved with a unique name corresponding to the formation type and grain size so that an efficiency calibration could be applied retrospectively. However, another step remained before the activities of the identified nuclides could be determined.

LabSOCS VERIFICATION AND VIRTUAL STANDARD CREATION

The Canberra software can be used to create a nearly exact MCNP-based computer model of any given HPGe detector. This model can be used in conjunction with LabSOCS and GENIE PC 2000 to simulate a standard for virtual efficiency

calibrations when a standard of the required characteristics could not be easily obtained. Each detector characterization is unique to that detector and works well enough that the use of a real standard is no longer necessary. However, to verify the accuracy of the characterization, a real 0.5-liter marinelli beaker standard was used to obtain a spectrum and perform an efficiency calibration. Once the real efficiency calibration had been applied and recorded, a virtual 0.5-liter marinelli beaker standard was created to duplicate the characteristics of the real one. This virtual standard was used to efficiency calibrate another 12-hour spectrum taken from the same real, 0.5-liter marinelli. The resulting activity and the error were compared to show that the virtual efficiency calibration worked as well as the real one. Thus, the use of the LabSOCS characterization was validated.

Information about the compositions and densities of the samples was required to create the LabSOCS standard. This information was obtained using a combination of XRF and carbon tetrachloride displacement. XRF was used to confirm the suspected predominant barium, strontium, and calcium sulfate composition of the scale and to determine that the jar lid composition was mostly iron and tin, with some manganese and chromium. Carbon tetrachloride displacement was used to determine the densities and individual grain sizes of scale from each formation. On average, the sample densities agreed with the expected value of 2.6 g cm^{-3} (Smith et al. 1996). However, the smaller the grain size the higher the density became with a maximum value of almost 3.6 g cm^{-3}. LabSOCS was used to create a virtual standard of the glass sample jars with a similar density, geometry, and composition. This virtual standard was used to provide an

efficiency calibration for determining the activities of the radium, bismuth, lead, and actinium in each sample.

It was necessary to determine the activities of bismuth, lead, and actinium because doing so would provide data with which to verify the activities of ^{226}Ra and ^{224}Ra. Different isotopes of the same nuclides were used in the activity verifications of ^{226}Ra and ^{224}Ra. Ra-226 was detected directly and its activity was used with the activities of ^{214}Bi and ^{214}Pb to create an average activity. Ra-224 did not appear as a statistically useable peak and the activities of ^{212}Bi, and ^{212}Pb were used to determine its activity. These radium activities were used to determine the respective ^{222}Rn and ^{220}Rn activities.

ELECTRET CALIBRATION

The first step in using any EIC for research purposes was to obtain the individual calibration coefficients for each electret. These coefficients indicated the voltage response of that particular electret to a known ^{222}Rn environment and allowed for calculation of the experimental ^{222}Rn concentration. It was not possible to calibrate the electrets for their response to ^{220}Rn as a pure thoron environment is nearly impossible to obtain. It was suggested by Dr. Paul Kotrappa of Rad Elec and NIST that as long as the ^{222}Rn calibration coefficients are near the suggested value range of 0.95 to 1.10 that the same coefficient can be applied to the ^{220}Rn sensitivity (Rad Elec 1994).

It was necessary to procure a ^{226}Ra/^{222}Rn emanation standard from NIST to obtain the calibration coefficients. These standards were only 4 to 5 Bq with an

emanation fraction of around 85% (see Appendix H), and included the NIST/Rad Elec procedure for obtaining the calibration coefficients. It was also necessary to acquire at least two 4-liter sealable glass jars (these came included with the calibration package) and a calibrated electret reader.

The NIST emanation standard was affixed to the interior of one of the 4-liter jars and it and the other jar (this would be used for the measurement of background) were left open to room air to air wash for a period of at least two days. After this, the calibrated electret reader was used to obtain initial voltages on the electrets that would be used (the NIST procedure provided volume corrections for the number of EICs used in each jar during the calibration; for this experiment two EICs were used per jar). The electrets were read by placing them in the aperture of the reader and pulling down on and holding the side lever for at least two seconds or until the voltage value stabilized (see figure 8).

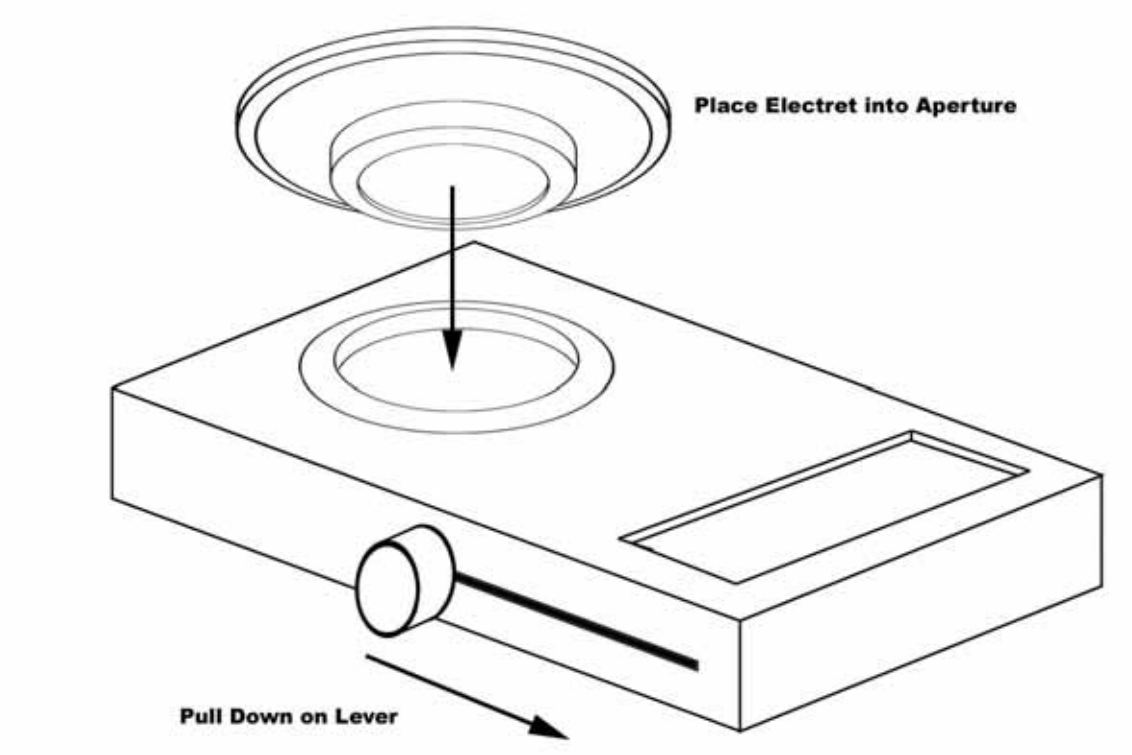

Fig 8 - Diagram demonstrating electret reading process

The reading procedure was repeated three times for each electret to establish an average voltage reading. One EIC was attached to the other by tying a string from the hanging loop of one to the hanging loop of the other. The electrets were attached to their respective EICs, and the top caps of the EICs were unscrewed to open them to the environment (the EIC configuration with the top unscrewed is the "on" configuration of the EIC as shown in figure 5). The EICs were inserted into their respective jars with one of the EICs hanging from the clip attached to the underside of the lid. The lid was screwed onto the jar until it fit snugly. A rubber sealing-gasket was fit around the rim of the lid and tightened (see figure 5).

This assembly was left undisturbed for approximately three days, at which point the EICs were removed. Before disassembling the EICs to read the electrets, they were allowed to air out for three hours in the "on" configuration (Rad Elec 1994). Each electret was removed and read using the electret reading procedure described above. The final voltages were recorded and used in the following equations to obtain the measured ^{222}Rn concentration in pCi/L:

$$CF = A + B \cdot \left(\frac{(I + F)}{2} \right) \quad \textbf{(3)}$$

$$C_m = \left(\frac{(I - F)}{CF \cdot T_A} \right) - BG \quad \textbf{(4)}$$

and,

$$BG = \left(\frac{(I - F)}{CF \cdot T_A} \right) \quad \textbf{(5)}$$

where:

CF – the general calibration factor in units of $\left[\frac{volts}{\frac{pCi}{L} \cdot day} \right]$ based on the voltage response;

A,B – constants for particular electret configuration (provided by Rad Elec);

I,F – the initial and final electret voltage in units of volts;

BG – the background radon and ambient gamma exposure effectively in pCi/L; and

C_m – the measured radon concentration in pCi/L after deployment time T_A in days.

The constants A and B were taken to be 1.69776 and 0.0005742 respectively from the NIST/Rad Elec procedure for electret calibration with short-term electrets in "S" chambers (Rad Elec 1994). The expected ^{222}Rn concentration was calculated using:

$$C_{Rn} = \frac{\frac{fA_{Ra}}{V_A}\left(1 - \frac{1 - e^{-\lambda_{Rn}T_A}}{\lambda_{Rn}T_A}\right)}{37} \qquad \textbf{(6)}$$

where:

f – fraction of ^{222}Rn released (provided by NIST in the source information sheet);

A_{Ra} – ^{226}Ra activity in Bq;

V_A – volume of the accumulator in m^3 (provided by Rad Elec, and depends on how many EICs are used);

λ_{Rn} – decay constant of ^{222}Rn in units of $days^{-1}$; and

C_{Rn} – average ^{222}Rn concentration in pCi/L after time T_A.

The volume of the accumulator, or jar, was taken to be 0.00372 m^3 from the NIST/Rad Elec procedure for electret calibration (Rad Elec 1994). Division by a factor of 37, as seen in equation 6, incorporated all the unit conversions needed to convert the original result of Bq m^{-3} into a far more convenient pCi L^{-1} for comparison to the activities determined using GENIE PC 2000.

The ratio of measured to expected ^{222}Rn concentrations, equation 7, yielded the ^{222}Rn calibration correction factor (Rad Elec 1994):

$$CF_{NIST} = \frac{C_m}{C_{Rn}} \qquad \textbf{(7)}$$

where:

CF_{NIST} – the individual calibration factor of the electret.

This calibration procedure was repeated for every electret used in the experiment. Although the electrets used to provide background readings were not calibrated, the error difference between their readings and those of the electrets being calibrated was small and would cancel out in these equations (Kotrappa 2004).

EMANATION FRACTION PROCEDURE

The first step to obtain the ^{222}Rn and ^{220}Rn emanation fractions was to open the sample jars to humid room air so as to wash off any ^{222}Rn or ^{220}Rn that might have deposited on the surface of the scale sample itself (Rood et al. 1998). This is called "air washing." It was important that the room air be humid enough to simulate the outdoor air conditions in which the pipes would have been stored. A hygrometer was used to measure the humidity outdoors and inside the lab and the relative humidity was found to be 68% and to vary from 52% to 68%. A relative humidity of between 52% and 68% ensured that the scale would not dry out more than if it were stored in the pipe yard. Therefore, the measured emanation fractions would reflect those of the pipe scale stored at a yard.

Another consideration was the dependence of radon emanation on scale temperature. The laboratory temperature was kept at approximately 20 degrees Celsius with a 1 to 2 degree Celsius variation over the course of the experiment.

The variation of radon emanation with both temperature and humidity has been well documented in the past and care was taken to remove as many variables that could adversely affect the emanation fractions as possible (Iskandar et al. 2004).

The samples were allowed to air wash for two days before beginning the sample emanation fraction measurements. After air washing, the EICs were carefully lowered into the 4-liter glass, sealable jars and each scale sample was slowly poured onto the convex bottom of the larger jar. A perfectly even distribution of scale across the bottom of the jar would have been ideal but, given the convex design of the bottom of the 4-liter jars, it was not possible to get a very uniform sample layer. However, this non-uniform layer simulates the random deposition that would occur in a pipe storage yard, and aided in the accurate simulation of the work environment.

To determine the activity of the emanated ^{222}Rn, the procedure described above for reading and mounting the electrets and EICs in the 4-liter jars was followed. However, in this case it was imperative that the lower of the two electrets not touch the bottom of the jar as that might have trapped some of the radon and artificially lowered the activity of emanated ^{222}Rn or ^{220}Rn. The jars were sealed and left undisturbed for a period of three days (Rood et al. 1998). After this period, the EICs were removed and the electrets read in the same manner as before. The procedure was repeated for each formation and grain size until all of the samples had been analyzed.

To determine the activity of the emanated ^{220}Rn, the same procedure was followed using the thoron "S" chambers. There were problems with loading the thoron EICs into the jars because of their construction. The thoron chambers had the carbon

coated Tyvek® progeny filters attached to their sides with electrician's tape; the rubberized surface gripped the glass wall of the 4-liter jar when it came into contact and prevented the EIC from rotating freely with each turn of the lid. To allow the EICs to rotate with the jar lid, the side of the jar was tapped with the handle of a screwdriver to loosen the grip of the EIC and allow it to rotate. The electrets were not sensitive to mechanical shock and tapping the jar hard enough to allow the EICs to rotate did not adversely affect the measurements.

After the prescribed 3-day period, the thoron chambers were removed and allowed to air out for 3 hours before reading. Since the thoron chambers were sensitive to both the ^{220}Rn and the ^{222}Rn, there was a noticeable increase in the voltage drop per electret.

EMANATION FRACTION DETERMINATION

The measured radon concentrations were multiplied by the volume of the accumulator (see equation 8) and divided by the activities of radon per sample determined from the HPGe/LabSOCS analysis and the equilibration equations (see equation 9) to obtain the emanation fractions for each grain size and formation type:

$$A_{RnTOT} = C_{Rn}\frac{pCi}{L}\cdot 0.00372m^3\cdot\frac{(100cm)^3}{m^3}\cdot\frac{1mL}{1cm^3}\cdot\frac{L}{1000mL} \quad \textbf{(8)}$$

where:

A_{RnTOT} – the total radon activity in pCi measured in the 4-liter jar.

The radon emanation fractions are given by:

$$f_{Rn} = \frac{A_{RnTOT}}{A_{RnHPGe}} \quad \textbf{(9)}$$

where:

A_{RnHPGe} – the radon activity in pCi derived from the HPGe/LabSOCS analysis; and

f_{Rn} – the radon emanation fraction for that sample.

