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HETEROGENEITY EFFECTS IN PLUTONIUM CONTAMINATED SOIL

THESIS

Orlando M. Chaparro, Captain, USMC

AFIT/GES/ENV/09-M01

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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HETEROGENEITY EFFECTS IN PLUTONIUM CONTAMINATED SOIL

THESIS

Presented to the Faculty

Department of Environmental and Engineering Management

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In Partial Fulfillment of the Requirements for the

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Orlando M. Chaparro

Captain, USMC

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Abstract

In 1960 at the McGuire Air Force Base, New Egypt, New Jersey a helium tank ruptured causing a fire to ignite a nearby nuclear tipped Boeing Michigan Aeronautical Research Center (BOMARC) missile. During the fire the weapons grade plutonium (Pu-239, Pu-240, and Pu-241) ignited and was released into the surrounding area, due to both firefighting efforts, where high pressure water was used to put out the fire, as well as smoke that deposited plutonium as oxidized particles in the surrounding area (Cicotte, 2007). This study investigates the heterogeneity of the distributed plutonium contamination in the McGuire Air Force Base BOMARC missile site soil based upon direct measurements of Am-241, a decay product of Pu-241. The heterogeneity of soil samples taken from the BOMARC missile site was quantified using a conjugate counting method with gamma spectroscopy analysis. Plutonium was shown to be heterogeneously distributed in the BOMARC missile site soil. The physical properties of the heterogeneously distributed plutonium contamination evaluated in this research likely consist of individual particles of plutonium metal alloys. The fate of these particles in the environment as they continuously are exposed to weathering and other physical factors is unknown.

Acknowledgments

I would like to express my utmost appreciation and thanks to my advisor for his continued guidance, support, inspiration, and mentorship throughout the thesis process. I would also like to thank my committee members, for their guidance and assistance.

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Orlando M. Chaparro

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Acronyms

AF	Air Force
BOMARC	Boeing Michigan Aeronautical Research Center
Bq	Becquerel
Sv	Sievert
Ci	Curie
EPA	Environmental Protection Agency
FIDLER	Field Instrument for Detecting Low Energy Radiation
GI	gastrointestinal tract
HpGe	hyperpure germainum
ICRP	International Commission on Radiological Protection
keV	kilo electron Volts
nCi	nanocurie
NCRP	National Council on Radiation Protection and Measurements
NTS	Nevada Test Site
pCi	picocurie
rad	radiation absorbed dose
RI	remedial investigation
rem	roetgen equivalent man
ROD	record of decision
UNLV	University of Las Vegas
WGP	weapons grade plutonium

HETEROGENEITY EFFECTS IN PLUTONIUM CONTAMINATED SOIL

I. Introduction

Background

In 1960 at McGuire Air Force Base, New Egypt, New Jersey a helium tank ruptured causing a fire to ignite a nearby nuclear tipped Boeing Michigan Aeronautical Research Center (BOMARC) missile. During the fire the weapons grade plutonium (WGP) ignited and was released into the surrounding area both due to firefighting efforts, where high pressure water was used to put out the fire, as well as smoke that deposited plutonium as oxidized particles in the surrounding area (Cicotte, 2007). Weapons grade plutonium is approximately 80-90% Pu-239 with additional isotopes of Pu-240 and Pu-241 including Am-241, the decay product of Am-241. Although the exact amount of plutonium released to the environment in 1960 is classified, estimates suggest that the amount that remained on site was 100g to 300g (Rademacher, 2001).

The exact amount of plutonium in soils is difficult to quantify. Much of the uncertainty involved with the sampling and analysis of plutonium contaminated soils is due to the discrete particulate properties of the plutonium metal alloys that were released during the accident (Rademacher, 2001). Practices have improved over the years in quantifying the heterogeneous distribution of plutonium particles. Chemical dissolution and alpha spectroscopy were used in the past in order to quantify the amount of plutonium in the soil. The use of gamma spectroscopy became more useful for soil

masses up to one kilogram once the ratio of Americium-241 (Am-241) and plutonium concentrations was established (Rademacher, 2001). Alpha spectroscopy is limited to analyzing very small samples (e.g., 1g) since the soil has to be dissolved in order to extract the plutonium. The restriction on sample size is a serious constraint when characterizing widely dispersed contamination in soil due to the presence of individual, heterogeneously distributed particles. Using gamma spectroscopy, larger mass amounts may be used to quantify plutonium levels in soil by measuring Am-241, the decay product of Pu-241. However, little research has been done in order to heterogeneously distributed particles (Rademacher, 2001).

Research Question

This study seeks to investigate whether plutonium contamination in the McGuire Air Force Base BOMARC missile site soil is heterogeneously distributed. Heterogeneously distributed contamination may suggest large, discrete particle formation of the Plutonium. Larger, heterogeneously distributed particles of insoluble plutonium compounds may exhibit a lower probability of biological uptake due to their inability to be suspended in the air and become respirable. The determination of a heterogeneous distribution of Plutonium contamination in the BOMARC missile site soil may potentially contribute to a greater extent of environmental stability and a lower probability of biological uptake than if the plutonium contamination were determined to be homogeneously distributed in smaller particles for similar activity concentrations. These findings may support further studies that characterize the plutonium contamination

such that a determination of a lower level of plutonium bioavailability may enable a less restrictive release criteria to be applied for remediation activities.

Methodology

Soil samples collected at the BOMARC missile site were analyzed for activity heterogeneity using dual counting methods with gamma spectroscopy using a hyper pure germanium (HpGe) counter. Each sample was partitioned into smaller aliquots in order to reduce the thickness of the sample to minimize attenuation of the 59.5 keV photons emitted by Am-241.

Except for Pu-241, plutonium isotopes have extremely long half-lives and decay by emitting alpha particles from the nucleus of the atom. The half-life of Pu-241 is only 14 years and it decays by beta particle emission to Am-241which emits a low energy (i.e. 59.5 keV) photon that is directly measureable in soil. Since the ratio between plutonium and Am-241 was established by Rademacher (2001) direct measure of Am-241 offers a reliable means to determine the quantity of plutonium in the soil. In order to account for the effects of heterogeneity in the analysis a conjugate counting method was used.

The conjugate counting method relies on a comparison of opposing geometric orientations when conducting analyses. If the activity in the soil contamination is homogeneously distributed, regardless of sample orientation, the measured activity will be constant. If the activity is heterogeneously distributed within each aliquot, then the measured activity will be highly dependent upon sample orientation (Rademacher 1999).

Purpose and Significance of Study

The objective of this study is to determine if plutonium (based on measurements of Am-241) is heterogeneously distributed in the soil. Heterogeneity may have implications with respect to plutonium transport and perceived activity concentrations in the environment. The focus of this study will be to quantify the heterogeneity of the plutonium distribution in the contaminated BOMARC missile site soil and what, if any, impact may occur regarding the fate of the plutonium contamination in the implications of the heterogeneous distribution on environmental transport of plutonium. Heterogeneity will be determined through the use of gamma spectroscopy analysis with the conjugate counting method.

Incidents, in which a fissile material such as plutonium contaminates the soil, as is the case with the BOMARC missile site at McGuire Air Force Base, are instructive as they may be used to determine how plutonium particles may behave in the environment.

Previous characterizations of the BOMARC site demonstrates that plutonium contamination, based upon direct measurements of Am-241, is heterogeneously distributed (Rademacher, 1999). This is fortunate, as risks may be less for larger heterogeneously distributed particles than if the material is homogeneously distributed with smaller more readily inhaled particles. Heterogeneously distributed activity among particles greatly reduces projected doses because a fraction of the contaminant is unavailable for air-suspension and unable to penetrate to deep portions of the lung where the greatest lung retention times are realized (Cicotte, 2007). Initial assays with such heterogeneously distributed material place unduly high weights on areas with large discrete particles, thereby increasing concentration estimates. The determination of a

heterogeneous distribution of plutonium contamination in the BOMARC missile site soil may potentially contribute to a greater extent of environmental stability and a lower probability of biological uptake than if the Plutonium contamination were determined to be homogeneously distributed in smaller particles for similar activity concentrations.

Plutonium oxides are resistant to dissolution and environmental weathering. Plutonium dioxide specifically, is the most environmentally stable of the plutonium oxides and is readily formed under a variety of conditions to include the ignition of plutonium in air as was the case of the Plutonium at the BOMARC site (Cicotte, 2007). Analysis by the University of Las Vegas (UNLV) shows the plutonium contaminant's resistance to vertical movement within the soil column for a period of approximately 40 years (Cabrera, 2006). A prediction on the future bioavailability of the plutonium contamination in this soil is beyond the scope of this study. The correlation between the heterogeneous distribution of plutonium contamination in soil and bioavailability has yet to be determined with any significance. Further studies that fully characterize the discrete plutonium alloy particles and their behavior in the environment may be able to make a definitive determination of the effects of heterogeneity on plutonium contamination. These studies may be able to show a correlation that the bioavailability of plutonium alloys may be different than with homogeneously distributed contamination since resuspension of larger particles is unlikely.

II. Literature Review

Discovered in America during the early 20th century, plutonium has been used extensively for engineering and military purposes. Because of its unique history there has been extensive research regarding the effects of plutonium on the human physiology (Argonne National Laboratory, 2001).

Plutonium, in all forms, is radioactive. Plutonium (Pu) is a transuranic, reactive, silvery-white metal that readily oxidizes in warm, humid air (NCRP Report No. 65). Plutonium-239 (Pu-239) emits alpha particles, as do Plutonium-238 (Pu-238) and Plutonium-240 (Pu-240), and has a 24,400-year physical half-life (NCRP Report No. 65). Table 1 summarizes the composition of the weapons grade plutonium at the time of manufacture. Once in the body the biological half-life is estimated to be approximately 200 years in man, with the biological half-lives in the bone and liver being 100 and 40 years respectively (NCRP Report No. 65).

Table 1. Composition (by mass) of WGP in BOMARC Weapon (Rademacher, 2000)

Nuclide	Half-life (yr)	Mass Fraction in 1958	Specific Activity (Ci/g)
^{238}Pu	87.74	0.0099	17.12
^{239}Pu	24,110	0.937	0.062
^{240}Pu	6,560	0.056	0.227
^{241}Pu	14.35	0.0047	103.37
^{242}Pu	376,000	Negligible	0.004
^{241}Am	432.2*	N/A	3.43*

* values obtained and calculated from Handbook of Health Physics and Radiological Health, 3rd Ed., 1998.

Human Interaction

Alpha particles will travel less than 5 cm in air and are unable to penetrate paper 0.1 cm thick. Alpha particles are most dangerous when they are inside the body. Outside

the body the particles are unable to penetrate the outer dead layers of skin. Of the three ways that plutonium can enter the body, inhalation, open wounds and ingestion, inhalation is the most dangerous although the most frequently encountered incident involving plutonium exposure occurs by wounds (Cember, 1996). Contamination of the skin by plutonium, as may be found with contaminated wounds, may result in long-term presence of plutonium at that site. This may potentially lead to the development of sarcoma or carcinoma although no cases have been reported to date (NCRP Report No. 65). Ingestion is the pathway of least concern due to the low solubility of plutonium, especially plutonium oxides. "Ingestion of plutonium results in the absorption of approximately 0.003 percent by the intestine" (NCRP Report No. 65). Once in the blood stream the plutonium will further partition off onto bone surfaces and to the liver with the remaining fraction distributing to other tissues in the body (Cember, 1996).