RESULTS AND DISCUSSION

VERIFICATION OF EQUILIBRIUM

The equilibration times were determined using equation 1 for both the uranium and thorium decay series for the parents and immediate progeny of their respective radon progeny to verify that all the samples were in secular equilibrium (see tables 1 and 2). The absence of all progeny (i.e., pure parent) initially was assumed to be maximally conservative.

Table 1 - Equilibration times assuming pure parent for uranium series

Ra226	**Rn222**	**t_m (min)**	**(days)**
λ (min)	λ (min)		
8.24×10^{-10}	1.26×10^{-4}	9.48×10^{4}	6.59×10^{1}
Rn222	**Po218**		
λ (min)	λ (min)		
1.26×10^{-4}	2.27×10^{-1}	3.30×10^{1}	2.29×10^{-2}
Po218	**Pb214**		
λ (min)	λ (min)		
2.27×10^{-1}	2.59×10^{-2}	1.08×10^{1}	7.49×10^{-3}
Pb214	**Bi214**		
λ (min)	λ (min)		
2.59×10^{-2}	3.50×10^{-2}	3.31×10^{1}	2.30×10^{-2}

Table 2 - Equilibration times assuming pure parent for thorium series

Th228	**Ra224**	**t_m (min)**	**(days)**
λ (min)	λ (min)		
6.90×10^{-7}	1.32×10^{-4}	4.01×10^{4}	2.79×10^{1}
Ra224	**Rn220**		
λ (min)	λ (min)		
1.32×10^{-4}	7.48×10^{-1}	1.16×10^{1}	8.03×10^{-3}
Rn220	**Po216**		
λ (min)	λ (min)		
7.48×10^{-1}	2.87×10^{2}	2.08×10^{-2}	1.44×10^{-5}
Po216	**Pb212**		
λ (min)	λ (min)		
2.87×10^{2}	1.09×10^{-3}	4.35×10^{-2}	3.02×10^{-5}
Pb212	**Bi212**		
λ (min)	λ (min)		
1.09×10^{-3}	1.14×10^{-2}	2.27×10^{2}	1.58×10^{-1}

The above equilibration times indicated that, since the samples were sealed for 121, days all of the equilibration times would have been satisfied. Therefore, the respective ^{222}Rn and ^{220}Rn activities could be determined using the uncertainty weighted averages of the activities of their parents and progeny as determined using the GENIE PC 2000 software.

DETERMINATION OF SAMPLE DENSITIES

The densities of each sample, depending on formation and grain size, were determined using the carbon tetrachloride displacement procedure mentioned previously

(see table 3). These densities greatly impacted the virtual standard creation since the more dense the scale the higher the activity per g cm^{-3}.

Table 3 - Densities for each formation and grain size as determined by carbon tetrachloride displacement

Mud Lake [g cm^{-3}]		Lake Sand [g cm^{-3}]		West Delta [g cm^{-3}]	
	General Bucket		General Bucket		General Bucket
density	3.35	density	2.43	density	2.3
	x>297		x>297		x>297
density	3.03	density	2.59	density	2.23
	297>x>105		297>x>105		297>x>105
density	3.41	density	3.13	density	2.61
	x<105		x<105		x<105
density	3.46	density	3.04	density	3.22

VERIFICATION OF EFFICIENCY CALIBRATIONS

Comparison of the actual marinelli beaker efficiency calibration and that determined by the LabSOCS virtual marinelli beaker calibration agreed most when the efficiency was performed using a 5^{th} order linear curve fit (see figure 9) (see Appendix A).

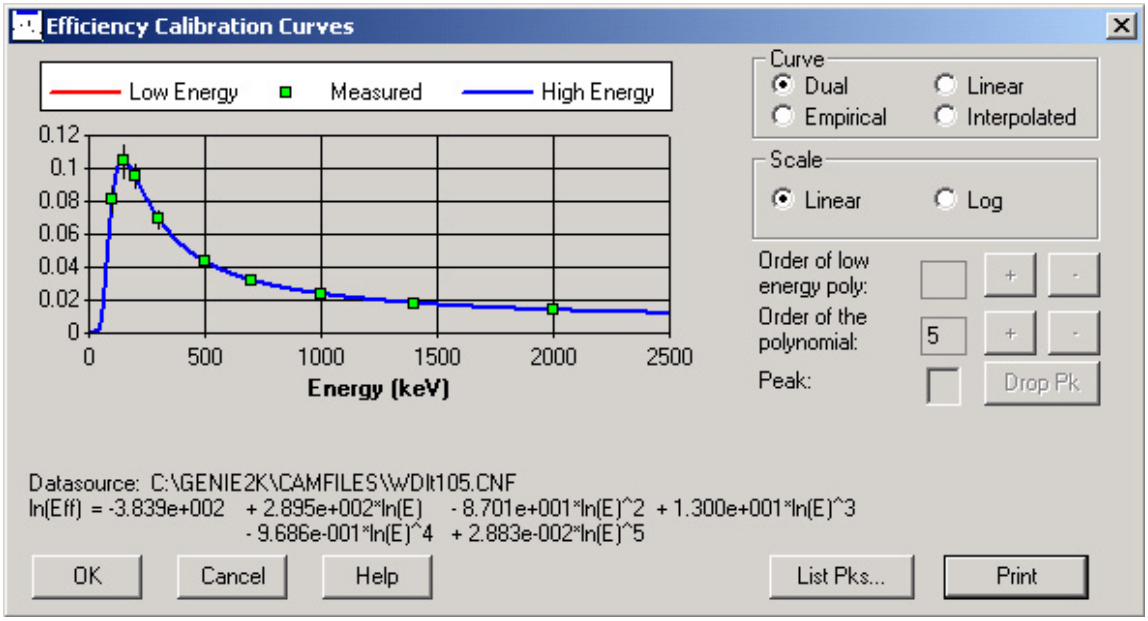

Fig 9 - Efficiency calibration showing the 5th order curve and equation

The activities estimated using GENIE PC 2000 for each gamma-ray energy agreed within the errors for most of the nuclides investigated. However, the LabSOCS efficiency calibration proved less accurate in the higher energy ranges. Invariably, there was some divergence between the activities returned by the actual efficiency calibration and the LabSOCS calibration. This divergence between activities was larger than the associated error when the gamma-ray energy was in the energy range of ^{60}Co gamma-rays.

Three separate, actual efficiency calibrations were 1) taken so that an uncertainty weighted average could be taken of the resulting activities and 2) decay corrected using the following equation (see equation 10). This decay correction was used to compare the activities returned by the marinelli beaker calibration to the original activities of the nuclides in the standard on the certificate date (see table 4).

$$A_0 = A(t)e^{\lambda t} \quad \textbf{(10)}$$

where:

A_0 – the original activity before decay in μCi;

A(t) – the current activity after decay in μCi;

λ - the decay constant of the nuclide; and

t – the time period over which the activity has decayed.

The uncertainty weighted activities were computed using the following equations (see equations 11, 12, and 13) (Cember 1996).

$$w_i = \frac{1}{\sigma_i^2} \quad \textbf{(11)}$$

where:

σ_i – the error associated with each activity; and

w_i – the weighting factor to be applied in the weighted average.

$$M_w = \frac{\sum_i w_i M_i}{\sum_i w_i} \quad \textbf{(12)}$$

where:

M_i – the activity to be multiplied by the weighting factor w_i; and

M_w – the uncertainty weighted average.

$$\sigma_{M_w} = \sqrt{\frac{1}{\sum_i w_i}} \qquad \textbf{(13)}$$

where:

σ_{Mw} – the error in the uncertainty weighted average.

Table 4 - Comparison of weighted average activities to original certificate data

Certificate Data		
	Activity [nCi]	Error [nCi]
Co60	105.4	2.108
Ba133	54.23	1.643169
Cs137	91.95	2.77689
Decay Corrected		
	Activity [nCi]	Error [nCi]
Co60	105.622427	0.731198
Ba133	54.438415	0.806429
Cs137	90.9492894	1.441922

Table 4, the decay-corrected, weighted average of the actual marinelli standard calibrations provided activities that agreed closely with the original certificate data. This shows that the detector system and accompanying software package was operating properly. The actual calibration-weighted average activities were used for comparison to the LabSOCS calibration.

VERIFICATION OF LabSOCS CALIBRATION

The LabSOCS calibration and the weighted average of the actual calibrations converged closely enough to each be within the error bars of the other for the low to mid range gamma-ray energy peaks. However, as mentioned above, there was some degree of divergence in the energy range of Co^{60} (see table 5).

Table 5 - Comparison of the averaged actual calibration to the LabSOCS calibration

Actual	Activity [µCi g^{-1}]	Error [µCi g^{-1}]
Co-60	4.97×10^{-2}	3.44×10^{-4}
Ba-133	3.73×10^{-2}	5.53×10^{-4}
Cs-137	7.97×10^{-2}	1.26×10^{-3}
LabSOCS	**Activity [µCi g^{-1}]**	**Error [µCi g^{-1}]**
Co-60	4.58×10^{-2}	7.72×10^{-4}
Ba-133	3.75×10^{-2}	1.33×10^{-3}
Cs-137	8.15×10^{-2}	3.25×10^{-3}

There were some difficulties in the actual construction of the LabSOCS virtual standard. To create a unique geometry, the user must write a short code, similar in nature to an MCNP code, that defines the inner and outer contours or boundaries of the object being modeled. This code cannot accept the definition of more than one object and, therefore, modeling the steel lid of the sample jar would prove exceedingly difficult and would have required special training in the software. However, the steel lid on the 2 oz sample jar was deemed unnecessary after discussing LabSOCS geometry coding with the technical support staff at Canberra. Removing the lid from the geometry was accomplished because the LabSOCS MCNP-based code only accounted for gamma-rays

emitted in a certain direction (similar to a 2π geometry configuration). Because of this, LabSOCS would not have considered those gamma-rays emitted toward the lid. Without the lid, the jar was nothing more than a glass tube for which LabSOCS already had a template and a material definition. Therefore, the virtual standard was created using the densities for each individual sample depending on grain size and formation, and using the material composition as determined by the XRF analysis (see Appendix D).

SAMPLE RADON AND THORON ACTIVITY DETERMINATION

The LabSOCS calibrated GENIE PC 2000 output files (see Appendix C) were each screened to remove any activities derived from gamma energies that were either identical or within one keV of a gamma-ray energy from another possible nuclide. This screening process provided accuracy in determining the activities of ^{222}Rn and ^{220}Rn. For instance, the low-energy gamma-ray peaks for both ^{214}Pb and ^{212}Pb are identical and, therefore, it is not possible to determine their respective activities using these peaks. This overlap made it impossible to use any peaks or gamma energies that might also be occupied by another nuclide. Because of the divergence between LabSOCS and the actual calibrations at the higher gamma energies mentioned above, another screening qualifier was used. All gamma-ray energies used in the activity calibration were below 1000 keV, at which point the divergence became pronounced. Therefore, only unique mid-range (85-970 keV) gamma-ray energies were used for determination of the parent and progeny activities.

There were exceptions to the identical energy gamma-ray exclusion. GENIE PC 2000 identified three gamma-ray energies as belonging to ^{235}U, and while the most abundant of these peaks overlapped the energy at which ^{226}Ra emits a primary gamma-ray, ^{226}Ra was not excluded from the activity calculations. The reason behind including ^{226}Ra was that GENIE PC 2000 only identified two less than two-percent abundant gamma-rays and the fifty-four percent abundant ray, but not the ten-percent abundant gamma-ray peak expected if ^{235}U was present. Since every energy identified was also an energy of a gamma-ray from another present nuclide, ^{235}U was not considered to be present in any consequential amount. This conclusion was reached because if the less than two-percent abundant gamma-rays were to be considered truly from ^{235}U and the fifty-four-percent abundant gamma-ray was to be considered due to ^{235}U then the ten-percent abundant gamma should also have been present. However, there were no counts at 143.76 keV (see table 6) where the ten-percent abundant ^{235}U gamma appears and there should have been at least some deviation from background if ^{235}U were to be present. The removal of ^{235}U also allowed for the removal of the ^{219}Rn and ^{211}Bi detected in the Mud Lake samples. These progeny could be removed for similar reasons as the ^{235}U. The only gamma rays detected from ^{219}Rn and ^{211}Bi were of identical energies to those from ^{214}Pb and ^{228}Ac, which were known to be present. Even if armed with no other knowledge than the natural abundance of ^{235}U, one could still deduce that these nuclides had been misidentified.

Natural uranium has been shown to be only 0.72% ^{235}U. This would imply that any detected activities of ^{235}U and its progeny would have to be several orders of

magnitude lower than those of the ^{238}U series. Another proof that ^{235}U and its progeny were misidentified was that it was listed as having similar activities to that expected of the known-to-be-present nuclides.

Table 6 - GENIE output file showing lack of ten-percent abundant gamma-ray

Nuclide	Energy [keV]	Yield (%)	Activity [µCi g^{-1}]	Error [µCi g^{-1}]
U-235	89.96	1.50	2.91×10^{-2}	5.12×10^{-3}
	93.35	2.50	8.98×10^{-3}	1.30×10^{-3}
	105	1.00		
	109.14	1.50		
	143.76	10.5		
	163.35	4.70		
	185.71	54.0	9.04×10^{-4}	6.39×10^{-5}
	202.12	1.00		
	205.31	4.70		

Removing ^{235}U from the output report made determining the activities of the remaining nuclides much simpler. Once again, uncertainty weighted averages were used to determine the activity of each nuclide present in the sample. Those activities were used to determine the ^{226}Ra and ^{224}Ra activities by using another uncertainty weighted average (see tables 7 and 8).

Table 7 - Parent and progeny activities and the ^{226}Ra activity determined

LS General Bucket		
U238		
Nuclide	Activity [μCi g^{-1}]	Error [μCi g^{-1}]
Bi-214	9.65x10^{-3}	4.51x10^{-4}
Pb-214	1.17x10^{-2}	5.66x10^{-4}
Ra-226	1.49x10^{-2}	1.03x10^{-3}
Average	**1.09x10^{-2}**	**3.34x10^{-4}**

Table 8 - Parent and progeny activities and the ^{224}Ra activity determined

LS General Bucket		
Th232		
Nuclide	Activity [μCi g^{-1}]	Error [μCi g^{-1}]
Bi-212	3.64x10^{-3}	1.55x10^{-4}
Pb-212	5.08x10^{-3}	5.13x10^{-4}
Average	**3.76x10^{-3}**	**1.49x10^{-4}**

These ^{226}Ra and ^{224}Ra activities for each sample (see Appendix E) were used to determine the activities of ^{222}Rn and ^{220}Rn.

The following equation was used to determine the activities of both ^{222}Rn and ^{220}Rn from their radium parent activities:

$$A_{Rn} = \lambda_{Rn}\left[\left(\frac{A_{Ra}}{\lambda_{Ra}}\right)\left(1 - e^{(-\lambda_{Ra}t)}\right)\right] \qquad \textbf{(14)}$$

where:

A_{Rn} – the activity of radon;

λ_{Rn} – the decay constant of radon in $days^{-1}$;

A_{Ra} – the activity of the parent isotope of radium;

λ_{Ra} – the decay constant of the parent isotope of radium in $days^{-1}$; and

t – the duration of the experiment in days.

Having obtained the ^{222}Rn and ^{220}Rn activities (see table 9 and Appendix F), the next step was to determine the ^{222}Rn and ^{220}Rn as measured by the EICs.

Table 9 - Determined ^{222}Rn and ^{220}Rn activities from the Lake Sand formation

(GB is the abbreviation of general bucket, or the mixed grain size)

Formation	Grain Size	Total Radon/Thoron Activity [pCi]	Error
LS Radon	x>297	$5.22x10^4$	$1.56x10^3$
	297>x>105	$6.92x10^4$	$2.07x10^3$
	x<105	$7.26x10^4$	$2.20x10^3$
	gb	$5.93x10^4$	$1.82x10^3$
LS Thoron	x>297	$8.30x10^7$	$3.04x10^6$
	297>x>105	$1.14x10^8$	$4.14x10^6$
	x<105	$1.12x10^8$	$4.48x10^6$
	gb	$9.38x10^7$	$3.72x10^6$

EIC CALIBRATION FACTORS

Equation 3 was applied to each data set obtained from the electret calibration procedure to determine the general calibration factors for each electret (see table 10 and Appendix F).

Table 10 - Examples of general electret calibration factors

Electret	General Cal Factor	Error
R1A	2.07	4.06×10^{-4}
R1B	2.09	1.66×10^{-4}
R2A	2.07	2.34×10^{-4}
R2B	2.08	4.69×10^{-4}
R3A	2.07	1.66×10^{-4}
R3B	2.09	4.69×10^{-4}
R4A	2.00	5.24×10^{-4}
R4B	2.08	3.71×10^{-4}

These general calibration factors were used with equations 4 and 5 to determine the measured ^{222}Rn concentrations emanating from the NIST sources (see table 11 and Appendix F).

Table 11 - Examples of ^{222}Rn concentrations using the NIST source

Electret	Measured Conc. [pCi L^{-1}]	Error
R1A	9.44	2.03×10^{-1}
R1B	9.66	2.01×10^{-1}
R2A	8.98	1.30×10^{-1}
R2B	8.08	2.59×10^{-1}
R3A	7.99	0.00
R3B	8.53	2.04×10^{-1}
R4A	7.92	9.20×10^{-2}
R4B	7.91	9.19×10^{-2}

The background measurement in equation 5 includes more than the ambient ^{222}Rn and ^{220}Rn concentrations. Since electrets respond in some small measure to gamma-ray radiation, the background readings obtained also included the ambient background gamma-ray radiation exposure. This made the gamma-ray radiation exposure correction as described in the Rad Elec procedure unnecessary. The Rad Elec suggested gamma-ray correction would be less precise because it uses an assumed background gamma exposure rate for each state (e.g., Texas), whereas the background measured in this experiment accurately reflected both the background gamma exposure and the ^{222}Rn and ^{220}Rn concentrations in the laboratory air.

With the measured ^{222}Rn concentrations acquired, all that remained was to determine the expected ^{222}Rn concentrations based on the known rate of ^{226}Ra decay using equation 6 (see table 12 and Appendix F).

Table 12 - Concentration of ^{222}Rn expected based on NIST source decay and emanation

Electret	Theoretical Conc. [pCi L^{-1}]	Error
R1A	7.89	$4.25x10^{-1}$
R1B	7.89	$4.25x10^{-1}$
R2A	7.81	$4.20x10^{-1}$
R2B	7.81	$4.20x10^{-1}$
R3A	7.81	$4.21x10^{-1}$
R3B	7.81	$4.21x10^{-1}$
R4A	7.81	$4.21x10^{-1}$
R4B	7.81	$4.21x10^{-1}$

The expected ^{222}Rn concentrations were combined with the measured concentrations above in equation 7 to calculate the individual NIST-traceable calibration factors (see table 13 and Appendix F).

Table 13 - Examples of NIST calibration factors

Electret	Individual NIST Cal	Error
R1A	1.06	6.27×10^{-2}
R1B	1.08	6.39×10^{-2}
R2A	1.01	5.71×10^{-2}
R2B	0.89	5.87×10^{-2}
R3A	0.88	4.77×10^{-2}
R3B	0.95	5.77×10^{-2}
R4A	0.87	4.87×10^{-2}
R4B	0.87	4.86×10^{-2}

The NIST calibration factors were all within an acceptable range of the given NIST variance from 0.95 ± 5% to 1.10 ± 5% allowing the calibration factors to be applied to the thoron chambers, as well.

EIC RADON AND THORON CONCENTRATIONS

Equations 3, 4, and 5 were used to provide the measured, uncalibrated concentrations of the ^{222}Rn and ^{220}Rn in each of the 4-liter jars. These uncalibrated concentrations were divided by their respective NIST calibration factors:

$$C_a = \frac{C_m}{CF_{NIST}} \qquad \textbf{(15)}$$

where:

C_a – the actual or calibrated ^{222}Rn or ^{220}Rn concentration.

Equation 14 was applied to each individual electret to determine the actual radon concentration in a particular jar. Since there were two EICs in each 4-liter jar, an uncertainty weighted average was calculated to provide an average ^{222}Rn or ^{220}Rn concentration. The average concentration was multiplied by the volume of the accumulator to obtain the total activity of emitted ^{222}Rn or ^{220}Rn.

The ^{222}Rn concentration from each jar was subtracted from the thoron chamber concentration for the same jar to determine the emitted activity of ^{220}Rn only. This subtraction could be performed because the ^{222}Rn concentration would be approximately the same for each measurement in the same jar since the jars were sealed for the same amount of time and ^{226}Ra had a long enough half-life that there would be no noticeable decrease in its activity.

EMANATION FRACTION DETERMINATION

The emanation fractions for both ^{222}Rn and ^{220}Rn for each scale formation and grain size could be calculated using the activities obtained above and equation 9. As discussed before, the emanation fraction is the ratio of activity emitted to that which remains locked in the scale. Despite the initial expectation of a surface-to-volume ratio dependence on the emanation fraction, insufficient evidence was found to support such a relationship (see table 14 and Appendix F).

Table 14 - Emanation fractions according to formation and grain size

Formation	Grain Size	Emanation Fraction by Grain Size	Error
LS Radon	x>297	4.90×10^{-5}	8.65×10^{-6}
	297>x>105	5.77×10^{-5}	9.06×10^{-6}
	x<105	1.11×10^{-4}	1.10×10^{-5}
	gb	7.79×10^{-5}	1.49×10^{-5}
LS Thoron	x>297	8.25×10^{-8}	9.14×10^{-9}
	297>x>105	5.72×10^{-8}	6.26×10^{-9}
	x<105	1.29×10^{-7}	1.06×10^{-8}
	gb	7.58×10^{-8}	9.28×10^{-9}

The higher voltage drop for the smaller grain sizes was due to a higher ^{222}Rn and ^{220}Rn generation rate because of elevated activities of the parent nuclides in those samples. The elevated activities as determined by LabSOCS probably occurred in the samples with the smaller grain sizes because of the increased densities of those samples.

The emanation fractions above differ by a factor of approximately 100 from the values obtained in the past by Arthur Rood (Rood et al. 1998). However, in his article Rood mentions the dependence of emanation fraction on the physical properties of the material in which the radon is trapped (Rood et al. 1998). The difference in structure between the scale in his experiment and in this experiment could cause such differences

in emanation fraction. The temperature relationship was only recently defined as an equation in 2004, however, and therefore Rood did not have that additional information when he conducted his experiment in 1996. It is possible that the differences in the emanation fractions are caused by variations in the temperature and humidity between the two experiments, or even in the way results from these two separate studies were reported.

CONCLUSIONS

It is unlikely that the ^{222}Rn and ^{220}Rn would be emitted in high enough concentrations to create detectable outdoor concentrations. This conclusion is based on the extremely small emanation fractions observed. Furthermore, it is concluded that the possibility of ^{222}Rn and ^{220}Rn inhalation causing any significant dose equivalent in the individuals who work around these pipes is remote.

Data obtained from this research are still applicable today even though there have been advances in safety with regards to pipe rattling methods. This can be said because the pipe scale may still be stored in yards in the same manner and this experiment was intended to determine the ability of radon to become airborne in the storage yard environment.

Perhaps in the future it will become easier to produce a pure thoron environment to use for determining the response of the thoron chambers more accurately. This added calibration would serve to make any subsequent thoron emanation fraction determinations more accurate.

However, before the above emanation fractions can be compared to previous research it would be necessary to establish the physical property dependence of emanation fractions. Temperature data could also be used to try to correlate the two sets of emanation fractions, as well as scale moisture content.

Future research should include an investigation into establishing the dependence of emanation fraction on both air and sample moisture content. This relationship could

prove very helpful in the correlation of differing emanation fraction results, and even lead to methods for further reducing the airborne concentrations of ^{222}Rn and ^{220}Rn in the oil field work environment. For example, pipes could be stored in a cool humid area since the lower temperatures would further reduce the emanation fraction and any recoil ^{222}Rn and ^{220}Rn that was emanated might be slowed or absorbed by the humid air.

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APPENDICES

APPENDIX A

EFFICIENCY CALIBRATION PERFORMED WITH MARINELLI BEAKER TO CALIBRATION PERFORMED USING LABSOCS

Real Marinelli Efficiency Calibration #1

Nuclide Identification Report 5/24/2004 10:20:47 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CO-60	1.000	1173.22*	100.00	4.948E-002	7.739E-004
		1332.49*	100.00	4.967E-002	9.730E-004
BA-133	0.966	79.62	2.55		
		81.00*	33.00	3.822E-002	3.215E-003
		276.40*	6.90	3.631E-002	2.291E-003
		302.84*	17.80	3.711E-002	2.035E-003
		356.01*	60.00	3.633E-002	1.928E-003
		383.85*	8.70	3.848E-002	1.906E-003
CS-137	1.000	661.65*	85.12	7.931E-002	2.285E-003

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 5/24/2004 10:20:47 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty

All peaks were identified.

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Real Marinelli Efficiency Calibration #2

Nuclide Identification Report 5/25/2004 9:52:31 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CO-60	0.999	1173.22*	100.00	4.934E-002	6.754E-004
		1332.49*	100.00	4.987E-002	8.488E-004
BA-133	0.964	79.62	2.55		
		81.00*	33.00	3.713E-002	2.720E-003
		276.40*	6.90	3.650E-002	2.242E-003
		302.84*	17.80	3.746E-002	2.000E-003
		356.01*	60.00	3.680E-002	1.915E-003
		383.85*	8.70	3.814E-002	1.850E-003
CS-137	1.000	661.65*	85.12	8.023E-002	1.998E-003

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 5/25/2004 2:26:48 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty

All peaks were identified.

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Real Marinelli Efficiency Calibration #3

Nuclide Identification Report 6/9/2004 3:25:19 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\Stdlibish.nlb

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CO-60	1.000	1173.22*	100.00	5.008E-002	8.867E-004
		1332.49*	100.00	5.022E-002	1.072E-003
BA-133	0.966	79.62	2.55		
		81.00*	33.00	3.741E-002	3.036E-003
		276.40*	6.90	3.675E-002	2.326E-003
		302.84*	17.80	3.707E-002	2.033E-003
		356.01*	60.00	3.664E-002	1.971E-003
		383.85*	8.70	3.950E-002	1.985E-003
CS-137	1.000	661.65*	85.12	7.927E-002	2.326E-003

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/9/2004 3:24:29 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty

All peaks were identified.