As the routes of contamination via contact and ingestion result in such negligible levels of risk, they are not focused on in this study. This study will focus on inhalation as the primary route of concern.

Inhalation

Inhalation is considered to be the most important route of exposure as it accounts for three out of four industrial exposure incidents (NCRP Report No. 65). As plutonium is primarily an alpha emitting particle, it is most dangerous if inhaled in the lungs where it may slowly partition into the bloodstream where the high linear energy transfer rate of alpha particles can impart thousands of ion pairs to tissue (Cember, 1996).

Inhaled particles that are of interest to this study comprise of relatively insoluble compounds as is the case of high-fired oxides that were resultant from low order detonations or fires as is the case with the BOMARC fire. Inhaled plutonium particle retention in the respiratory tract can be significant. Once inhaled, a fraction of the plutonium can enter the blood stream and subject adjacent lung tissue to ionizing radiation continuously over the course of months or years (NCRP Report No. 65).

The biological half-life associated with this partitioning is dependent on the composition of the compound. The default biological half-life for high-fired oxides exhibits a biological half-life of 1000 days in the pulmonary region of the lung whereas plutonium chloride will exhibit a biological half-life of approximately 150 days in the pulmonary region of the lung (NCRP Report No. 65). All regulations concerning inhalation and exposure values are based on the recommendations of the International Commission on Radiological Protection (ICRP). The ICRP publication 78 sets the recommended annual limit on intake (ALI) by either ingestion or inhalation for Pu-239 at 200 Bq for inhalation class W and 500 Bq for inhalation class Y. These exposures are encompassed in the ICRP recommended annual dose equivalent of 0.05 Sv for radiation workers to include external and internal exposures. The inhalable limits are based on the annual dose equivalent limits such that they could inhale the aforementioned ALI values and still be in keeping with the annual dose equivalent limit.

Plutonium Sources

Although plutonium is found in nature in trace amounts, most notably in the natural Oklo reactor in Africa, it is generally considered to be a man made element (Amarillo National Resource Center for Plutonium, 1998). There are several sources of anthropogenic plutonium in the environment. The most abundant source is nuclear weapons testing. Although Pu-239 is the main component of nearly all atomic weapon devices there are other isotopes of plutonium that are included in the definition of "weapons grade" material (Perelygin and Chuburkov, 1997). Prior to the 1960s, nuclear weapon testing was conducted above ground via atmospheric detonations.

These tests continued throughout the last century by countries that had nuclear technologies. The above ground testing of nuclear weapons in the late 1950s and 1960s released about five tons of plutonium into the earth's atmosphere (Taylor 1995). After 1960, testing was primarily conducted underground, which resulted in a reduction in surface nuclear material deposition. Even so, in places like the Nevada Test Site (NTS), in south western Arizona, there is a significant amount of plutonium and other contaminants left over from testing done over half a century ago (Turner et al 2003). However, the chemical and physical form of the plutonium contamination derived from a weapons test is different that the residual plutonium soil contamination produced as a result of the BOMARC incident.

BOMARC Contamination

A costly and time consuming remediation of the McGuire Air Force Base BOMARC site is still underway in order to reduce the site activity concentrations below the Environmental Protection Agency (EPA) screening criteria levels of 200 pCi/m^2 for plutonium (Chanin et al, 1996). There is a significant amount of affected soil to be considered. On the 218 acres of the BOMARC site, approximately 160 cubic yards of soil was contaminated at concentrations above the accepted EPA screening criteria levels.

Hand held devices used in obtaining field measurements such as the Field Instrument for Detecting Low Energy Radiation (FIDLER) do not accurately portray the contamination levels if there is a heterogeneous distribution of contamination. Although the FIDLER is a specialized sodium-iodine (NaI) detector designed for measuring contamination such as WGP on site, it is not without problems. For example, an area that has a large discrete particle of contamination will be heavily weighted towards a higher concentration than is warranted. Likewise, counting methods for characterization of the soil with smaller soil samples also fail to address the potential for heterogeneity by assuming that the distribution of material within the sample is uniform and sampling from only one geometric orientation.

EPA Remediation Criteria

The EPA does work with other agencies to establish correct remediation criteria specific to each site to include the physical and chemical form of the radio nuclide, the exposure pathway, and an exposure probability to the public resulting in a one in a million risk of contracting cancer (Chanin et al, 1996). The screening level is used as a threshold value below which the area is not considered to be of a concern for

remediation. Those areas that exceed the threshold screening level are then reassessed for specific criteria germane to that site.

Hence for areas that exceed 200 pCi/m^2 for plutonium, a site specific assessment of exposure pathways is recommended by the EPA if the exposures that would result from occupancy of that area would result in an exposure that would exceed the criteria for public radiation protection. This allows for some flexibility and suitability in the determination of remediation levels for individual contamination sites.

Remediation Criteria Assumptions

Although the EPA procedurally seeks to attain the most suitable remediation criteria for individual sites, the criteria are all based on the assumption of homogeneously distributed contaminant. While the assessment of exposure pathways does make a determination of the risk associated with inhalable sizes, the screening levels that trigger the assessment are based on bulk counting methods. For example, an area that has large discrete particles of contamination heavily weights the assessment of that area towards a higher concentration than is warranted.

Plutonium Heterogeneity

The assumption of homogeneous distribution of contamination is not well founded with respect to plutonium contamination (Rademacher, 1999; Refosco, 2001). Previous studies have shown evidence that plutonium contamination is heterogeneously distributed in other areas such as the Nevada Test Site in Nevada where safety tests

resulted in the detonation of Plutonium and at the Johnston Atoll Site where aborted missile launch warheads were detonated (Rademacher, 1999).

The BOMARC site has also been characterized as having heterogeneous plutonium contamination (Rademacher, 1999; Rademacher, 2001; Cicotte, 2007). Recognizing this, recommendations for spot remediation of surface particles using the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) and final status survey methods (FSS) were made by Cabrera Services Inc. This would allow the site to come in compliance with EPA screening criteria levels and existing Record of Decision (ROD) conditions (Cabrera Services Inc, 2006).

Bioavailibility

The 2006 recommendations made by Cabrera Services, Inc were, in large part, due to the findings by the UNLV discrete particle study that highlighted the heterogeneous distribution of the Plutonium in the soil and characterized several aspects of the plutonium contamination transport potential.

III. Experimental Methodology

Sample Preparation

One hundred and six surface samples of approximately 300 grams each were taken from the BOMARC site in 2007. The samples were taken from the first five centimeters of the surface soil and other surfaces such as concrete and asphalt. The soil samples were then placed in a 15-centimeter diameter screw tight Petri dish that ranged from three centimeters to five centimeters in height. Minimal processing of the sample was conducted other than the removal of large sections of organic material. Fine sieving, blending or removal of sample moisture was not conducted.

Initial Sample Screening

Each of the 106 samples were then screened by gamma spectroscopy for 250 seconds each in order to identify which samples had activities that were in the range of interest, two to eight pCi/gm.

A Hyper Pure Germanium Detector (HpGe) with a coaxial germanium crystal height of 60 mm, a radius of 40 mm, $\rho = 5.3$ g cm^{-3} and a μ/ρ (60 keV) = 1.9 cm^{2} g^{-1}. Pre World War II steel shielding was used for gamma spectroscopy with the conjugate counting method used to conduct analysis. The samples that were identified to be of interest were then subdivided into smaller aliquots for investigation into the heterogeneity effects of the soil samples with reduced soil attenuation. The samples were processed to a uniform soil size. The soil was packed tightly into Lab-Tek standard sterile Petri dishes with a 60 mm diameter and a height ranging from 20 to 25 mm. The sides were taped

with standard black electrical tape and marked with a sample number and tared weight with a non-smearing marker. A standard control was then set using a point source of Americium-241 on an aluminum ring in order to ensure proper calibration.

Gamma Spectroscopy

Each of the Petri dishes was counted for 2,500 sec, first with the detector in contact with the top and then repeated with the detector in contact with the bottom of the dish. The counting time of 2,500 sec was adopted because it provided a relative uncertainty less than 5%, which is adequate for this research. The comparative gamma spectroscopy nuclide reports are show in Appendix C and D.

Each of the small Petri dishes was measured twice for Am-241, first with the detector in contact with the top of the dish and then the bottom of the dish. Photopeaks at 59.5 keV from Am-241 were detected in the samples and are a result of the decay of Pu-241, a minor constituent of weapons grade plutonium. The quantity of Am-241 detected in each sample can be related to the total content of plutonium, since the relationship between Am-241 and Pu-239 has been established. The results were then analyzed with the dual counting method. The aliquots were then shipped to the University of Cincinnati for further study.

IV. Experimental Results

Aggregate Heterogeneity

The results of the gamma spectroscopy using conjugate counting method show that the Plutonium is heterogeneously distributed in the soil samples. Of the 106 soil samples initially counted, only 10 were in excess of two pCi/gm Am-241. The ten soil samples were then divided into four or five sub-aliquots for further analysis. Each aliquot also showed significant heterogeneity that was most likely emphasized due to the reduction of soil attenuation by lowering soil height of the sample.

Table 3. Aggregate Soil Analysis Results

n=43	Mass	Up Orientation Pu 239 (pCi/gm)	Down Orientation Pu 239 (pCi/gm)	Mean of Up and Down Pu 239 (pCi/gm)
Mean	75.82	26.61	81.07	53.84
Median	78.20	10.37	20.84	15.34
%CV	12.59%	139.45%	221.93%	187.78%
Maximum	89.90	171.72	1042.20	575.10
Minimum	56.10	0.41	0.67	0.67
Max/Min	1.60	417.87	1564.15	856.59

Conjugate Counting Effects

Table 2 lists the plutonium activity determined by measuring the top and bottom of each sample, assuming a constant ratio for plutonium to Am-241, as well as the arithmetic mean. The coefficient of variation among the samples is very high which confirms that the activity is distributed very heterogeneously in the sample.

Activity Concentration Ratio Disparity

Figure 1 is a scatter plot showing the ratio of sample activity measured from the top and bottom versus the mean. All data points were normalized to values of one or greater e.g. if the ratio of the sample activity was a fraction less than one, the fraction was inverted such that a value of ¼ would be normalized to four. Figure 1 suggests that all sample activity concentrations show heterogenetiy deriving from what is very likely individual, discrete particles in each sample. This is most notable for sample activity concentrations that are above 10 pCi/gm. However, samples less than one pCi/gm also show this ratio disparity.