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

LABSOCS Virtual Marinelli Calibration

Nuclide Identification Report 6/9/2004 7:44:05 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\Stdlibish.nlb

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CO-60	1.000	1173.22*	100.00	4.612E-002	1.044E-003
		1332.49*	100.00	4.532E-002	1.145E-003
BA-133	0.964	79.62	2.55		
		81.00*	33.00	3.140E-002	3.734E-003
		276.40*	6.90	3.644E-002	2.978E-003
		302.84*	17.80	3.754E-002	2.839E-003
		356.01*	60.00	3.814E-002	2.775E-003
		383.85*	8.70	4.146E-002	2.832E-003
CS-137	1.000	661.65*	85.12	8.154E-002	3.252E-003

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/9/2004 7:43:54 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty

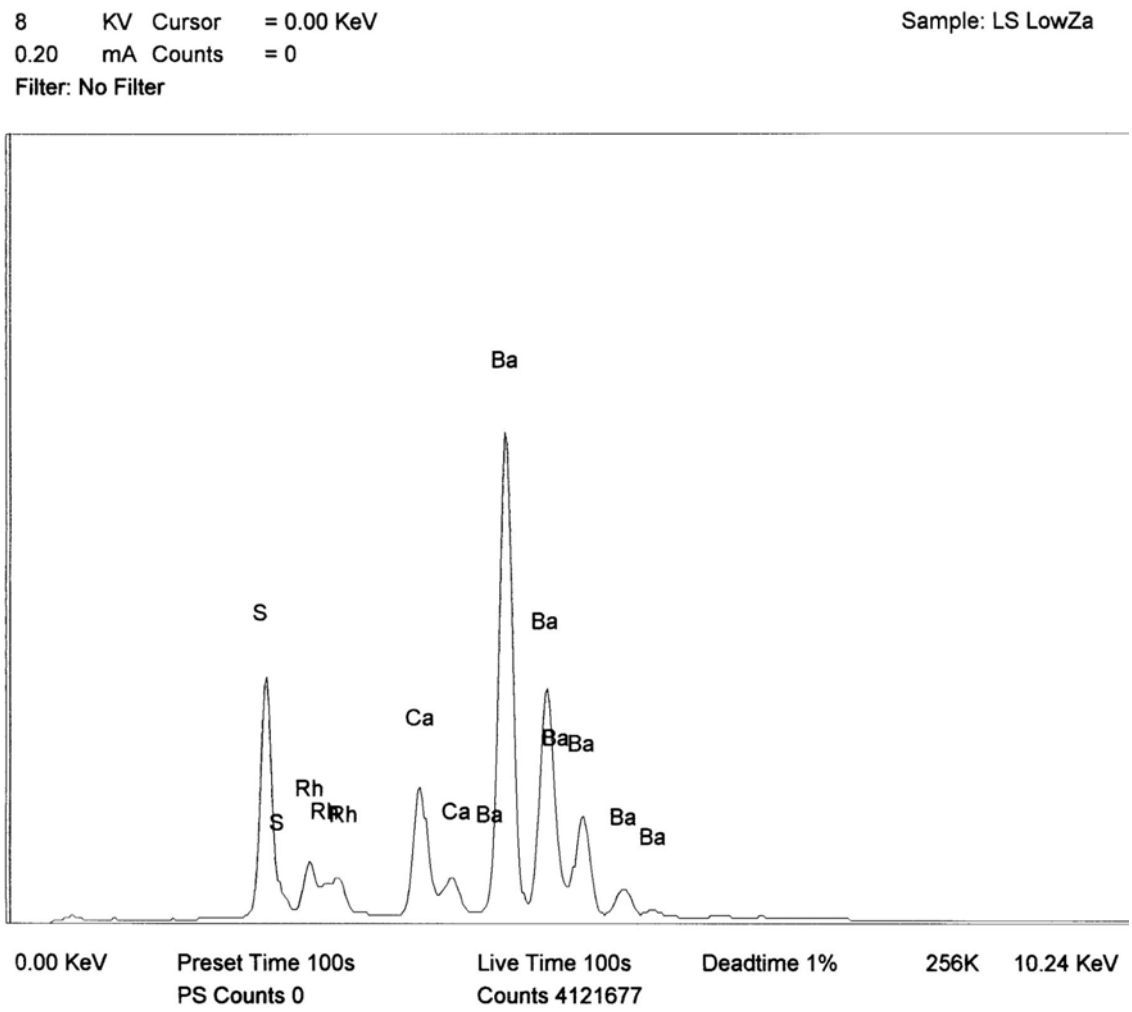
All peaks were identified.

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

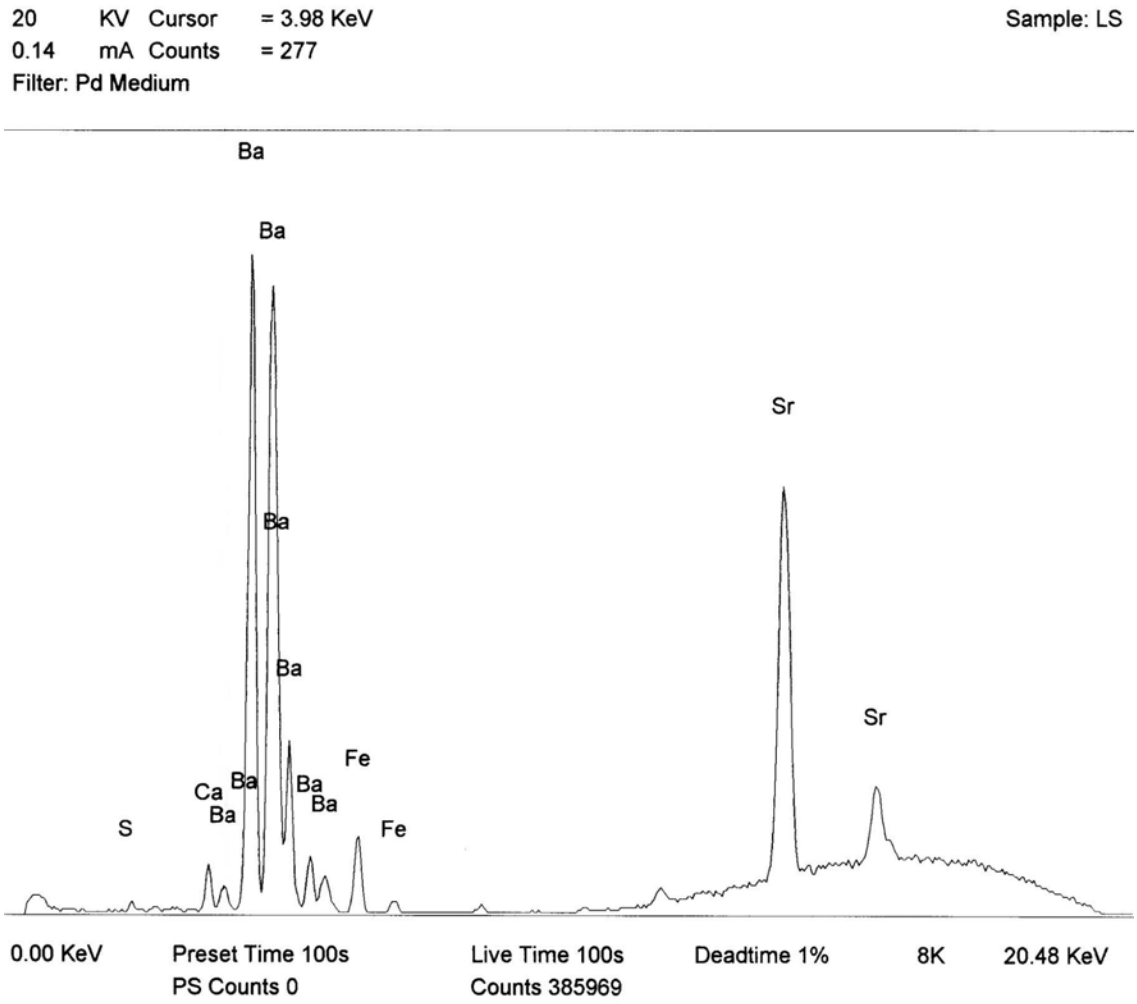
Errors quoted at 1.000 sigma

APPENDIX B

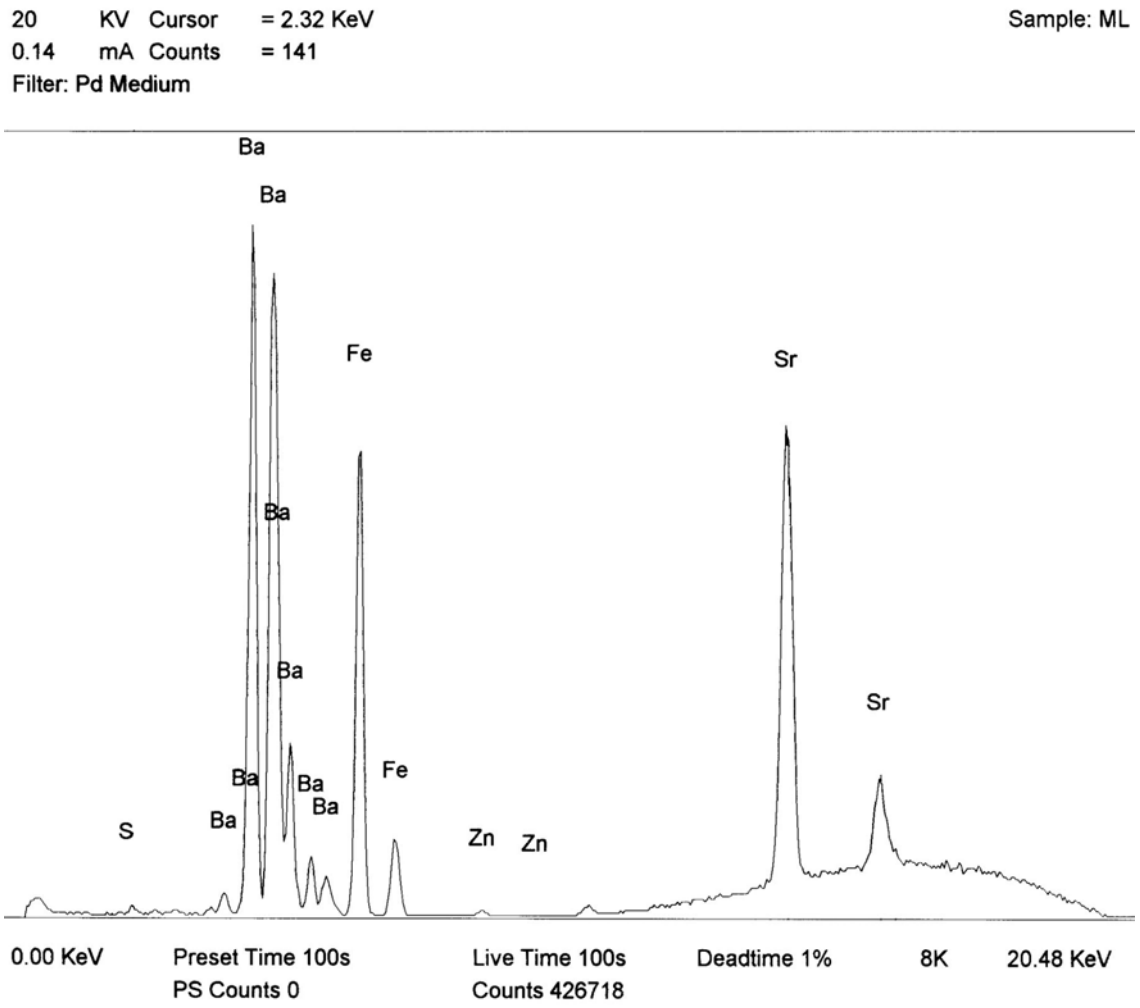
RESULTS OF XRF ANALYSIS ON SCALE SAMPLES OF LAKE SAND AND MUD LAKE FORMATIONS



XRF output graph showing the $BaSO_4$ composition of the Lake Sand scale. Note also, the indicated $CaSO_4$ which corresponds to the predicted composition.



XRF output graph showing all elements identified by the system from the Lake Sand sample. Note the presence of strontium in this expanded view. The presence of strontium completely verifies the expected scale composition by indicating the presence $SrSO_4$.



XRF output graph of the Mud Lake scale sample indicating similar composition to the Lake Sand. Still the presence of $BaSO_4$, and $SrSO_4$ stand out while the calcium abundance dropped to too small a level to be detected. However the iron concentration increased probably leading to the Mud Lake scale having a rusty color.

APPENDIX C

LABSOCS CALIBRATED GENIE PC 2000 OUTPUT FILES

Lake Sand > 297 microns

Nuclide Identification Report 6/15/2004 4:44:42 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-211	0.303	72.87	1.20		
		351.10*	12.20	3.039E-002	2.001E-003
		404.80	4.10		
		426.90	1.90		
		831.80	3.30		
BI-212	0.594	39.86	1.10		
		727.17*	11.80	3.124E-003	1.326E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.983	74.81*	9.60	2.060E-002	9.161E-003
		77.11*	17.50	1.530E-002	6.248E-003
		87.20*	6.30	1.304E-002	2.731E-003
		89.80*	1.75	2.203E-002	3.901E-003
		115.19	0.60		
		238.63*	44.60	5.057E-003	5.549E-004
		300.09*	3.41	4.839E-003	4.243E-004
BI-214	0.544	609.31*	46.30	8.442E-003	3.831E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	8.404E-003	2.623E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	9.331E-003	3.456E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.814	74.81*	6.33	3.125E-002	1.389E-002
		77.11*	10.70	2.502E-002	1.022E-002
		87.20*	3.70	2.220E-002	4.650E-003
		89.80*	1.03	3.742E-002	6.629E-003
		241.98	7.49		
		295.21*	19.20	1.019E-002	6.918E-004
		351.92*	37.20	9.968E-003	6.562E-004
		785.91	1.10		
RA-226	0.995	186.21*	3.28	1.294E-002	8.810E-004
AC-228	0.756	89.95*	2.10	1.836E-002	3.251E-003
		93.35*	3.50	5.461E-003	8.653E-004
		129.08*	2.80	3.616E-003	3.179E-004

		209.28*	4.40	3.892E-003	2.454E-004
		270.23*	3.60	3.742E-003	2.580E-004
		327.64*	3.20	3.888E-003	2.633E-004
		338.32*	11.40	4.346E-003	2.905E-004
		409.51	2.13		
		463.00*	4.40	4.175E-003	2.161E-004
		794.70	4.60		
		911.60*	27.70	4.038E-003	1.440E-004
		964.60	5.20		
		969.11*	16.60	3.651E-003	2.613E-004
		1587.90	3.71		
U-235	0.528	89.96*	1.50	2.570E-002	4.552E-003
		93.35*	2.50	7.646E-003	1.211E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	7.859E-004	5.499E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:44:29 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.54	5.0193E-001	2.86
18	583.01	1.6602E+000	2.65

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Lake Sand 297 microns > x >105 microns