It should be noted that not all samples exhibited activity ratios representing a heterogeneous distributions of activity. This occurred in samples that exhibited lower mean activity concentrations. In general, as noted in other similar studies done on Plutonium soil contamination, heterogeneity effects were more common for samples of high mean activity concentration (Rademacher, 1999). Figure 1 supports this conclusion.

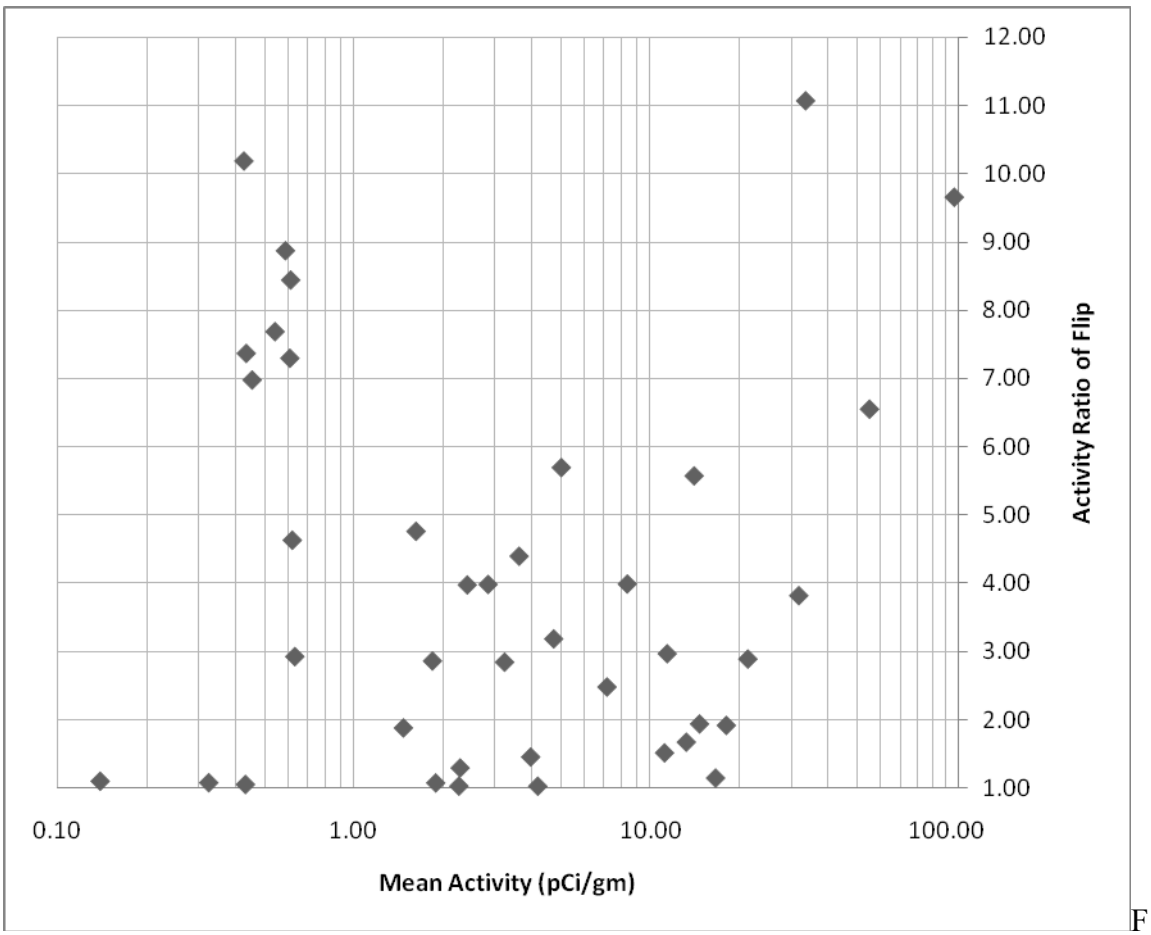

Figure 1. Activity Ratio of Up to Down Orientation vs. Sample Mean Activity

Sample Size Effects on Observed Heterogeneity

The selected sample size imacts the observed heterogeneous nature of the activity concentrations. The presence of a hot particle in a large sample size would increase the flip ratio due to attenuation. Smaller samples will have less self-absorption which would give a smaller flip ratio.

Hence the decision to include an aliquot partitioning of the soil samples not only reduced the percent variability of the detector through the reduction of soil attenuation,

but it also increases the mean activity of the soil samples thereby making the presence of heterogeniety clearly visible. A concern of reducing the soil sample mass is that the smaller aliquots of the larger sample may not be as representative of the sample whole. This is very important since one cannot adequately charcterize environmental contamination when the activity is heterogeneously distributed.

Heterogeneity Effects in Individual Samples

Figure 2 shows the aliquot activity concentration ratios of sample 4479. The activity ratio of aliquot 4479D clearly shows the presence of what is most likely one or more particles that accounts for the preponderance of activity in the sample. The ratio of the up to down orientations from the two counting trials suggest that the sample concentration was spatially positioned to have the effects from the attenuation of soil be clearly seen. Similar inferences can be made from the activity ratio of sample 7374 as seen in Appendix A. Figure 9. where the up orientation to down orientation ratio of aliquot 7374D is ten. Sample 4032 also shows this disparity where aliquot 4032B counting trial shows the down orientation counting trial gives an activity concentration greater than 40 times that of the up orientation.

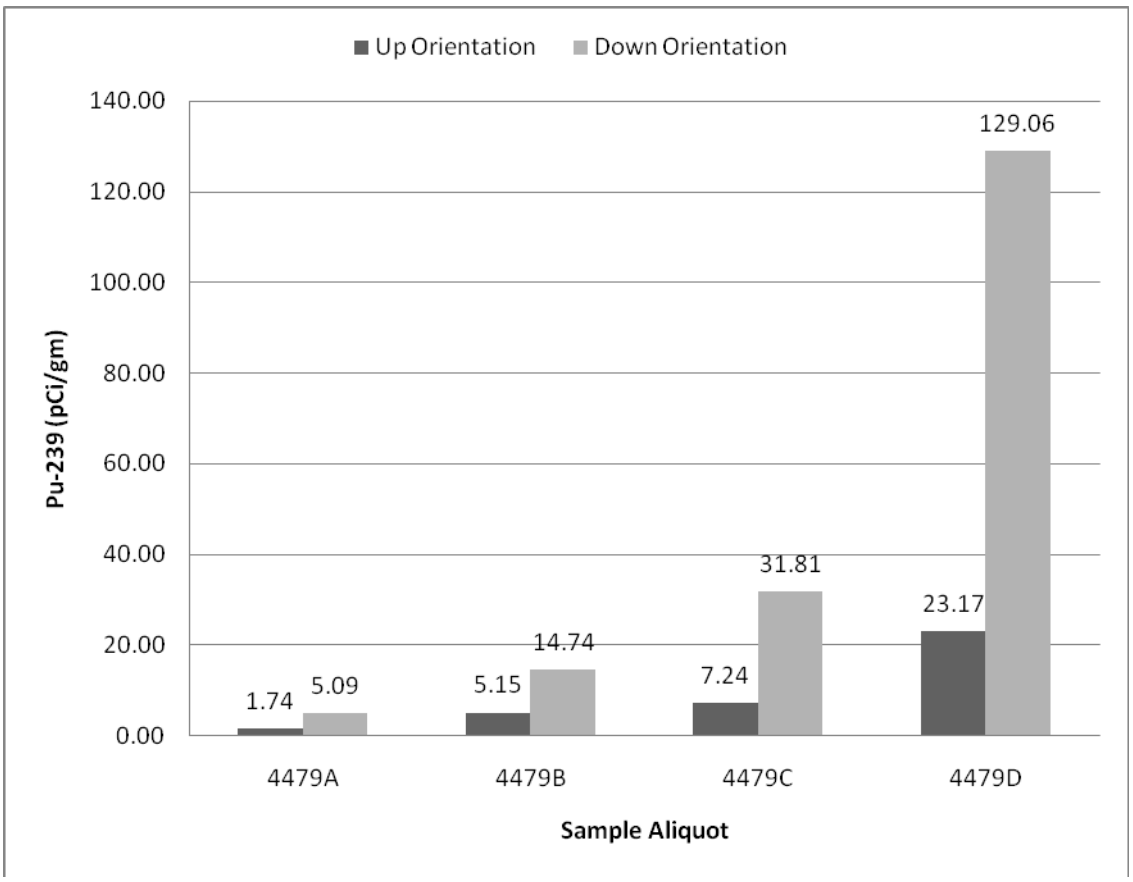

Figure 2. Sample 4479 Aliquot Activity Concentration Ratios

Figure 3 shows the distribution of the activity of the aliquots in sample 4479. Consistent with Figure 2, the significant fraction of activity is found in the aliquot of 4479D. With 70 percent of the activity localized in one aliquot, it is of note that the relative activities of the other three aliquots were low. This suggests that the heterogeneous nature of the activity distribution allows for a small mass of material to be removed in order to significantly reduce the aggregate activity concentration of the sample. Similar results are found in all of the other samples and their respective aliquots as seen in Appendix A. Sample 4032 for example has 98 percent of the activity distributed in only one of the aliquots. Once found, individual hot spots may be

remediated by localizing the area of activity and removing the localized activity concentration.

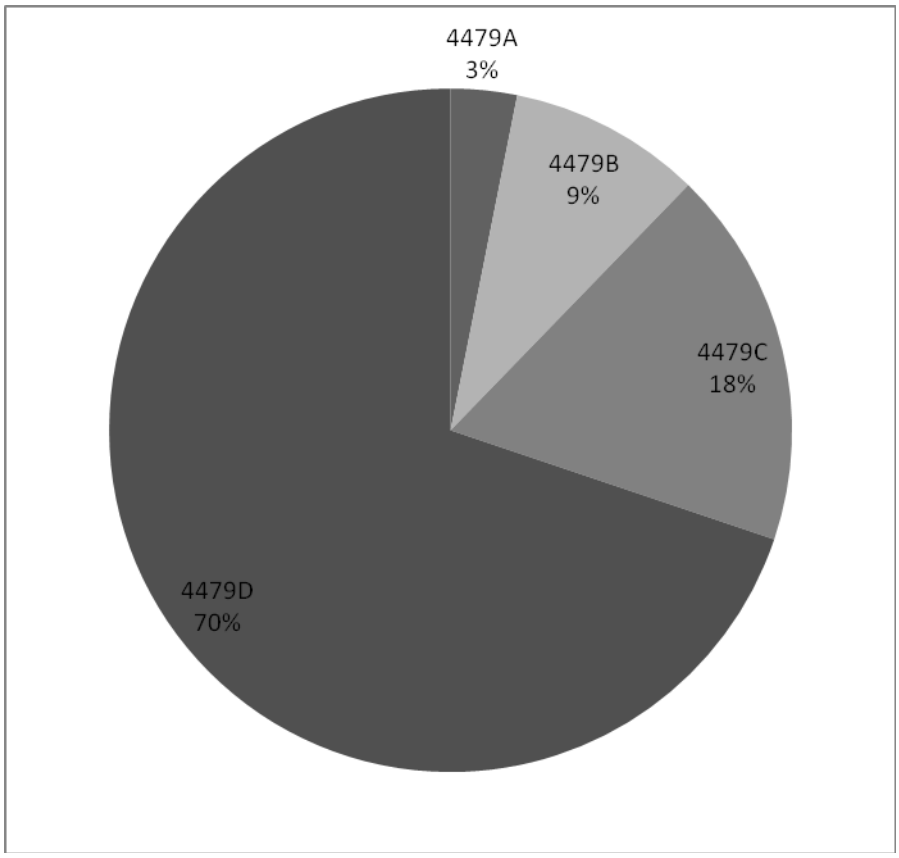

Figure 3. Sample 4479 Aliquot Activity Distribution

Table 2 shows the aggregate soil analysis results for sample 4479. The aliquot masses for sample 4479 show a coefficient of variance that are within the accepted margin of error of 10 percent. This is in contrast to the coefficient of variance for both the up and down orientations which were 101.93 and 126.19 percent respectively. This high level of variance within the alquot orientations suggests a high level of