Nuclide Identification Report 6/15/2004 4:46:42 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-211	0.301	72.87	1.20		
		351.10*	12.20	4.131E-002	2.732E-003
		404.80	4.10		
		426.90	1.90		
		831.80	3.30		
BI-212	0.596	39.86	1.10		
		727.17*	11.80	4.268E-003	1.775E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.984	74.81*	9.60	2.973E-002	1.321E-002
		77.11*	17.50	2.233E-002	9.095E-003
		87.20*	6.30	1.870E-002	3.910E-003
		89.80*	1.75	3.283E-002	5.762E-003
		115.19	0.60		
		238.63*	44.60	7.063E-003	7.740E-004
		300.09*	3.41	6.691E-003	5.899E-004
BI-214	0.545	609.31*	46.30	1.125E-002	5.087E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	1.095E-002	3.316E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	1.224E-002	4.557E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.813	74.81*	6.33	4.509E-002	2.003E-002
		77.11*	10.70	3.652E-002	1.487E-002
		87.20*	3.70	3.184E-002	6.658E-003
		89.80*	1.03	5.578E-002	9.789E-003
		241.98	7.49		
		295.21*	19.20	1.391E-002	9.504E-004
		351.92*	37.20	1.355E-002	8.961E-004
		785.91	1.10		

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
RA-226	0.997	186.21*	3.28	1.779E-002	1.223E-003
AC-228	0.756	89.95*	2.10	2.736E-002	4.801E-003
		93.35*	3.50	7.596E-003	1.241E-003
		129.08*	2.80	5.178E-003	4.566E-004
		209.28*	4.40	5.567E-003	3.454E-004
		270.23*	3.60	5.192E-003	3.468E-004
		327.64*	3.20	5.494E-003	3.681E-004
		338.32*	11.40	6.142E-003	4.135E-004
		409.51	2.13		
		463.00*	4.40	5.760E-003	2.890E-004
		794.70	4.60		
		911.60*	27.70	5.591E-003	1.981E-004
		964.60	5.20		
		969.11*	16.60	5.083E-003	3.571E-004
		1587.90	3.71		
U-235	0.528	89.96*	1.50	3.830E-002	6.722E-003
		93.35*	2.50	1.063E-002	1.738E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	1.081E-003	7.630E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:46:30 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.55	6.4308E-001	2.43
18	583.03	2.2039E+000	2.68

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Lake Sand < 105 microns

Nuclide Identification Report 6/15/2004 4:48:30 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CD-109	0.878	88.03*	3.72	3.188E-002	6.727E-003
BI-212	0.596	39.86	1.10		
		727.17*	11.80	4.386E-003	1.872E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.983	74.81*	9.60	2.912E-002	1.291E-002
		77.11*	17.50	2.164E-002	8.801E-003
		87.20*	6.30	1.882E-002	3.933E-003
		89.80*	1.75	3.265E-002	5.714E-003
		115.19	0.60		
		238.63*	44.60	7.185E-003	7.902E-004
		300.09*	3.41	3.174E-003	1.062E-003
BI-214	0.550	609.31*	46.30	1.177E-002	5.456E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	1.156E-002	3.587E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	1.286E-002	4.727E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.815	74.81*	6.33	4.416E-002	1.958E-002
		77.11*	10.70	3.540E-002	1.439E-002
		87.20*	3.70	3.205E-002	6.697E-003
		89.80*	1.03	5.548E-002	9.708E-003
		241.98	7.49		
		295.21*	19.20	1.461E-002	9.961E-004
		351.92*	37.20	1.415E-002	9.436E-004
		785.91	1.10		
RA-226	0.998	186.21*	3.28	1.842E-002	1.273E-003
AC-228	0.766	89.95*	2.10	2.721E-002	4.761E-003
		93.35*	3.50	8.121E-003	1.165E-003
		129.08*	2.80	5.045E-003	4.568E-004

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
AC-228	0.766	209.28*	4.40	5.685E-003	3.651E-004
		270.23*	3.60	5.388E-003	3.621E-004
		327.64*	3.20	5.556E-003	3.668E-004
		338.32*	11.40	6.228E-003	4.233E-004
		409.51	2.13		
		463.00*	4.40	5.839E-003	2.950E-004
		794.70	4.60		
		911.60*	27.70	5.680E-003	2.078E-004
		964.60	5.20		
		969.11*	16.60	5.209E-003	3.791E-004
		1587.90	3.71		
U-235	0.524	89.96*	1.50	3.810E-002	6.666E-003
		93.35*	2.50	1.137E-002	1.630E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	1.119E-003	7.938E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:48:18 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.65	6.5766E-001	2.41
18	583.12	2.2603E+000	2.84

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Lake Sand General Bucket

Nuclide Identification Report 6/15/2004 4:42:19 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-212	0.595	39.86	1.10		
		727.17*	11.80	3.643E-003	1.554E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.983	74.81*	9.60	2.165E-002	9.619E-003
		77.11*	17.50	1.625E-002	6.637E-003
		87.20*	6.30	1.422E-002	2.973E-003
		89.80*	1.75	2.494E-002	4.387E-003
		115.19	0.60		
		238.63*	44.60	5.877E-003	6.623E-004
		300.09*	3.41	3.877E-003	8.098E-004
BI-214	0.549	609.31*	46.30	9.648E-003	4.511E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	9.506E-003	2.947E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	1.064E-002	3.903E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.816	74.81*	6.33	3.283E-002	1.459E-002
		77.11*	10.70	2.657E-002	1.086E-002
		87.20*	3.70	2.421E-002	5.061E-003
		89.80*	1.03	4.238E-002	7.453E-003
		241.98	7.49		
		295.21*	19.20	1.180E-002	8.194E-004
		351.92*	37.20	1.152E-002	7.828E-004
		785.91	1.10		
RA-226	0.996	186.21*	3.28	1.487E-002	1.025E-003
AC-228	0.763	89.95*	2.10	2.078E-002	3.656E-003
		93.35*	3.50	6.417E-003	9.257E-004
		129.08*	2.80	4.173E-003	3.761E-004
		209.28*	4.40	4.581E-003	2.977E-004
		270.23*	3.60	4.295E-003	2.924E-004
		327.64*	3.20	4.582E-003	3.059E-004
		338.32*	11.40	5.167E-003	3.513E-004
		409.51	2.13		

		463.00*	4.40	4.710E-003	2.357E-004
		794.70	4.60		
		911.60*	27.70	4.731E-003	1.706E-004
		964.60	5.20		
		969.11*	16.60	4.279E-003	3.234E-004
		1587.90	3.71		
U-235	0.526	89.96*	1.50	2.910E-002	5.118E-003
		93.35*	2.50	8.984E-003	1.296E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	9.035E-004	6.392E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:42:08 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.59	5.5242E-001	2.52
18	583.07	1.9283E+000	2.97

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Mud Lake > 297 microns

Nuclide Identification Report 6/15/2004 4:31:00 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-212	0.595	39.86	1.10		
		727.17*	11.80	5.601E-003	2.291E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.987	74.81*	9.60	4.273E-002	1.888E-002
		77.11*	17.50	3.229E-002	1.301E-002
		87.20*	6.30	2.747E-002	5.731E-003
		89.80*	1.75	4.328E-002	7.635E-003
		115.19	0.60		
		238.63*	44.60	9.071E-003	1.021E-003
		300.09*	3.41	8.675E-003	7.053E-004
BI-214	0.551	609.31*	46.30	1.853E-002	8.326E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	1.836E-002	5.594E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	2.027E-002	7.468E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.816	74.81*	6.33	6.481E-002	2.864E-002
		77.11*	10.70	5.281E-002	2.128E-002
		87.20*	3.70	4.678E-002	9.758E-003
		89.80*	1.03	7.354E-002	1.297E-002
		241.98	7.49		
		295.21*	19.20	2.253E-002	1.494E-003
		351.92*	37.20	2.201E-002	1.423E-003
		785.91	1.10		
RA-226	1.000	186.21*	3.28	2.829E-002	1.893E-003
AC-228	0.769	89.95*	2.10	3.607E-002	6.363E-003
		93.35*	3.50	7.072E-003	1.618E-003
		129.08*	2.80	5.724E-003	5.143E-004
		209.28*	4.40	6.097E-003	3.736E-004
		270.23*	3.60	5.759E-003	3.925E-004
		327.64*	3.20	6.091E-003	3.958E-004
		338.32*	11.40	6.881E-003	4.481E-004
		409.51	2.13		

		463.00*	4.40	6.457E-003	3.154E-004
		794.70	4.60		
		911.60*	27.70	6.387E-003	2.261E-004
		964.60	5.20		
		969.11*	16.60	5.789E-003	4.063E-004
		1587.90	3.71		
U-235	0.519	89.96*	1.50	5.050E-002	8.908E-003
		93.35*	2.50	9.901E-003	2.265E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	1.718E-003	1.183E-004
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:30:41 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.70	8.9238E-001	2.27
18	583.19	2.9398E+000	2.64

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Mud Lake 297 microns > x >105 microns

Nuclide Identification Report 6/15/2004 4:39:48 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CD-109	0.889	88.03*	3.72	6.277E-002	1.325E-002
BI-212	0.596	39.86	1.10		
		727.17*	11.80	7.439E-003	3.049E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.987	74.81*	9.60	5.887E-002	2.602E-002
		77.11*	17.50	4.387E-002	1.762E-002
		87.20*	6.30	3.706E-002	7.744E-003
		89.80*	1.75	5.853E-002	1.035E-002
		115.19	0.60		
		238.63*	44.60	1.224E-002	1.267E-003
		300.09*	3.41	1.122E-002	1.002E-003
BI-214	0.551	609.31*	46.30	2.382E-002	1.039E-003
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	2.340E-002	7.117E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	2.642E-002	9.866E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.814	74.81*	6.33	8.928E-002	3.946E-002
		77.11*	10.70	7.176E-002	2.882E-002
		87.20*	3.70	6.311E-002	1.319E-002
		89.80*	1.03	9.945E-002	1.759E-002
		241.98	7.49		
		295.21*	19.20	2.912E-002	1.896E-003
		351.92*	37.20	2.848E-002	1.811E-003
		785.91	1.10		
RA-226	1.000	186.21*	3.28	3.674E-002	2.429E-003
AC-228	0.768	89.95*	2.10	4.878E-002	8.628E-003
		93.35*	3.50	9.535E-003	2.255E-003
		129.08*	2.80	7.713E-003	6.671E-004
		209.28*	4.40	8.208E-003	4.969E-004
		270.23*	3.60	7.617E-003	4.981E-004
		327.64*	3.20	8.146E-003	5.145E-004
		338.32*	11.40	9.185E-003	5.881E-004

		409.51	2.13		
		463.00*	4.40	8.560E-003	4.135E-004
		794.70	4.60		
		911.60*	27.70	8.507E-003	2.972E-004
		964.60	5.20		
		969.11*	16.60	7.767E-003	5.268E-004
		1587.90	3.71		
U-235	0.520	89.96*	1.50	6.829E-002	1.208E-002
		93.35*	2.50	1.335E-002	3.157E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	2.232E-003	1.519E-004
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:39:33 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.71	1.1619E+000	2.41
18	583.19	3.8812E+000	2.34

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Mud Lake < 105 microns

Nuclide Identification Report 6/15/2004 3:44:23 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CD-109	0.949	88.03*	3.72	6.656E-002	1.407E-002
BI-211	0.317	72.87	1.20		
		351.10*	12.20	1.014E-001	6.398E-003
		404.80	4.10		
		426.90	1.90		
		831.80	3.30		
BI-212	0.596	39.86	1.10		
		727.17*	11.80	8.597E-003	3.447E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.987	74.81*	9.60	6.112E-002	2.701E-002
		77.11*	17.50	4.649E-002	1.858E-002
		87.20*	6.30	3.930E-002	8.229E-003
		89.80*	1.75	6.151E-002	1.096E-002
		115.19	0.60		
		238.63*	44.60	1.388E-002	1.401E-003
		300.09*	3.41	1.263E-002	1.187E-003
BI-214	0.551	609.31*	46.30	2.793E-002	1.211E-003
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	2.725E-002	8.372E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	3.073E-002	1.148E-003
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.814	74.81*	6.33	9.269E-002	4.097E-002
		77.11*	10.70	7.604E-002	3.039E-002
		87.20*	3.70	6.692E-002	1.401E-002
		89.80*	1.03	1.045E-001	1.861E-002
		241.98	7.49		
		295.21*	19.20	3.401E-002	2.191E-003
		351.92*	37.20	3.324E-002	2.098E-003
		785.91	1.10		
RN-219	0.378	271.23*	9.90	3.152E-003	2.057E-004
		401.78	6.60		
RA-226	1.000	186.21*	3.28	4.206E-002	2.739E-003

AC-228	0.774	89.95*	2.10	5.125E-002	9.130E-003
		93.35*	3.50	9.475E-003	2.457E-003
		129.08*	2.80	8.347E-003	7.292E-004
		209.28*	4.40	9.326E-003	5.629E-004
		270.23*	3.60	8.668E-003	5.657E-004
		327.64*	3.20	9.165E-003	5.715E-004
		338.32*	11.40	1.059E-002	6.670E-004
		409.51	2.13		
		463.00*	4.40	1.013E-002	5.009E-004
		794.70	4.60		
		911.60*	27.70	9.831E-003	3.444E-004
		964.60	5.20		
		969.11*	16.60	8.745E-003	5.935E-004
		1587.90	3.71		
U-235	0.532	89.96*	1.50	7.176E-002	1.278E-002
		93.35*	2.50	1.326E-002	3.439E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	2.555E-003	1.714E-004
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.500 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 3:44:10 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.72	1.3018E+000	2.54
18	583.21	4.4493E+000	2.12

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Mud Lake General Bucket

Nuclide Identification Report 6/15/2004 4:26:55 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\STDLIB.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
CD-109	0.948	88.03*	3.72	6.112E-002	1.290E-002
BI-211	0.317	72.87	1.20		
		351.10*	12.20	8.587E-002	5.477E-003
		404.80	4.10		
		426.90	1.90		
		831.80	3.30		
BI-212	0.596	39.86	1.10		
		727.17*	11.80	7.318E-003	2.994E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.987	74.81*	9.60	5.701E-002	2.521E-002
		77.11*	17.50	4.318E-002	1.733E-002
		87.20*	6.30	3.609E-002	7.543E-003
		89.80*	1.75	5.725E-002	1.013E-002
		115.19	0.60		
		238.63*	44.60	1.186E-002	1.247E-003
		300.09*	3.41	1.130E-002	9.837E-004
BI-214	0.551	609.31*	46.30	2.345E-002	1.024E-003
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	2.286E-002	7.011E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	2.585E-002	9.649E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.815	74.81*	6.33	8.646E-002	3.824E-002
		77.11*	10.70	7.062E-002	2.835E-002
		87.20*	3.70	6.145E-002	1.284E-002
		89.80*	1.03	9.727E-002	1.721E-002
		241.98	7.49		
		295.21*	19.20	2.894E-002	1.890E-003
		351.92*	37.20	2.816E-002	1.796E-003
		785.91	1.10		
RN-219	0.378	271.23*	9.90	2.691E-003	1.784E-004