heterogeneity which is in keeping with both Figure 2 and Figure 3. The mean up to down activity concentration is clearly an important parameter to measure. The mean activity for the entire sample is 27.25 pCi/gm for plutonium which is a significantly larger value than the 7.24 pCi/gm for plutonium from the up orientation. This is important to note due to the fact that if the sample had been analyzed with only one counting trial as is the standard practice, then the soil sample activity would have been underestimated. Likewise had the activity concentration been derived from the down orientation, then the activity concentration would have been incorrectly overestimated. These findings further reinforce the recommendation of conjugate counting for heterogeneously distributed Plutonium contamination.

Table 2. Sample 4479 Aggregate Soil Analysis Results

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean Up & Down (pCi/gm)
4479A	88.60	1.74	5.09	3.41
4479B	88.90	5.15	14.74	9.95
4479C	89.90	7.24	31.81	19.52
4479D	77.20	23.17	129.06	76.11
Mean	86.15	9.32	45.17	27.25
Median	88.60	7.24	31.81	19.52
%CV	6.96%	101.93%	126.19%	121.99%
Maximum	89.90	23.17	129.06	76.11
Minimum	77.20	1.74	5.09	3.41
Max/Min	1.16	13.32	25.37	22.30

V. Discussion and Implications of Research

Counting Methods

The use of hyper pure germanium detectors with gamma spectroscopy and conjugate counting methods is a viable method of determining if the distribution of the discrete particles of plutonium in a given sample mass is not homogeneously distributed. Counting methods that do not address the heterogeneous nature of Plutonium contamination will have inherent error when analyzing the results from gamma spectroscopy.

The conjugate counting method is based on accounting for the attenuation of gamma radiation from the 59.5 keV photon from Am-241. Attenuation from the soil will vary depending on the orientation of the discrete particle within the soil mass with respect to the detector. By comparing both sides of the sample via gamma spectroscopy, a more detailed and meaningful description of the soil activity may be made.

Regardless of counting method, if discrete particles of contamination are homogeneously distributed in the sample, then the conjugate counting method is likely to determine that the activity in the sample is homogeneously distributed. The gamma spectroscopy would then show results similar to the activity of a homogeneously distributed sample mass. It is therefore, important to make the reasonable assumption that the heterogeneous discrete particle masses are not spatially homogeneous within the sample space. However, it must also be assumed that the radioactive particles within a soil sample are heterogeneously distributed (Kennedy, 1990; Watts and Collins, 1992).

Samples will have varying levels of heterogeneity to the extent that some samples will either have all of their activity localized to a few particles or will have a close approximation of a homogeneous distribution of Plutonium (Rademacher, 1999).

Environmental Stability and Bioavailability

The environmental impacts that result from including the effects of heterogeneity on deposition and transport of Plutonium may be determined to be lower than if homogeneity is assumed in contaminated soil.

Particle characterization has shown the plutonium oxides to be especially resistant to environmental weathering. This suggests that once deposited into soil, the discrete plutonium particles will remain intact for at least several decades and not reduce in size or chemical composition in such a way as to increase their probability of becoming bio available by respiration. Plutonium also has a very low coefficient of solubility, which lowers its potential effects if plutonium particles were to enter the water table although it would remain there for a significant amount of time. Hence, once a particle of plutonium is deposited into soil, it remains there, in place, with little weathering effects from.

Field methods using instrumentation that is able to account for heterogeneity in soil contaminated with plutonium is preferred. Procedures that incorporate an evaluation for heterogeneous effects should also be used in conjunction with assays on plutonium contaminated soil.

This high level of environmental stability and low probability of biological uptake could allow for the possibility of future Plutonium contaminated site releases at a lower cost of remediation than has been historically undertaken.

Limitations

There are several clear limitations with respect to this study. The study looks at the presence of heterogeneity in a limited number of samples taken from the BOMARC missile site. This determination of heterogeneity does not describe or quantify the extent of the heterogeneity within the samples.

The determination of the presence of heterogeneity does not determine if the discrete particles are inherently whole particles of plutonium or are smaller particles attached to a larger inert particle. The study did not seek to isolate the individual particles of plutonium in the soil.

Future Research

Autoradiography would allow for individual particles to be isolated for further analysis with a scanning electron microscope. The use of a scanning electron microscope would be able to determine the physical characteristics of actual particles of contamination. In doing so questions with respect to the inherent risks derived from spherical aerodynamic equivalent diameter values with respect to maximum particle activity would be more accurately portrayed.

Further characterization of the discrete plutonium particles can be used to determine the chemical composition of the particles. The chemical composition gives some insight to the environmental stability of the particles. It would also allow for some determination to be made for a more extensive risk analysis. Studies involving the

chemical behavior of the discrete particles when suspended in lung fluid for example would be beneficial. Once the discrete particles were lodged in the lung, a partition coefficient specific to the BOMARC missile site contamination might be developed.

The question of long-term stability has been historically documented for a time frame of a few decades. Long-term stability of the discrete plutonium particles may be further studied using accelerated aging analysis. This would enable studies to more accurately predict the aging behavior of the contamination giving site release authorities information in order to make more informed decisions regarding remediation criteria for plutonium contaminated sites.

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Appendix A

Table 1. Soil Sampling Results for Sample 4029

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN) (pCi/gm)
4029A	62.40	48.06	72.90	60.48
4029B	70.10	22.19	55.08	38.64
4029C	60.00	10.37	5.51	7.94
4029D	74.60	10.75	13.93	12.34
Mean	66.78	22.84	36.86	29.85
Median	66.78	22.19	36.86	29.85
%CV	10.13%	77.42%	87.78%	82.11%
Maximum	74.60	48.06	72.90	60.48
Minimum	60.00	10.37	5.51	7.94
Max/Min	1.24	4.64	13.24	7.62

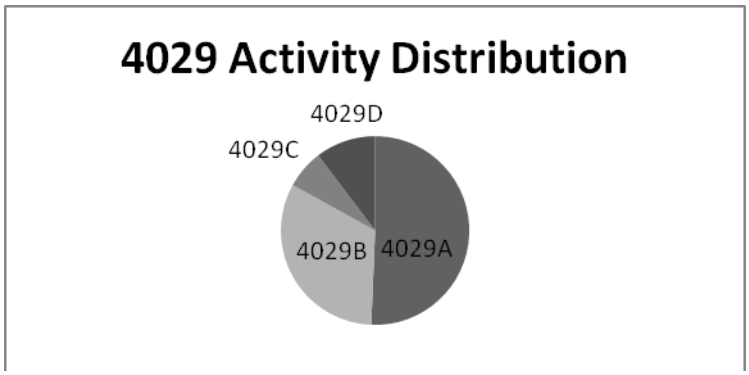

Figure 1. 4029 Activity Distribution

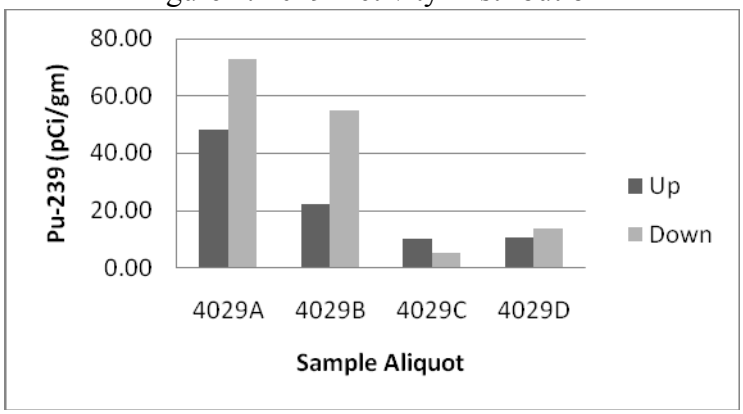

Figure 2. 4029 Aliquot Ratios

Table 2. Soil Sampling Results for Sample 7379

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
7379A	78.20	25.33	17.39	21.36
7379B	87.70	66.96	128.52	97.74
7379C	84.40	10.58	9.83	10.21
7379D	69.40	22.90	22.25	22.57
Mean	79.93	31.44	44.50	37.97
Median	79.93	25.33	22.25	22.57
%CV	10.07%	78.06%	126.41%	105.97%
Maximum	87.70	66.96	128.52	97.74
Minimum	69.40	10.58	9.83	10.21
Max/Min	1.26	6.33	13.08	9.58