		401.78	6.60		
RA-226	1.000	186.21*	3.28	3.622E-002	2.392E-003
AC-228	0.774	89.95*	2.10	4.771E-002	8.442E-003
		93.35*	3.50	9.464E-003	2.197E-003
		129.08*	2.80	7.155E-003	6.207E-004
		209.28*	4.40	7.879E-003	4.892E-004
		270.23*	3.60	7.399E-003	4.906E-004
		327.64*	3.20	7.751E-003	4.849E-004
		338.32*	11.40	8.902E-003	5.664E-004
		409.51	2.13		
		463.00*	4.40	8.424E-003	4.233E-004
		794.70	4.60		
		911.60*	27.70	8.244E-003	2.892E-004
		964.60	5.20		
		969.11*	16.60	7.534E-003	5.083E-004
		1587.90	3.71		
U-235	0.533	89.96*	1.50	6.679E-002	1.182E-002
		93.35*	2.50	1.325E-002	3.075E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	2.200E-003	1.495E-004
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.500 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:26:42 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.70	1.1050E+000	2.51
18	583.19	3.7391E+000	2.27

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

West Delta > 297 microns

Nuclide Identification Report 6/15/2004 4:54:16 PM Page 1

****
***** NUCLIDE IDENTIFICATION REPORT *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-212	0.594	39.86	1.10		
		727.17*	11.80	6.349E-003	2.654E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.986	74.81*	9.60	3.123E-002	1.382E-002
		77.11*	17.50	2.218E-002	9.068E-003
		87.20*	6.30	1.833E-002	3.862E-003
		89.80*	1.75	4.331E-002	7.575E-003
		115.19	0.60		
		238.63*	44.60	1.053E-002	8.550E-004
		300.09*	3.41	9.577E-003	7.209E-004
BI-214	0.551	609.31*	46.30	4.033E-003	1.862E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	3.906E-003	1.369E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	4.350E-003	1.608E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.819	74.81*	6.33	4.736E-002	2.096E-002
		77.11*	10.70	3.627E-002	1.483E-002
		87.20*	3.70	3.121E-002	6.575E-003
		89.80*	1.03	7.358E-002	1.287E-002
		241.98	7.49		
		295.21*	19.20	4.989E-003	3.445E-004
		351.92*	37.20	4.794E-003	3.201E-004
		785.91	1.10		
RA-226	0.999	186.21*	3.28	6.399E-003	4.442E-004
AC-228	0.769	89.95*	2.10	3.609E-002	6.312E-003
		93.35*	3.50	1.830E-002	2.596E-003
		129.08*	2.80	1.026E-002	9.214E-004
		209.28*	4.40	1.050E-002	6.812E-004

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
AC-228	0.769	270.23*	3.60	1.010E-002	6.734E-004
		327.64*	3.20	1.020E-002	6.860E-004
		338.32*	11.40	1.152E-002	7.995E-004
		409.51	2.13		
		463.00*	4.40	1.031E-002	5.425E-004
		794.70	4.60		
		911.60*	27.70	1.058E-002	3.895E-004
		964.60	5.20		
		969.11*	16.60	9.847E-003	7.304E-004
		1587.90	3.71		
U-235	0.520	89.96*	1.50	5.053E-002	8.837E-003
		93.35*	2.50	2.562E-002	3.634E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	3.887E-004	2.770E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:54:04 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.64	9.3604E-001	2.81
18	583.13	3.3115E+000	2.68

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

West Delta 297 microns > x > 105 microns

Nuclide Identification Report 6/15/2004 4:56:12 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-212	0.595	39.86	1.10		
		727.17*	11.80	1.105E-002	5.490E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.983	74.81*	9.60	1.839E-002	8.286E-003
		77.11*	17.50	2.194E-002	8.582E-003
		87.20*	6.30	1.739E-002	3.919E-003
		89.80*	1.75	3.194E-002	7.131E-003
		115.19	0.60		
		238.63*	44.60	1.653E-002	1.421E-003
		300.09*	3.41	9.117E-003	2.151E-003
BI-214	0.551	609.31*	46.30	8.486E-003	4.694E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	8.617E-003	3.736E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	9.673E-003	4.237E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.817	74.81*	6.33	2.789E-002	1.257E-002
		77.11*	10.70	3.589E-002	1.404E-002
		87.20*	3.70	2.961E-002	6.674E-003
		89.80*	1.03	5.426E-002	1.212E-002
		241.98	7.49		
		295.21*	19.20	9.133E-003	7.651E-004
		351.92*	37.20	9.432E-003	7.592E-004
		785.91	1.10		
RA-226	1.000	186.21*	3.28	1.018E-002	9.664E-004
AC-228	0.771	89.95*	2.10	2.661E-002	5.942E-003
		93.35*	3.50	1.762E-002	3.298E-003
		129.08*	2.80	1.236E-002	1.460E-003
		209.28*	4.40	1.488E-002	1.299E-003

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
AC-228	0.771	270.23*	3.60	1.494E-002	1.218E-003
		327.64*	3.20	1.543E-002	1.188E-003
		338.32*	11.40	1.901E-002	1.528E-003
		409.51	2.13		
		463.00*	4.40	1.723E-002	1.090E-003
		794.70	4.60		
		911.60*	27.70	1.982E-002	9.102E-004
		964.60	5.20		
		969.11*	16.60	1.763E-002	9.891E-004
		1587.90	3.71		
U-235	0.517	89.96*	1.50	3.726E-002	8.319E-003
		93.35*	2.50	2.467E-002	4.618E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	6.180E-004	5.954E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:55:11 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.69	1.5406E+000	5.18
18	583.19	5.8701E+000	4.00

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

West Delta < 105 microns

Nuclide Identification Report 6/15/2004 4:57:16 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-212	0.596	39.86	1.10		
		727.17*	11.80	1.588E-002	6.330E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.986	74.81*	9.60	7.568E-002	3.344E-002
		77.11*	17.50	5.552E-002	2.227E-002
		87.20*	6.30	4.538E-002	9.524E-003
		89.80*	1.75	1.007E-001	1.771E-002
		115.19	0.60		
		238.63*	44.60	2.646E-002	1.776E-003
		300.09*	3.41	2.416E-002	1.643E-003
BI-214	0.551	609.31*	46.30	1.333E-002	5.702E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	1.297E-002	4.316E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	1.445E-002	5.403E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.815	74.81*	6.33	1.148E-001	5.072E-002
		77.11*	10.70	9.080E-002	3.642E-002
		87.20*	3.70	7.727E-002	1.622E-002
		89.80*	1.03	1.712E-001	3.009E-002
		241.98	7.49		
		295.21*	19.20	1.603E-002	1.026E-003
		351.92*	37.20	1.568E-002	9.791E-004
		785.91	1.10		
RA-226	0.999	186.21*	3.28	2.061E-002	1.350E-003
AC-228	0.770	89.95*	2.10	8.395E-002	1.476E-002
		93.35*	3.50	4.389E-002	6.252E-003
		129.08*	2.80	2.524E-002	2.157E-003
		209.28*	4.40	2.644E-002	1.588E-003

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
AC-228	0.770	270.23*	3.60	2.518E-002	1.548E-003
		327.64*	3.20	2.529E-002	1.574E-003
		338.32*	11.40	2.950E-002	1.887E-003
		409.51	2.13		
		463.00*	4.40	2.643E-002	1.283E-003
		794.70	4.60		
		911.60*	27.70	2.740E-002	9.673E-004
		964.60	5.20		
		969.11*	16.60	2.485E-002	1.652E-003
		1587.90	3.71		
U-235	0.522	89.96*	1.50	1.175E-001	2.066E-002
		93.35*	2.50	6.144E-002	8.753E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	1.252E-003	8.446E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:57:06 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.70	2.2654E+000	2.77
18	583.20	8.1688E+000	1.84

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

West Delta General Bucket

Nuclide Identification Report 6/15/2004 4:53:06 PM Page 1

****
***** N U C L I D E I D E N T I F I C A T I O N R E P O R T *****
****

Sample Title: Sample title.
Nuclide Library Used: C:\GENIE2K\CAMFILES\pipescale.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
BI-212	0.594	39.86	1.10		
		727.17*	11.80	8.970E-003	3.703E-004
		785.42	2.00		
		1620.56	2.75		
PB-212	0.986	74.81*	9.60	3.939E-002	1.742E-002
		77.11*	17.50	2.853E-002	1.158E-002
		87.20*	6.30	2.375E-002	4.968E-003
		89.80*	1.75	5.438E-002	9.525E-003
		115.19	0.60		
		238.63*	44.60	1.462E-002	1.122E-003
		300.09*	3.41	1.345E-002	9.083E-004
BI-214	0.552	609.31*	46.30	6.581E-003	2.944E-004
		768.36	5.04		
		806.17	1.23		
		934.06	3.21		
		1120.29*	15.10	6.468E-003	2.111E-004
		1155.19	1.69		
		1238.11	5.94		
		1280.96	1.47		
		1377.67	4.11		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.49*	15.80	7.168E-003	2.620E-004
		1847.44	2.12		
		2118.54	1.21		
PB-214	0.819	74.81*	6.33	5.974E-002	2.641E-002
		77.11*	10.70	4.666E-002	1.894E-002
		87.20*	3.70	4.044E-002	8.458E-003
		89.80*	1.03	9.240E-002	1.618E-002
		241.98	7.49		
		295.21*	19.20	7.974E-003	5.279E-004
		351.92*	37.20	7.730E-003	5.016E-004
		785.91	1.10		
RA-226	0.999	186.21*	3.28	1.003E-002	6.657E-004
AC-228	0.771	89.95*	2.10	4.532E-002	7.938E-003
		93.35*	3.50	2.348E-002	3.337E-003
		129.08*	2.80	1.358E-002	1.187E-003
		209.28*	4.40	1.455E-002	9.164E-004

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
AC-228	0.771	270.23*	3.60	1.403E-002	8.995E-004
		327.64*	3.20	1.415E-002	9.196E-004
		338.32*	11.40	1.622E-002	1.087E-003
		409.51	2.13		
		463.00*	4.40	1.474E-002	7.349E-004
		794.70	4.60		
		911.60*	27.70	1.506E-002	5.429E-004
		964.60	5.20		
		969.11*	16.60	1.379E-002	9.789E-004
		1587.90	3.71		
U-235	0.520	89.96*	1.50	6.345E-002	1.111E-002
		93.35*	2.50	3.287E-002	4.672E-003
		105.00	1.00		
		109.14	1.50		
		143.76	10.50		
		163.35	4.70		
		185.71*	54.00	6.093E-004	4.161E-005
		202.12	1.00		
		205.31	4.70		

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 6/15/2004 4:52:42 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 8192

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
17	510.67	1.3094E+000	2.82
18	583.16	4.6608E+000	2.36

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

APPENDIX D

LABSOCS GEOMETRY COMPOSER REPORT FILE

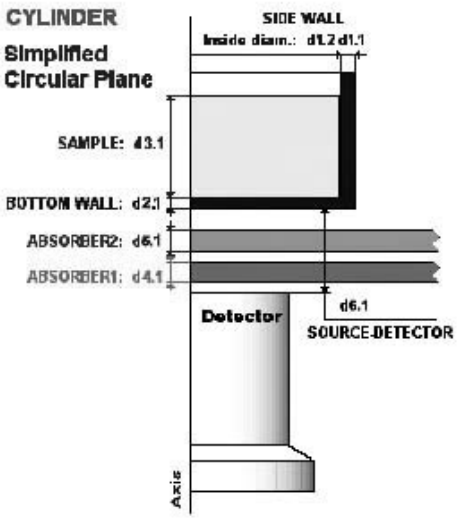
Geometry Composer Report

Date: Thursday, June 10, 2004
Description: none
Comment: none
File Name: C:\GENIE2K\Isocs\Data\Geometry\Laboratory\CYLINDER_DISK_AND_POINT\MLeff.geo
Software: LabSOCS
Template: CYLINDER_DISK_AND_POINT, Version: cylinder
Detector: 7707
Environment: Temperature= 22 C, Pressure= 760 mmHg, Rel.Humidity= 30%
Integration: Convergence= 1.00%, MDRPN= 2^(4) CRPN= 2^(4)

#	Geometry Compon.	Dimensions (cm): d1	d2	d3	d4	d5	d6	Material	D(g/cm3)	R.Conc.
1	Side Walls	0.24	5.11					glass	2.60	
2	Bottom Walls	0.34						glass	2.60	
3	Sample	0.32						pscalem1	2.30	
4	Absorber1							none		
5	Absorber2							none		
6	Source-Detector									

List of energies for efficiency curve generation:

100.0 150.0 200.0 300.0 500.0 700.0 1000.0 1400.0 2000.0



APPENDIX E

PARENT AND DAUGHTER ACTIVITIES AND THEIR RESPECTIVE RADON AND THORON ACTIVITIES

LS General Bucket		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	9.65E-03	4.51E-04
Pb-214	1.17E-02	5.66E-04
Ra-226	1.49E-02	1.03E-03
Ra-226	**1.09E-02**	**3.34E-04**

LS General Bucket		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	3.64E-03	1.55E-04
Pb-212	5.08E-03	5.13E-04
Ra-224	**3.76E-03**	**1.49E-04**

LS > 297		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	8.442E-03	3.831E-04
Pb-214	1.007E-02	4.761E-04
Ra-226	1.294E-02	8.810E-04
Ra-226	**9.480E-03**	**2.827E-04**

LS > 297		
Th232		
Nuclide	Activity [uCi/gram]	Error [uCi/gram]
Bi-212	3.124E-03	1.326E-04
Pb-212	4.919E-03	3.371E-04
Ra-224	**3.365E-03**	**1.234E-04**

LS 297 > x > 105		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	1.125E-02	5.087E-04
Pb-214	1.372E-02	6.520E-04
Ra-226	1.779E-02	1.223E-03
Ra-226	**1.273E-02**	**3.811E-04**

LS 297 > x > 105		
Th232		
Nuclide	Activity [uCi/gram]	Error [uCi/gram]
Bi-212	4.268E-03	1.775E-04
Pb-212	6.828E-03	4.692E-04
Ra-224	**4.588E-03**	**1.660E-04**

LS < 105		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	1.177E-02	5.456E-04
Pb-214	1.437E-02	6.850E-04
Ra-226	1.842E-02	1.273E-03
Ra-226	**1.335E-02**	**4.046E-04**

LS < 105		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	4.386E-03	1.872E-04
Pb-212	5.756E-03	6.340E-04
Ra-224	**4.496E-03**	**1.795E-04**

WD General Bucket		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	6.581E-03	2.944E-04
Pb-214	7.846E-03	3.636E-04
Ra-226	1.003E-02	6.657E-04
Ra-226	**7.393E-03**	**2.164E-04**

WD General Bucket		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	8.970E-03	3.703E-04
Pb-212	1.391E-02	7.060E-04
Ra-224	**1.004E-02**	**3.279E-04**

WD > 297		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	4.033E-03	1.862E-04
Pb-214	4.884E-03	2.345E-04
Ra-226	6.399E-03	4.442E-04
Ra-226	**4.560E-03**	**1.385E-04**

WD > 297		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	6.349E-03	2.654E-04
Pb-212	9.973E-03	5.511E-04
Ra-224	**7.031E-03**	**2.391E-04**

WD 297 > x > 105		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	8.49E-03	4.69E-04
Pb-214	9.28E-03	5.39E-04
Ra-226	1.02E-02	9.66E-04
Ra-226	**8.99E-03**	**3.32E-04**

WD 297 > x > 105		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	1.11E-02	5.49E-04
Pb-212	1.43E-02	1.19E-03
Ra-224	**1.16E-02**	**4.98E-04**

WD < 105		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	1.33E-02	5.70E-04
Pb-214	1.58E-02	7.08E-04
Ra-226	2.06E-02	1.35E-03
Ra-226	**1.49E-02**	**4.22E-04**

WD < 105		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	1.59E-02	6.33E-04
Pb-212	2.52E-02	1.21E-03
Ra-224	**1.79E-02**	**5.60E-04**

ML General Bucket		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	2.35E-02	1.02E-03
Pb-214	2.85E-02	1.30E-03
Ra-226	3.62E-02	2.39E-03
Ra-226	**2.65E-02**	**7.63E-04**

ML General Bucket		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	7.32E-03	2.99E-04
Pb-212	1.15E-02	7.72E-04
Ra-224	**7.87E-03**	**2.79E-04**

ML > 297		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	1.85E-02	8.33E-04
Pb-214	2.23E-02	1.03E-03
Ra-226	2.83E-02	1.89E-03
Ra-226	**2.09E-02**	**6.13E-04**

ML > 297		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	5.60E-03	2.29E-04
Pb-212	8.80E-03	5.80E-04
Ra-224	**6.03E-03**	**2.13E-04**

ML 297 > x > 105		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	2.38E-02	1.04E-03
Pb-214	2.88E-02	1.31E-03
Ra-226	3.67E-02	2.43E-03
Ra-226	**2.68E-02**	**7.72E-04**

ML 297 > x > 105		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	7.44E-03	3.05E-04
Pb-212	1.16E-02	7.86E-04
Ra-224	**7.98E-03**	**2.84E-04**

ML < 105		
U238		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-214	2.79E-02	1.21E-03
Pb-214	3.36E-02	1.52E-03
Ra-226	4.21E-02	2.74E-03
Ra-226	**3.14E-02**	**8.94E-04**

ML < 105		
Th232		
Nuclide	Activity [uCi/gram	Error [uCi/gram
Bi-212	8.60E-03	3.45E-04
Pb-212	1.32E-02	9.06E-04
Ra-224	**9.17E-03**	**3.22E-04**

APPENDIX F

RADON AND THORON EMANATION FRACTIONS AND ALL ACCOMPANYING CALIBRATION FACTORS CALCULATIONS AND ERRORS PER FORMATION AND GRAIN SIZE

Formation	Grain Size	Electret	Initial Voltages			Error	Final Voltages			Error	Duration of Experiment [d]	General Cal Factor	Error	Individual Cal	Error	Measured Conc. [pCi/l]	Error	Conc - Bkgnd	Error	Measure Total Activty [pCi]	Error	w	wM
LS Radon	x>297	R1A	654	652	653	1	636	638	637	1	3.04E+00	2.07E+00	4.06E-04	1.06E+00	6.27E-02	2.55E+00	2.71E-01	1.44E+00	2.74E-01	5.07E+00	1.01E+00	9.78E-01	4.95E+00
		R1B	692	693	693	0.58	682	682	682	0	3.04E+00	2.09E+00	1.66E-04	1.08E+00	6.39E-02	1.68E+00	1.34E-01	5.70E-01	1.41E-01	1.96E+00	4.96E-01	4.06E+00	7.95E+00
	297>x>105	R2A	651	651	652	0.58	639	640	639	0.58	3.00E+00	2.07E+00	2.34E-04	1.01E+00	5.71E-02	1.93E+00	1.71E-01	8.26E-01	1.76E-01	3.05E+00	6.72E-01	2.21E+00	6.75E+00
		R2B	680	681	681	0.58	659	662	660	1.53	3.00E+00	2.08E+00	4.69E-04	8.93E-01	5.87E-02	3.25E+00	3.38E-01	2.15E+00	3.40E-01	8.94E+00	1.53E+00	4.25E-01	3.80E+00
	x<105	R3A	649	649	649	0	630	631	631	0.58	3.00E+00	2.07E+00	1.66E-04	8.81E-01	4.77E-02	2.96E+00	1.85E-01	1.85E+00	1.90E-01	7.81E+00	9.07E-01	1.22E+00	9.50E+00
		R3B	687	686	686	0.58	664	667	666	1.53	3.00E+00	2.09E+00	4.69E-04	9.51E-01	5.77E-02	3.30E+00	3.29E-01	2.19E+00	3.32E-01	8.59E+00	1.40E+00	5.11E-01	4.39E+00
	gb	R4A	531	531	530	0.58	518	521	521	1.73	3.00E+00	2.00E+00	5.24E-04	8.72E-01	4.87E-02	1.78E+00	3.20E-01	6.70E-01	3.23E-01	2.86E+00	1.39E+00	5.21E-01	1.49E+00
		R4B	666	666	665	0.58	649	651	651	1.15	3.00E+00	2.08E+00	3.71E-04	8.71E-01	4.86E-02	2.46E+00	2.49E-01	1.35E+00	2.52E-01	5.78E+00	1.12E+00	7.90E-01	4.57E+00
LS Thoron	x>297	R1A	636	635	635	0.58	621	619	621	1.15	3.00E+00	2.06E+00	3.71E-04	1.06E+00	6.27E-02	2.43E+00	2.54E-01	1.32E+00	2.57E-01	4.65E+00	9.47E-01	1.12E+00	5.19E+00
		R1B	679	679	680	0.58	655	654	655	0.58	3.00E+00	2.08E+00	2.34E-04	1.08E+00	6.39E-02	3.95E+00	2.67E-01	2.84E+00	2.70E-01	9.75E+00	1.09E+00	8.39E-01	8.19E+00
	297>x>105	R2A	640	640	639	0.58	624	625	624	0.58	3.05E+00	2.06E+00	2.34E-04	1.01E+00	5.71E-02	2.44E+00	1.90E-01	1.33E+00	1.94E-01	4.92E+00	7.68E-01	1.69E+00	8.33E+00
		R2B	660	660	660	0	635	634	635	0.58	3.05E+00	2.07E+00	1.66E-04	8.93E-01	5.87E-02	4.02E+00	2.79E-01	2.91E+00	2.82E-01	1.21E+01	1.42E+00	4.97E-01	6.01E+00
	x<105	R3A	629	629	630	0.58	604	604	603	0.58	3.05E+00	2.05E+00	2.34E-04	8.81E-01	4.77E-02	4.11E+00	2.58E-01	3.00E+00	2.61E-01	1.27E+01	1.30E+00	5.93E-01	7.50E+00
		R3B	661	661	661	0	626	625	626	0.58	3.05E+00	2.07E+00	1.66E-04	9.51E-01	5.77E-02	5.61E+00	3.53E-01	4.50E+00	3.55E-01	1.76E+01	1.75E+00	3.25E-01	5.73E+00
	gb	R4A	519	518	520	1	505	504	505	0.58	3.05E+00	1.99E+00	3.32E-04	8.72E-01	4.87E-02	2.36E+00	2.31E-01	1.25E+00	2.35E-01	5.35E+00	1.05E+00	9.13E-01	4.88E+00
		R4B	650	649	649	0.58	629	627	627	1.15	3.05E+00	2.06E+00	3.71E-04	8.71E-01	4.86E-02	3.44E+00	2.81E-01	2.34E+00	2.84E-01	9.98E+00	1.34E+00	5.60E-01	5.59E+00
WD Radon	x>297	R5A	675	675	674	0.58	646	646	646	0	3.05E+00	2.08E+00	1.66E-04	7.96E-01	4.53E-02	4.53E+00	2.73E-01	3.42E+00	2.76E-01	1.60E+01	1.58E+00	4.01E-01	6.41E+00
		R5B	668	668	668	0	637	637	637	0	3.05E+00	2.07E+00	0.00E+00	8.41E-01	4.76E-02	4.91E+00	2.77E-01	3.80E+00	2.81E-01	1.68E+01	1.56E+00	4.10E-01	6.88E+00
	297>x>105	R6A	679	679	679	0	598	597	597	0.58	3.05E+00	2.06E+00	1.66E-04	8.80E-01	5.28E-02	1.30E+01	7.85E-01	1.19E+01	7.86E-01	5.02E+01	4.49E+00	4.97E-02	2.49E+00
		R6B	659	659	659	0	564	564	564	0	3.05E+00	2.05E+00	0.00E+00	9.04E-01	5.16E-02	1.52E+01	8.68E-01	1.41E+01	8.69E-01	5.80E+01	4.87E+00	4.21E-02	2.44E+00
	x<105	R7A	672	672	671	0.58	534	534	533	0.58	3.05E+00	2.04E+00	2.34E-04	9.37E-01	5.08E-02	2.21E+01	1.21E+00	2.10E+01	1.21E+00	8.36E+01	6.60E+00	2.30E-02	1.92E+00
		R7B	686	686	685	0.58	547	545	546	1	3.05E+00	2.05E+00	3.32E-04	8.95E-01	5.02E-02	2.23E+01	1.27E+00	2.12E+01	1.27E+00	8.82E+01	7.23E+00	1.91E-02	1.69E+00
	gb	R8A	678	677	678	0.58	626	622	622	2.31	3.05E+00	2.07E+00	6.83E-04	9.62E-01	5.52E-02	8.60E+00	6.21E-01	7.50E+00	6.23E-01	2.90E+01	2.93E+00	1.17E-01	3.39E+00
		R8B	687	687	687	0	623	623	624	0.58	3.05E+00	2.07E+00	1.66E-04	8.65E-01	5.03E-02	1.01E+01	5.93E-01	8.96E+00	5.95E-01	3.85E+01	3.40E+00	8.65E-02	3.33E+00
WD Thoron	x>297	R5A	644	644	644	0	588	586	588	1.15	3.05E+00	2.05E+00	3.32E-04	7.96E-01	4.53E-02	9.06E+00	5.47E-01	7.95E+00	5.49E-01	3.72E+01	3.32E+00	9.05E-02	3.36E+00
		R5B	637	637	637	0	556	556	555	0.58	3.05E+00	2.04E+00	1.66E-04	8.41E-01	4.76E-02	1.31E+01	7.45E-01	1.20E+01	7.46E-01	5.29E+01	4.46E+00	5.04E-02	2.67E+00
	297>x>105	R6A	597	597	597	0	423	422	422	0.58	3.05E+00	1.99E+00	1.66E-04	8.80E-01	5.28E-02	2.88E+01	1.73E+00	2.77E+01	1.73E+00	1.17E+02	1.02E+01	9.70E-03	1.14E+00
		R6B	564	564	565	0.58	287	287	288	0.58	3.05E+00	1.94E+00	2.34E-04	9.04E-01	5.16E-02	4.68E+01	2.67E+00	4.57E+01	2.67E+00	1.88E+02	1.54E+01	4.24E-03	7.97E-01
	x<105	R7A	532	532	532	0	232	232	233	0.58	3.05E+00	1.92E+00	1.66E-04	9.37E-01	5.08E-02	5.13E+01	2.78E+00	5.02E+01	2.78E+00	1.99E+02	1.54E+01	4.19E-03	8.35E-01
		R7B	545	545	545	0	183	180	182	1.53	3.05E+00	1.91E+00	4.39E-04	8.95E-01	5.02E-02	6.25E+01	3.52E+00	6.14E+01	3.52E+00	2.55E+02	2.05E+01	2.39E-03	6.09E-01
	gb	R8A	612	611	611	0.58	482	481	482	0.58	3.05E+00	2.01E+00	2.34E-04	9.62E-01	5.52E-02	2.11E+01	1.22E+00	2.00E+01	1.22E+00	7.75E+01	6.49E+00	2.38E-02	1.84E+00
		R8B	624	622	623	1	437	437	436	0.58	3.05E+00	2.00E+00	3.32E-04	8.65E-01	5.03E-02	3.05E+01	1.79E+00	2.94E+01	1.79E+00	1.27E+02	1.06E+01	8.83E-03	1.12E+00
ML Radon	x>297	R1A	608	608	609	0.58	589	588	588	0.58	3.05E+00	2.04E+00	2.34E-04	1.06E+00	6.27E-02	3.21E+00	2.31E-01	2.11E+00	2.35E-01	7.42E+00	9.38E-01	1.14E+00	8.44E+00
		R1B	636	635	635	0.58	608	610	609	1	3.05E+00	2.06E+00	3.32E-04	1.08E+00	6.39E-02	4.20E+00	3.09E-01	3.10E+00	3.12E-01	1.06E+01	1.24E+00	6.51E-01	6.92E+00
	297>x>105	R2A	605	606	605	0.58	575	575	575	0	3.05E+00	2.04E+00	1.66E-04	1.01E+00	5.71E-02	4.89E+00	2.92E-01	3.78E+00	2.95E-01	1.39E+01	1.34E+00	5.55E-01	7.73E+00
		R2B	612	613	612	0.58	577	577	580	1.73	3.05E+00	2.04E+00	5.24E-04	8.93E-01	5.87E-02	5.52E+00	4.67E-01	4.41E+00	4.68E-01	1.84E+01	2.29E+00	1.90E-01	3.49E+00
	x<105	R9A	675	677	675	1.15	610	610	612	1.15	3.05E+00	2.07E+00	4.69E-04	8.93E-01	5.35E-02	1.03E+01	6.70E-01	9.21E+00	6.71E-01	3.84E+01	3.62E+00	7.64E-02	2.93E+00
		R9B	657	656	656	0.58	577	577	577	0	3.05E+00	2.05E+00	1.66E-04	9.76E-01	5.40E-02	1.27E+01	7.08E-01	1.16E+01	7.10E-01	4.41E+01	3.65E+00	7.52E-02	3.32E+00
	gb	R10A	669	670	670	0.58	637	640	638	1.53	3.05E+00	2.07E+00	4.69E-04	8.99E-01	5.01E-02	4.96E+00	3.78E-01	3.85E+00	3.80E-01	1.59E+01	1.81E+00	3.07E-01	4.88E+00
		R10B	661	660	660	0.58	626	627	627	0.58	3.05E+00	2.07E+00	2.34E-04	9.30E-01	5.30E-02	5.34E+00	3.31E-01	4.23E+00	3.33E-01	1.69E+01	1.65E+00	3.69E-01	6.25E+00
ML Thoron	x>297	R1A	588	586	587	1	564	565	564	0.58	3.05E+00	2.03E+00	3.32E-04	1.06E+00	6.27E-02	3.67E+00	2.87E-01	2.56E+00	2.90E-01	9.01E+00	1.15E+00	7.54E-01	6.79E+00
		R1B	611	611	608	1.73	567	568	566	1	3.05E+00	2.04E+00	5.74E-04	1.08E+00	6.39E-02	6.93E+00	5.20E-01	5.82E+00	5.22E-01	2.00E+01	2.14E+00	2.18E-01	4.35E+00
	297>x>105	R2A	575	575	574	0.58	512	512	512	0	3.05E+00	2.01E+00	1.66E-04	1.01E+00	5.71E-02	1.02E+01	5.86E-01	9.12E+00	5.88E-01	3.36E+01	2.88E+00	1.20E-01	4.04E+00
		R2B	578	581	578	1.73	542	542	543	0.58	3.05E+00	2.02E+00	5.24E-04	8.93E-01	5.87E-02	5.96E+00	4.91E-01	4.85E+00	4.93E-01	2.02E+01	2.44E+00	1.68E-01	3.39E+00
	x<105	R9A	611	609	609	1.15	530	529	530	0.58	3.05E+00	2.02E+00	3.71E-04	8.93E-01	5.35E-02	1.30E+01	8.04E-01	1.19E+01	8.05E-01	4.94E+01	4.47E+00	5.00E-02	2.47E+00
		R9B	576	575	575	0.58	430	430	429	0.58	3.05E+00	1.99E+00	2.34E-04	9.76E-01	5.40E-02	2.41E+01	1.34E+00	2.29E+01	1.34E+00	8.75E+01	7.04E+00	2.02E-02	1.77E+00
	gb	R10A	637	636	636	0.58	602	603	602	0.58	3.05E+00	2.05E+00	2.34E-04	8.99E-01	5.01E-02	5.43E+00	3.29E-01	4.32E+00	3.32E-01	1.79E+01	1.70E+00	3.48E-01	6.21E+00
		R10B	627	626	627	0.58	572	572	571	0.58	3.05E+00	2.04E+00	2.34E-04	9.30E-01	5.30E-02	8.84E+00	5.20E-01	7.73E+00	5.22E-01	3.09E+01	2.73E+00	1.34E-01	4.14E+00