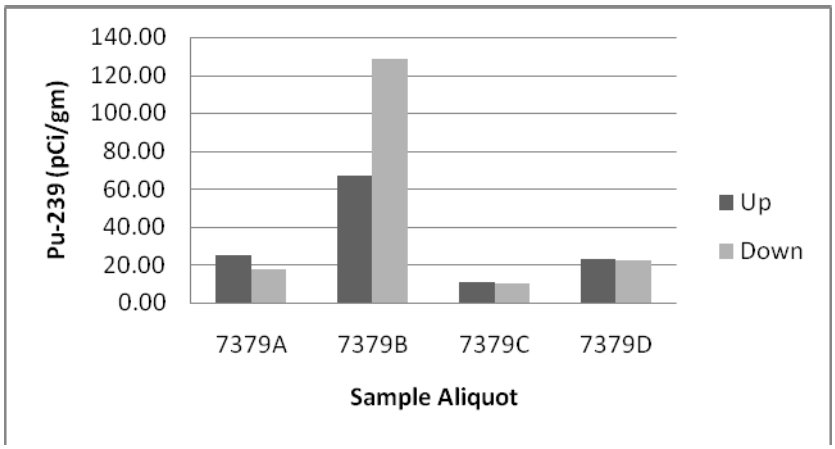

Figure 3. 7379 Aliquot Ratios

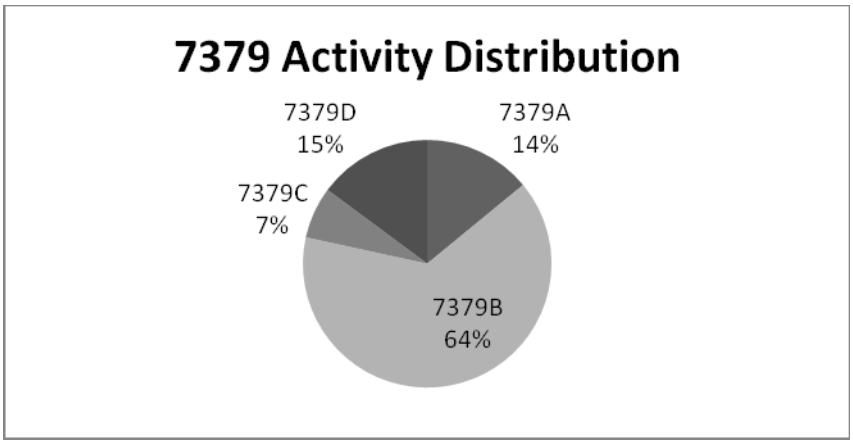

Figure 4. 7379 Activity Distribution

Table 3. Soil Sampling Results for Sample 7586

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
7586A	81.70	171.72	59.40	115.56
7586B	87.30	54.00	104.76	79.38
7586C	85.70	12.42	12.04	12.23
7586D	79.90	71.28	272.16	171.72
Mean	83.65	77.36	112.09	94.72
Median	83.65	71.28	104.76	94.72
%CV	4.11%	87.37%	101.02%	70.56%
Maximum	87.30	171.72	272.16	171.72
Minimum	79.90	12.42	12.04	12.23
Max/Min	1.09	13.83	22.60	14.04

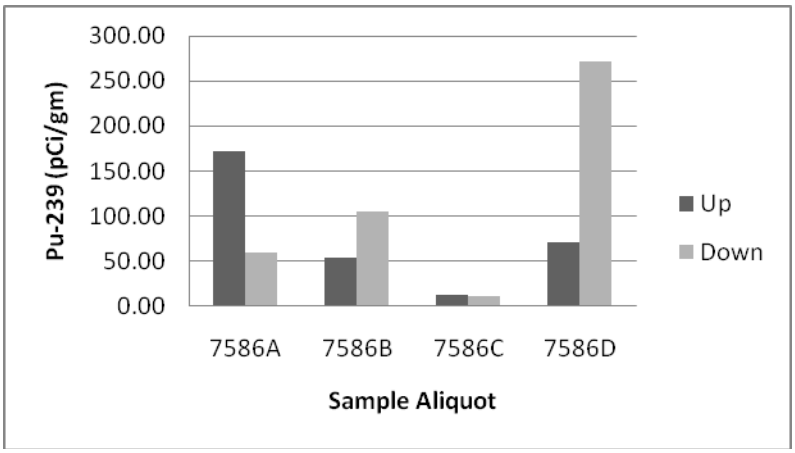

Figure 5. 7586 Aliquot Ratios

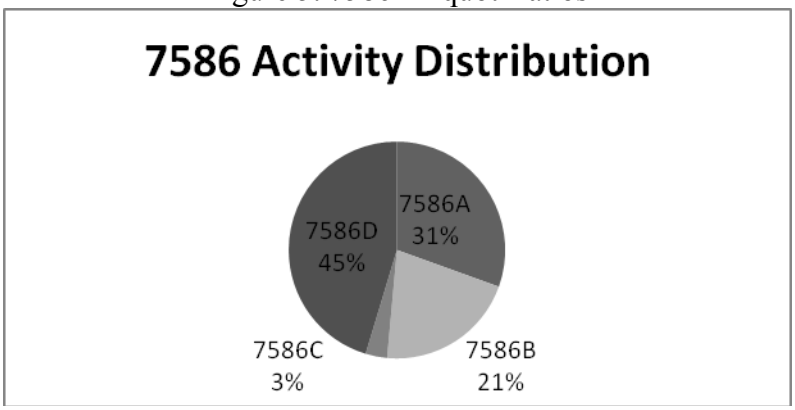

Figure 6. 7586 Activity Distribution

Table 4. Soil Sampling Results for Sample 4479

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
4479A	88.60	1.74	5.09	3.41
4479B	88.90	5.15	14.74	9.95
4479C	89.90	7.24	31.81	19.52
4479D	77.20	23.17	129.06	76.11
Mean	86.15	9.32	45.17	27.25
Median	88.60	7.24	31.81	19.52
%CV	6.96%	101.93%	126.19%	121.99%
Maximum	89.90	23.17	129.06	76.11
Minimum	77.20	1.74	5.09	3.41
Max/Min	1.16	13.32	25.37	22.30

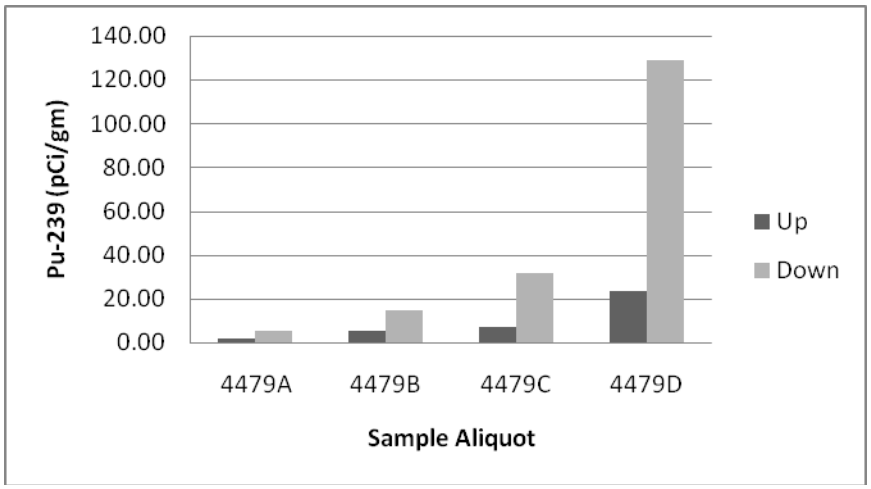

Figure 7. 4479 Aliquot Ratios

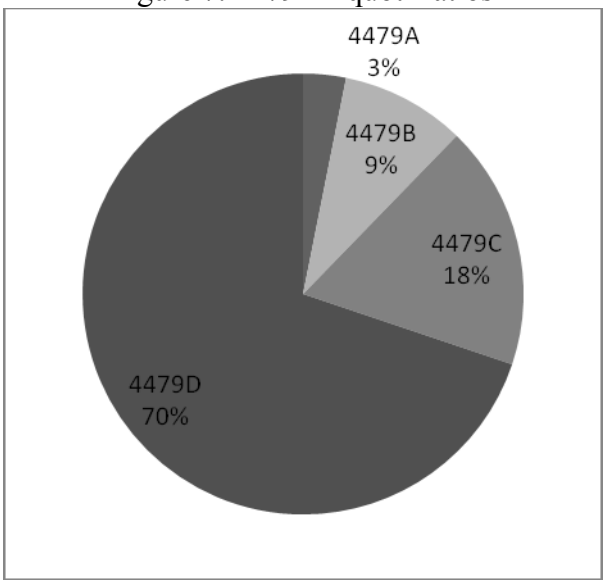

Figure 8. 4479 Activity Distribution

Table 5. Soil Sampling Results for Sample 7374

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
7374A	74.40	30.02	332.10	181.06
7374B	83.70	12.20	38.88	25.54
7374C	82.40	9.07	25.81	17.44
7374D	81.60	108.00	1042.20	575.10
Mean	80.53	39.83	359.75	199.79
Median	81.60	30.02	332.10	181.06
%CV	5.18%	116.45%	132.44%	130.79%
Maximum	83.70	108.00	1042.20	575.10
Minimum	74.40	9.07	25.81	17.44
Max/Min	1.13	11.90	40.38	32.97

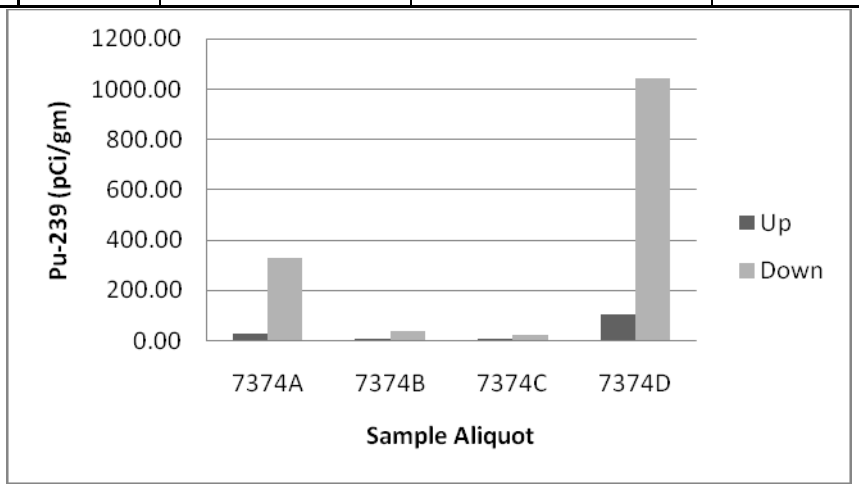

Figure 9. 7374 Aliquot Ratios

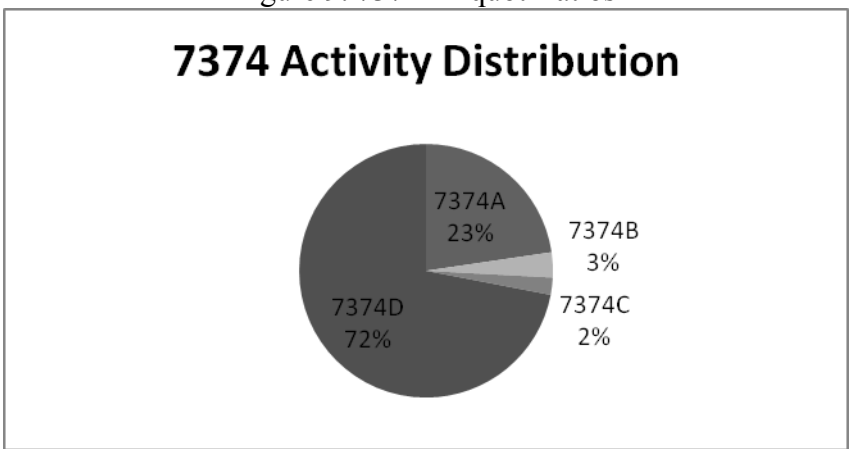

Figure 10. 7374 Activity Distribution

Table 6. Soil Sampling Results for Sample 4409

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
4409A	87.50	5.24	20.84	13.04
4409B	87.10	8.10	46.12	27.11
4409C	84.00	18.14	72.36	45.25
4409D	80.50	6.16	24.52	15.34
Mean	84.78	9.41	40.96	25.18
Median	84.78	8.10	40.96	25.18
%CV	3.83%	63.15%	57.91%	58.48%
Maximum	87.50	18.14	72.36	45.25
Minimum	80.50	5.24	20.84	13.04
Max/Min	1.09	3.46	3.47	3.47

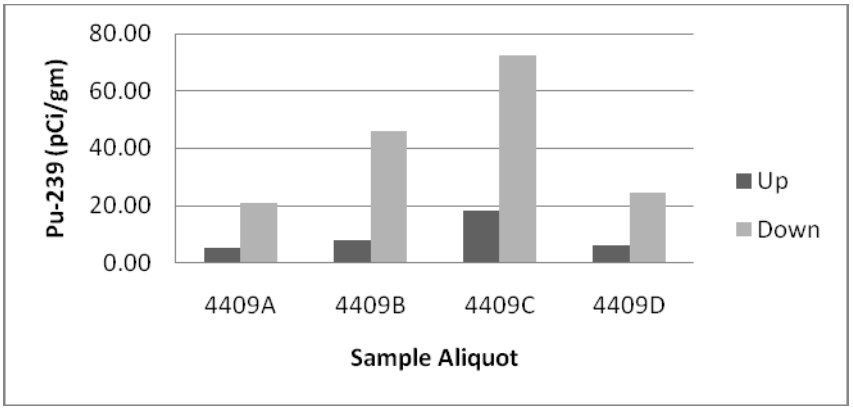

Figure 11. 4409 Aliquot Ratios

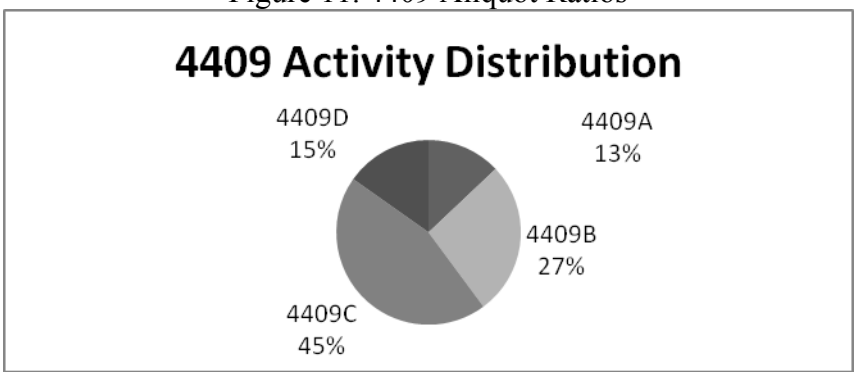

Figure 12. 4409 Activity Distribution

Table 7. Soil Sampling Results for Sample 4370

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
4370A	69.00	0.64	5.70	3.17
4370B	66.90	1.19	5.50	3.34
4370C	67.30	0.67	5.17	2.92
4370D	75.60	0.41	4.18	2.30
4370E	68.70	53.57	89.64	71.60
Mean	69.50	11.30	22.04	16.67
Median	68.85	0.93	5.60	3.26
%CV	5.07%	209.19%	171.48%	184.26%
Maximum	75.60	53.57	89.64	71.60
Minimum	66.90	0.41	4.18	2.30
Max/Min	1.13	130.35	21.43	31.17

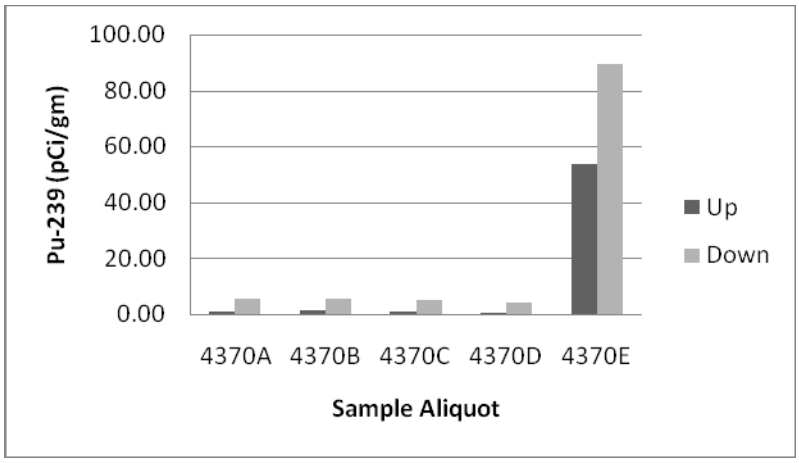

Figure 13. 4370 Aliquot Ratios

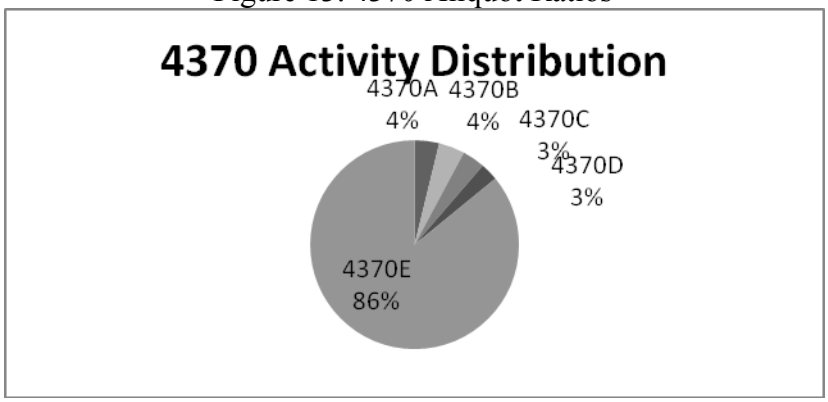

Figure 14. 4370 Activity Distribution

Table 8. Soil Sampling Results for Sample 4503

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
4503A	74.50	0.61	4.28	2.45
4503B	79.40	3.04	14.47	8.76
4503C	78.90	83.70	96.12	89.91
4503D	78.80	0.56	4.12	2.34
Mean	77.90	21.98	29.75	25.86
Median	78.80	3.04	14.47	8.76
%CV	2.93%	187.29%	149.63%	165.50%
Maximum	79.40	83.70	96.12	89.91
Minimum	74.50	0.56	4.12	2.34
Max/Min	1.07	149.64	23.34	38.44

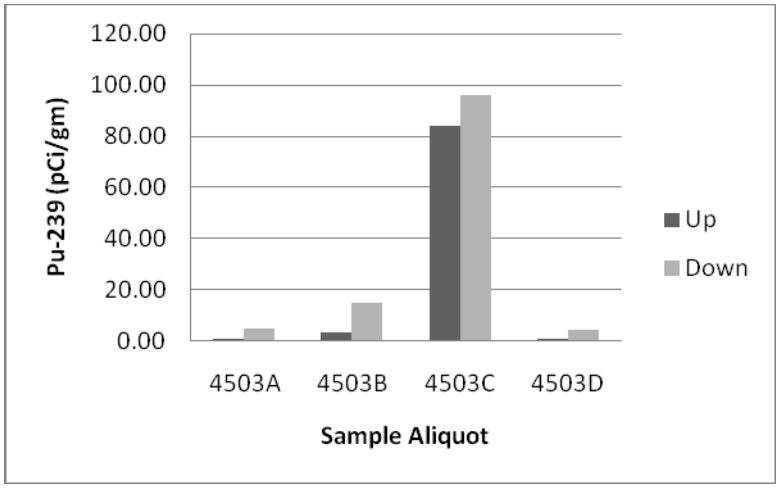

Figure 15. 4503 Aliquot Ratios

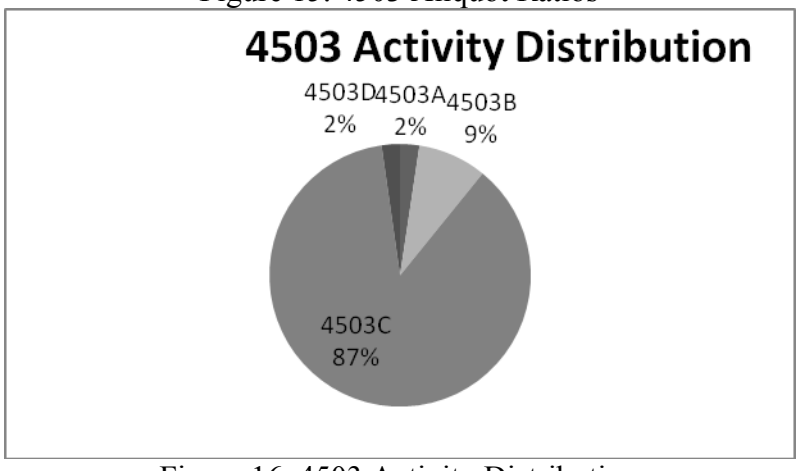

Figure 16. 4503 Activity Distribution

Table 9. Soil Sampling Results for Sample 4032

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
4032A	60.30	0.79	5.78	3.28
4032B	56.10	78.84	516.24	297.54
4032C	58.10	0.70	5.91	3.30
4032D	58.60	0.71	0.79	0.75
4032E	60.80	0.68	0.67	0.67
Mean	58.78	16.34	105.88	61.11
Median	58.60	0.71	5.78	3.28
%CV	3.19%	213.75%	216.68%	216.29%
Maximum	60.80	78.84	516.24	297.54
Minimum	56.10	0.68	0.67	0.67
Max/Min	1.08	116.55	774.78	443.18

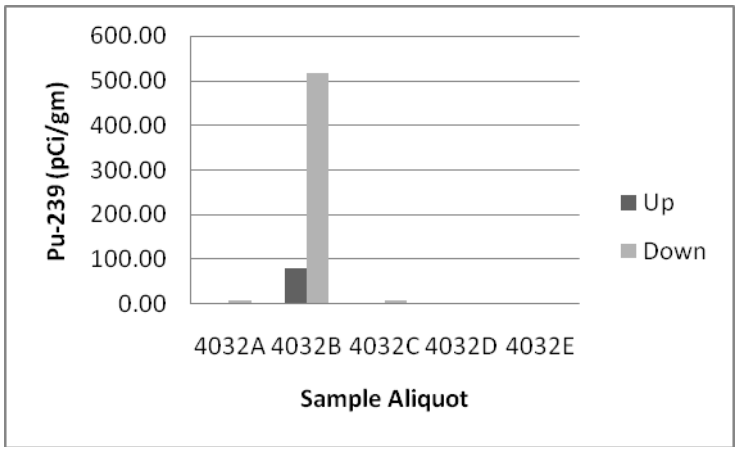

Figure 17. 4032 Aliquot Ratios

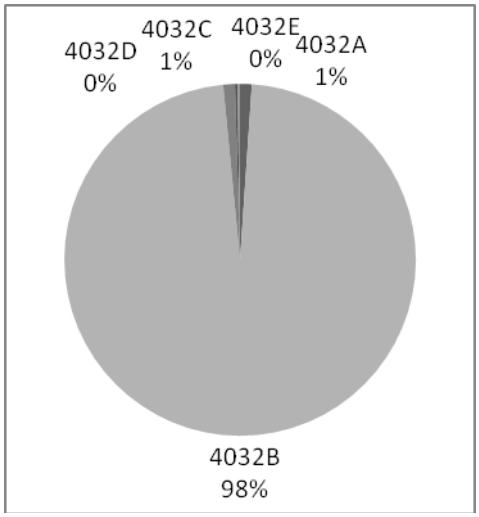

Figure 18. 4032 Activity Distribution

Table 10. Soil Sampling Results for Sample 8615

Aliquot	mass (gm)	UP Pu 239 (pCi/gm)	DOWN Pu 239 (pCi/gm)	Mean (UP & DOWN)
8615A	71.30	92.34	31.10	61.72
8615B	73.90	1.68	1.81	1.75
8615C	77.00	2.39	2.26	2.32
8615D	78.80	3.22	2.81	3.02
8615E	78.90	57.78	132.30	95.04
Mean	75.98	31.48	34.06	32.77
Median	77.00	3.22	2.81	3.02
%CV	4.35%	132.21%	165.36%	132.05%
Maximum	78.90	92.34	132.30	95.04
Minimum	71.30	1.68	1.81	1.75
Max/Min	1.11	54.98	72.92	54.40