Average Activity [pCi]	Radon Error	Average Thoron Activity [pCi]	Thoron Error	HPGe Radium Activity [uCi/g]	Grams per sample	HPGe Radium Activity [pCi]	Error	Ra Decay Constant [d^-1]	Rn Decay Constant [d^-1]	Total Radon/Thoron Activity [pCi]	Error	Emanation Fraction by Grain Size	Error
2.56E+00	4.45E-01			9.48E-03	10.00	9.48E+04	2.83E+03	1.19E-06	1.81E-01	5.22E+04	1.56E+03	4.90E-05	8.65E-06
4.00E+00	6.15E-01			1.27E-02	10.00	1.27E+05	3.81E+03	1.19E-06	1.81E-01	6.92E+04	2.07E+03	5.77E-05	9.06E-06
8.04E+00	7.61E-01			1.34E-02	10.00	1.34E+05	4.05E+03	1.19E-06	1.81E-01	7.26E+04	2.20E+03	1.11E-04	1.10E-05
4.62E+00	8.73E-01			1.09E-02	10.00	1.09E+05	3.34E+03	1.19E-06	1.81E-01	5.93E+04	1.82E+03	7.79E-05	1.49E-05
6.84E+00	7.15E-01	4.28E+00	8.43E-01	3.37E-03	10.00	3.37E+04	1.23E+03	1.89E-01	1.08E+03	8.30E+07	3.04E+06	8.25E-08	9.14E-09
6.55E+00	6.76E-01	2.55E+00	9.14E-01	4.59E-03	10.00	4.59E+04	1.66E+03	1.89E-01	1.08E+03	1.14E+08	4.14E+06	5.72E-08	6.26E-09
1.44E+01	1.04E+00	6.37E+00	1.29E+00	4.50E-03	10.00	4.50E+04	1.80E+03	1.89E-01	1.08E+03	1.12E+08	4.48E+06	1.29E-07	1.06E-08
7.11E+00	8.24E-01	2.48E+00	1.20E+00	3.76E-03	10.00	3.76E+04	1.49E+03	1.89E-01	1.08E+03	9.38E+07	3.72E+06	7.58E-08	9.28E-09
1.64E+01	1.11E+00			4.56E-03	10.00	4.56E+04	1.39E+03	1.19E-06	1.81E-01	2.52E+04	7.65E+02	6.51E-04	4.83E-05
5.38E+01	3.30E+00			8.99E-03	10.00	8.99E+04	3.32E+03	1.19E-06	1.81E-01	4.97E+04	1.83E+03	1.08E-03	7.75E-05
8.57E+01	4.87E+00			1.49E-02	10.00	1.49E+05	4.22E+03	1.19E-06	1.81E-01	8.23E+04	2.33E+03	1.04E-03	6.61E-05
3.30E+01	2.22E+00			7.39E-03	10.00	7.39E+04	2.16E+03	1.19E-06	1.81E-01	4.09E+04	1.20E+03	8.09E-04	5.92E-05
4.28E+01	2.66E+00	2.64E+01	2.89E+00	7.03E-03	10.00	7.03E+04	2.39E+03	1.89E-01	1.08E+03	1.75E+08	5.96E+06	2.44E-07	1.73E-08
1.39E+02	8.47E+00	8.48E+01	9.09E+00	1.16E-02	10.00	1.16E+05	4.98E+03	1.89E-01	1.08E+03	2.89E+08	1.24E+07	4.79E-07	3.58E-08
2.20E+02	1.23E+01	1.34E+02	1.33E+01	1.79E-02	10.00	1.79E+05	5.60E+03	1.89E-01	1.08E+03	4.47E+08	1.40E+07	4.92E-07	3.16E-08
9.08E+01	5.54E+00	5.77E+01	5.97E+00	1.00E-02	10.00	1.00E+05	3.28E+03	1.89E-01	1.08E+03	2.50E+08	8.18E+06	3.62E-07	2.51E-08
8.58E+00	7.48E-01			2.09E-02	10.00	2.09E+05	6.13E+03	1.19E-06	1.81E-01	1.16E+05	3.39E+03	7.43E-05	6.83E-06
1.51E+01	1.16E+00			2.68E-02	10.00	2.68E+05	7.72E+03	1.19E-06	1.81E-01	1.48E+05	4.27E+03	1.02E-04	8.35E-06
4.12E+01	2.57E+00			3.14E-02	10.00	3.14E+05	8.94E+03	1.19E-06	1.81E-01	1.74E+05	4.94E+03	2.38E-04	1.63E-05
1.65E+01	1.22E+00			2.65E-02	10.00	2.65E+05	7.63E+03	1.19E-06	1.81E-01	1.46E+05	4.22E+03	1.13E-04	8.92E-06
1.15E+01	1.01E+00	2.88E+00	1.26E+00	6.03E-03	10.00	6.03E+04	2.13E+03	1.89E-01	1.08E+03	1.50E+08	5.31E+06	7.62E-08	7.26E-09
2.58E+01	1.86E+00	1.07E+01	2.19E+00	7.98E-03	10.00	7.98E+04	2.84E+03	1.89E-01	1.08E+03	1.99E+08	7.08E+06	1.30E-07	1.04E-08
6.03E+01	3.77E+00	1.91E+01	4.56E+00	9.17E-03	10.00	9.17E+04	3.22E+03	1.89E-01	1.08E+03	2.29E+08	8.03E+06	2.64E-07	1.89E-08
2.15E+01	1.44E+00	5.03E+00	1.89E+00	7.87E-03	10.00	7.87E+04	2.79E+03	1.89E-01	1.08E+03	1.96E+08	6.96E+06	1.10E-07	8.30E-09

APPENDIX G

ERROR PROPAGATION EQUATIONS NOT LISTED IN TEXT

The following equations from chapter three of Knoll pages 87-89 were used for error propagation

For addition or subtraction of two numbers with an associated error:

$$\sigma_c = \sqrt{\sigma_a^2 + \sigma_b^2}$$

For multiplication or division of two numbers with an associated error:

$$\left(\frac{\sigma_c}{c}\right)^2 = \left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2$$

which, when solved for error is:

$$\sigma_c = c\sqrt{\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2}$$

For multiplying by a constant with no associated error:

$$\sigma_b = A\sigma_x$$

For dividing by a constant with no associated error:

$$\sigma_b = \frac{\sigma_x}{A}$$

APPENDIX H

NIST SOURCE CERTIFICATE FILE

PROPERTIES OF SRM 4968
(Certified values are shown in bold type)

Source identification number	NIST SRM 4968-129		
Physical Properties:			
Source description	Liquid in heat-sealed polyethylene capsule		
Capsule specifications	Right circular cylinder of low-density polyethylene. Nominal inside diameter of polyethylene = 0.34 cm Nominal outside diameter of polyethylene = 0.45 cm Nominal inside length of polyethylene = 1.7 cm Nominal outside length of polyethylene = 2.0 cm Nominal polyethylene mass = 0.19 g Nominal solution mass = 0.14 g		
Total capsule mass	(0.339 ± 0.002) g [b]		
Chemical Properties:			
Solution composition	Chemical Formula	Concentration ($mol \cdot L^{-1}$)	Mass Fraction ($g \cdot g^{-1}$)
	H_2O	54	0.95
	HCl	1.4	0.05
	$BaCl_2$	0.008	0.002
	$^{226}RaCl_2$	6×10^{-10}	2×10^{-10}
Radiological Properties:			
Radionuclide	**Radium-226 / Radon-222**		
Reference time	**1200 EST, 15 September 1998**		
Radium-226 activity	**4.716 Bq**		
Relative expanded uncertainty (k=2) of the radium-226 activity	**1.4%** [d] [e]		
Radon-222 emanation fraction [c]	**0.884 at 21°C**		
Relative expanded uncertainty (k=2) of the radon-222 emanation fraction	**5.2%** [d] [e]		
Half lives used	Radon-222: (3.8235 ± 0.0003) d [f] [5] Radium-226: (1600 ± 7) a [f] [5]		
Measuring instrument(s) and calibration method for the radium-226 activity	Pressurized "4π"γ ionization chamber "A" calibrated using national radium standards, liquid scintillation spectrometry, and pulse ionization chamber radon analyses. [g]		
Measuring instrument(s) and calibration method for the radon-222 emanation fraction	Pulse ionization chambers (part of the NIST primary radon measurement system [6,7]) calibrated using national radium standards [g].		

VITA

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EDUCATION

Texas A&M University (TAMU), College Station, TX
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EMPLOYMENT

August 2003-August 2004
- Graduate Assistant
- TAMU Nuclear Engineering Department, College Station, TX
  - Responsible for class preparation and grading assignments for junior and senior level radiation detection and radiation physics classes

November 2002-Present
- Health Physics Assistant
- Foxfire Scientific, College Station, TX
  - Responsible for locating references needed for health physics related research and compiling data in a presentable/readable form

January 2002-August 2003
- Radiation Safety Technician
- TAMU Environmental Health & Safety Office, College Station, TX
  - Responsible for ensuring safe transportation of radioactive materials, and safety of the researchers in the labs using radioactive materials

PUBLICATIONS, CERTIFICATIONS, ACTIVITIES, AND HONORS

- Published Researcher (2003)
  - In situ gamma spectroscopic analysis of the vault and components of a 30MeV cyclotron in preparation for decommissioning. Cezeaux JR, Fruchtnicht EH, Hicks AL, Jimenez SM, Stoicescu L, Turley RS, Watson JA. Texas A&M University Undergrad Journal of Science. College Station, TX. 2003;3(2):20-25.
- Sigma Xi Student Presenter (2002)
- Radiation Worker Certification (2002)
- National Dean's List 22nd Ed. Vol.2, p. 172, P-64 (1999)