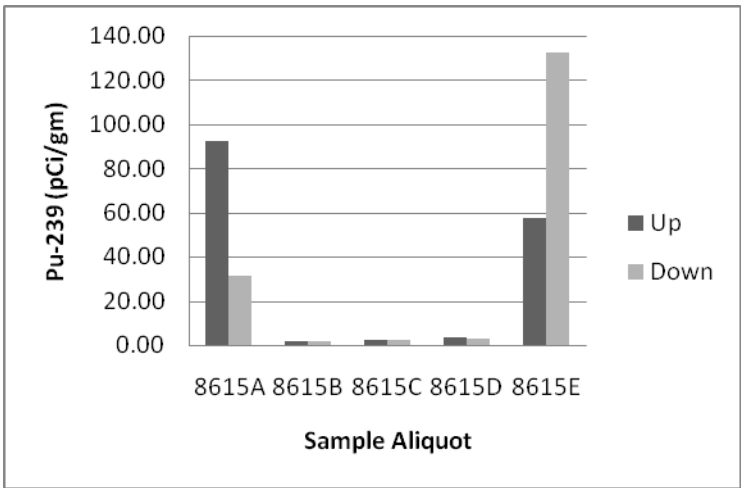

Figure 19. 8615 Aliquot Ratios

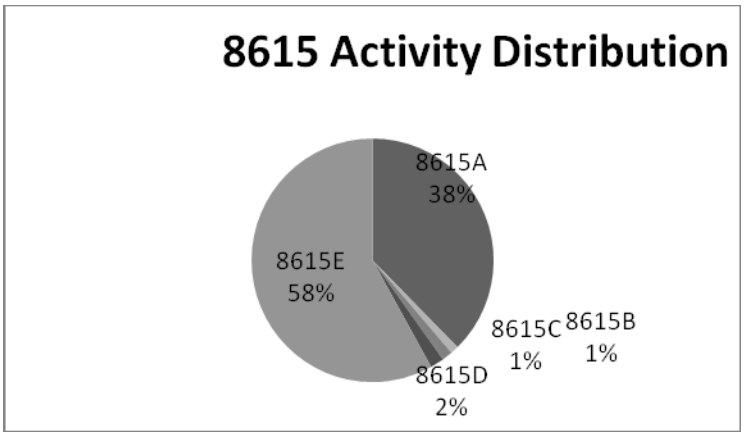

Figure 20. 8615 Activity Distribution

Appendix B

Batch 1 UP	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4029A	62.4	8.90	48.06	0.60228
4029B	70.1	4.11	22.19	0.31414
4029C	60.0	1.92	10.37	0.19082
4029D	74.6	1.99	10.75	0.1806
7379A	78.2	4.69	25.33	0.3382
7379B	87.7	12.40	66.96	0.78445
7379C	84.4	1.96	10.58	0.17459
7379D	69.4	4.24	22.90	0.30878
7586A	81.7	31.80	171.72	1.9098
7586B	87.3	10.00	54.00	0.64443
7586C	85.7	2.30	12.42	0.19362
7586D	79.9	13.20	71.28	0.83774
Batch 1 Down	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4029A	62.4	13.50	72.90	0.8628
4029B	70.1	10.20	55.08	0.6656
4029C	60.0	1.02	5.51	0.12179
4029D	74.6	2.58	13.93	0.20796
7379A	78.2	3.22	17.39	0.25401
7379B	87.7	23.80	128.52	1.4427
7379C	84.4	1.82	9.83	0.16675
7379D	69.4	4.12	22.25	0.31288
7586A	81.7	11.00	59.40	0.70781
7586B	87.3	19.40	104.76	1.1906
7586C	85.7	2.23	12.04	0.19052
7586D	79.9	50.40	272.16	2.9945
Batch 2 UP	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4479A	88.6	0.32	1.74	0.072778
4479B	88.9	0.95	5.15	0.11192
4479C	89.9	1.34	7.24	0.14541
4479D	77.2	4.29	23.17	0.3174
7374A	74.4	5.56	30.02	0.39848
7374B	83.7	2.26	12.20	0.18471
7374C	82.4	1.68	9.07	0.15729
7374D	81.6	20.00	108.00	1.2347
4409A	87.5	0.97	5.24	0.10225

4409B	87.1	1.50	8.10	0.14718
4409C	84.0	3.36	18.14	0.25857
4409D	80.5	1.14	6.16	0.13018
Batch 2 Down	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4479A	88.6	0.94	5.09	0.28501
4479B	88.9	2.73	14.74	0.39945
4479C	89.9	5.89	31.81	0.56551
4479D	77.2	23.90	129.06	1.6732
7374A	74.4	61.50	332.10	3.888
7374B	83.7	7.20	38.88	0.66499
7374C	82.4	4.78	25.81	0.52306
7374D	81.6	193.00	1042.20	12.302
4409A	87.5	3.86	20.84	0.40785
4409B	87.1	8.54	46.12	0.73639
4409C	84.0	13.40	72.36	1.4563
4409D	80.5	4.54	24.52	0.49868
Batch 3 UP	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4370A	69.0	0.12	0.64	
4370B	66.9	0.22	1.19	0.073792
4370C	67.3	0.12	0.67	
4370D	75.6	0.08	0.41	0.071766
4370E	68.7	9.92	53.57	0.64312
4503A	74.5	0.11	0.61	
4503B	79.4	0.56	3.04	0.09492
4503C	78.9	15.50	83.70	0.96493
4503D	78.8	0.10	0.56	
4032A	60.3	0.15	0.79	
4032B	56.1	14.60	78.84	0.94371
4032C	58.1	0.13	0.70	
Batch 3 Down	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4370A	69.0	1.06	5.70	
4370B	66.9	1.02	5.50	
4370C	67.3	0.96	5.17	
4370D	75.6	0.77	4.18	
4370E	68.7	16.60	89.64	1.7108
4503A	74.5	0.79	4.28	
4503B	79.4	2.68	14.47	0.69799
4503C	78.9	17.80	96.12	1.8018
4503D	78.8	0.76	4.12	
4032A	60.3	1.07	5.78	

4032B	56.1	95.60	516.24	7.2166
4032C	58.1	1.09	5.91	
Batch 4 UP	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4032D	58.6	0.13	0.71	
4032E	60.8	0.13	0.68	
8615A	71.3	17.10	92.34	1.0659
8615B	73.9	0.31	1.68	0.080907
8615C	77.0	0.44	2.39	0.079563
8615D	78.8	0.60	3.22	0.097744
8615E	78.9	10.70	57.78	0.67886
Batch 4 Down	**mass (gm)**	**Am 241 (pCi/gm)**	**Pu 239 (pCi/gm)**	**[+/- (pCi/gm)]**
4032D	58.6	0.15	0.79	
4032E	60.8	0.12	0.67	
8615A	71.3	5.76	31.10	0.39796
8615B	73.9	0.34	1.81	0.059832
8615C	77.0	0.42	2.26	0.068195
8615D	78.8	0.52	2.81	0.091392
8615E	78.9	24.50	132.30	1.4805

Appendix C

Aliquot	average activity	ratio of flip	Aliquot activity percent
4029A	11.20	1.52	50.66%
4029B	7.16	2.48	32.36%
4029C	1.47	1.88	6.65%
4029D	2.29	1.30	10.33%
7379A	3.96	1.46	14.06%
7379B	18.10	1.92	64.36%
7379C	1.89	1.08	6.72%
7379D	4.18	1.03	14.86%
7586A	21.40	2.89	30.50%
7586B	14.70	1.94	20.95%
7586C	2.27	1.03	3.23%
7586D	31.80	3.82	45.32%
4479A	0.63	2.93	3.13%
4479B	1.84	2.86	9.13%
4479C	3.62	4.40	17.91%
4479D	14.10	5.57	69.83%
7374A	33.53	11.06	22.66%
7374B	4.73	3.19	3.20%
7374C	3.23	2.85	2.18%
7374D	106.50	9.65	71.96%
4409A	2.42	3.98	12.95%
4409B	5.02	5.69	26.91%
4409C	8.38	3.99	44.92%
4409D	2.84	3.98	15.22%
4370A	0.59	8.87	3.81%
4370B	0.62	4.63	4.01%
4370C	0.54	7.68	3.51%
4370D	0.43	10.18	2.76%
4370E	13.26	1.67	85.92%
4503A	0.45	6.97	2.37%
4503B	1.62	4.76	8.46%
4503C	16.65	1.15	86.91%
4503D	0.43	7.36	2.26%
4032A	0.61	7.29	0.81%
4032B	55.10	6.55	73.19%
4032C	0.61	8.44	0.81%
4032D	0.14	1.10	0.18%
4032E	0.12	0.98	0.17%
8615A	11.43	2.97	37.67%
8615B	0.32	1.08	1.07%
8615C	0.43	1.05	1.42%
8615D	0.56	0.87	1.84%
8615E	17.60	0.44	58.00%

Appendix D


```
**************************************************************************
*****             BROOKS AFB, RADIOANALYTICAL BRANCH                 *****
*****             N U C L I D E S   T O   R E P O R T                *****
**************************************************************************
                Filename:  G:\GAMMAN2K\CAMFILES\FILTER\FIL00197.CNF
           Detector Name:  HPGE1
         Sample Geometry:  PTFA
  Sample Identification:  4029A UP
   Nuclide Library Used:  G:\GENIE2K\CAMFILES\Stdlib.nlb
```

	Nuclide Name	Nuclide MDA or Activity	Uncertainty or Units	Units
+	BE-7	< 4.0605E-001		(pCi/gm)
+	NA-22	< 5.6608E-002		(pCi/gm)
+	NA-24	< 6.3165E-002		(pCi/gm)
	K-40	1.10E+000	+/- 4.8196E-001	(pCi/gm)
+	CR-51	< 4.4481E-001		(pCi/gm)
+	MN-54	< 4.8798E-002		(pCi/gm)
+	CO-57	< 3.6954E-002		(pCi/gm)
+	CO-58	< 4.8252E-002		(pCi/gm)
+	FE-59	< 8.8976E-002		(pCi/gm)
+	CO-60	< 5.3455E-002		(pCi/gm)
+	NI-65	< 4.1156E-001		(pCi/gm)
+	ZN-65	< 1.3408E-001		(pCi/gm)
+	KR-85	< 1.6045E+001		(pCi/gm)
+	KR-85M	< 5.8452E-002		(pCi/gm)
+	SR-85	< 6.9548E-002		(pCi/gm)
+	Y-88	< 5.5484E-002		(pCi/gm)
+	NB-94	< 4.9314E-002		(pCi/gm)
+	NB-95	< 5.3353E-002		(pCi/gm)
+	ZR-95	< 9.2581E-002		(pCi/gm)
+	TC-99M	< 4.6949E-002		(pCi/gm)
+	RU-103	< 4.4714E-002		(pCi/gm)
+	RU-106	< 4.2692E-001		(pCi/gm)
+	CD-109	< 7.2118E-001		(pCi/gm)
+	SN-113	< 6.3572E-002		(pCi/gm)
+	SB-122	< 6.4851E-002		(pCi/gm)
+	SB-124	< 4.5100E-002		(pCi/gm)
+	SB-125	< 1.3754E-001		(pCi/gm)
+	I-130	< 4.3720E-002		(pCi/gm)
+	I-131	< 5.2288E-002		(pCi/gm)
+	BA-133	< 7.1425E-002		(pCi/gm)
+	CS-134	< 5.5448E-002		(pCi/gm)
+	I-135	< 2.5533E-001		(pCi/gm)
+	CS-136	< 4.8146E-002		(pCi/gm)
	CS-137	8.74E-002	+/- 3.2322E-002	(pCi/gm)
+	CS-138	< 4.7593E-001		(pCi/gm)
+	CE-139	< 4.5613E-002		(pCi/gm)
+	BA-140	< 2.0680E-001		(pCi/gm)
+	LA-140	< 7.2927E-002		(pCi/gm)
+	EU-152	< 1.0800E-001		(pCi/gm)
+	EU-154	< 7.7887E-002		(pCi/gm)
+	EU-155	< 8.1547E-002		(pCi/gm)
+	TL-201	< 4.5262E-002		(pCi/gm)
+	TL-202	< 4.5141E-002		(pCi/gm)

+	HG-203	< 5.1419E-002		(pCi/gm)

```
      TL-208      3.44E-002  +/-  3.2720E-002 (pCi/gm  )
   +  PB-210    < 1.2336E+000                (pCi/gm  )
   +  BI-211    < 2.6621E-001                (pCi/gm  )
   +  PB-211    < 1.3997E+000                (pCi/gm  )
   +  BI-212    < 4.1121E-001                (pCi/gm  )
      PB-212      1.04E-001  +/-  3.8049E-002 (pCi/gm  )
      BI-214      1.91E-001  +/-  5.2907E-002 (pCi/gm  )
      PB-214      1.73E-001  +/-  4.7500E-002 (pCi/gm  )
   +  RA-224    < 1.3041E+000                (pCi/gm  )
      RA-226    < 1.2871E+000                (pCi/gm  )
   +  TH-227    < 4.2925E-001                (pCi/gm  )
   +  AC-228T   < 2.1606E-001                (pCi/gm  )
   +  PA-231    < 1.2251E+000                (pCi/gm  )
   +  TH-231    < 2.9804E-001                (pCi/gm  )
   +  PA-233    < 1.1827E-001                (pCi/gm  )
   +  PA-234M   < 9.8058E+000                (pCi/gm  )
      TH-234U     5.13E-001  +/-  3.2829E-001 (pCi/gm  )
   +  U-235     < 7.8180E-002                (pCi/gm  )
   +  NP-237    < 2.1565E-001                (pCi/gm  )
      AM-241      8.33E+000  +/-  5.0293E-001 (pCi/gm  )
   +  CM-245    < 1.2043E-001                (pCi/gm  )
   +  CF-249    < 6.3849E-002                (pCi/gm  )

If the nuclide is not Identified an MDA is Reported, When Identified and the
uncertainty is greater than the calculated nuclide weighted mean activity
the MDA is reported.  All other circumstances the nuclide weighted
mean +/- the weight uncertainty is reported
************************************************************************
*****              BROOKS AFB, RADIOANALYTICAL BRANCH              *****
*****        G A M M A   S P E C T R U M    A N A L Y S I S        *****
*****              Sample Counted on Detector: HPGE1               *****
************************************************************************


Filename: G:\GAMMAN2K\CAMFILES\FILTER\FIL00197.CNF

Report Generated On             : 6/10/2008   4:08:32 PM

Sample Title                    :
Sample Identification           : 4029A UP
Sample Type                     : Filter
Sample Geometry                 : PTFA

Peak Locate Threshold           :  3.00
Peak Locate Range (in channels) :     1 -  4096
Peak Area Range (in channels)   :     1 -  4096
Identification Energy Tolerance :    1.000 keV

Sample Size                     :  6.240E+001 gm

Sample Taken On                 : 6/20/2008   1:00:00 PM
Acquisition Started             : 6/20/2008   1:21:47 PM

Live Time                       :    10000.0 seconds
Real Time                       :    10001.5 seconds

Dead Time                       :   0.01 %


              Energy Calibration Used Done On       : 6/20/2008
              Efficiency Calibration Used Done On   : 6/20/2008
              Efficiency ID                         : PTFA

Peak Locate Analysis Report  6/10/2008   4:08:32 PM 4029A UP        Page  4

************************************************************************
*****              BROOKS AFB, RADIOANALYTICAL BRANCH              *****
*****             P E A K   L O C A T E   R E P O R T              *****
************************************************************************
```

Detector Name: HPGE1
Sample Identification: 4029A UP
Peak Locate Performed on: 6/10/2008 4:08:30 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 4096
Peak Search Sensitivity: 3.00

Peak No.	Centroid Channel	Centroid Uncertainty	Energy (keV)	Peak Significance
1	99.79	0.3914	49.97	3.85
2	119.10	0.0896	59.64	64.92
3	149.34	0.3827	74.74	4.52
4	154.20	0.3338	77.18	4.60
5	185.27	0.3246	92.73	3.90
6	370.99	0.3118	185.58	5.17
7	476.98	0.2394	238.56	8.65
8	589.95	0.3303	295.04	4.66
9	703.34	0.2713	351.73	5.62
10	1166.09	0.3265	583.08	4.04
11	1218.10	0.2704	609.08	4.95
12	1323.11	0.3133	661.58	4.10
13	2922.22	0.2455	1461.04	5.63

? = Adjacent peak noted

Errors quoted at 1.960 sigma

****
***** BROOKS AFB, RADIOANALYTICAL BRANCH *****
***** 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 Identification: 4029A UP
Nuclide Library Used: G:\GENIE2K\CAMFILES\Stdlib.nlb

IDENTIFIED NUCLIDES

Nuclide Name	Energy (keV)	Yield (%)	Activity (pCi/gm)	WtMean Act (pCi/gm)	WtMean ERR (pCi/gm)
K-40	1460.81*	10.75	1.104E+000	1.104E+000	4.820E-001
CS-137	661.62*	84.60	8.735E-002	8.735E-002	3.232E-002
TL-208	72.80	2.00			
	74.97*	3.50	6.044E-001		
	84.80	1.20			
	211.50	0.17			
	233.50	0.30			
	252.60	0.70			
	277.36	6.50			
	510.72	22.50			
	583.14*	86.00	3.528E-002		
	722.30	0.27			
	763.30	1.70			
	860.47	12.00			
	927.70	0.13			
	982.80	0.20			
	1093.90	0.38			
	2614.47	100.00			
PB-212	74.81*	9.60	2.203E-001	1.042E-001	3.805E-002
	77.11*	17.50	1.979E-001		
	87.20	6.30			
	89.80	1.75			
	115.18	0.58			
	238.63*	43.10	1.296E-001		
	300.09	3.27			

BI-214	609.32*	46.09	1.908E-001	1.908E-001	5.291E-002
	768.36	4.89			
	806.17	1.23			
	934.05	3.16			
	1120.28	15.04			
	1155.19	1.69			
	1238.11	5.92			
	1280.96	1.47			
	1377.65	4.02			
	1385.31	0.78			
	1401.50	1.39			
	1407.98	2.48			
	1509.19	2.19			
	1661.28	1.15			
	1729.60	3.05			
	1764.51	15.92			
	1847.44	2.12			

Nuclide Name	Energy (keV)	Yield (%)	Activity (pCi/gm)	WtMean Act (pCi/gm)	WtMean ERR (pCi/gm)
BI-214	2118.54	1.21			
PB-214	74.81*	6.33	3.342E-001	1.730E-001	4.750E-002
	77.11*	10.70	3.236E-001		
	87.20	3.70			
	89.80	1.03			
	241.92	7.47			
	295.22*	19.20	1.638E-001		
	351.99*	37.10	1.938E-001		
	785.95	1.09			
RA-226	185.99*	3.28	6.439E-001	6.439E-001	7.679E-001
TH-234U	92.60*	5.57	5.127E-001	5.127E-001	3.283E-001
	112.81	0.25			
AM-241	59.54*	36.30	8.334E+000	8.334E+000	5.029E-001

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.20
Errors quoted at 1.960 sigma

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

Peak Locate Performed on: 6/10/2008 4:08:30 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 4096

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
m 1	49.97	3.1279E-002	26.14

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

Errors quoted at 1.960 sigma

****
***** 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:
Nuclide Library Used: G:\GENIE2K\CAMFILES\Stdlib.nlb

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

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (pCi/gm)	Activity Uncertainty
K-40	0.991	1460.81*	10.75	1.10432E+000	4.81961E-001
CS-137	1.000	661.62*	84.60	8.73518E-002	3.23221E-002
TL-208	0.557	72.80	2.00		
		74.97*	3.50	6.04355E-001	1.95647E-001
		84.80	1.20		
		211.50	0.17		
		233.50	0.30		
		252.60	0.70		
		277.36	6.50		
		510.72	22.50		
		583.14*	86.00	3.52785E-002	3.30941E-002
		722.30	0.27		
		763.30	1.70		
		860.47	12.00		
		927.70	0.13		
		982.80	0.20		
		1093.90	0.38		
		2614.47	100.00		
PB-212	0.752	74.81*	9.60	2.20337E-001	7.00261E-002
		77.11*	17.50	1.97870E-001	4.65005E-002
		87.20	6.30		
		89.80	1.75		
		115.18	0.58		
		238.63*	43.10	1.29570E-001	5.71877E-002
		300.09	3.27		
BI-214	0.211	609.32*	46.09	1.90841E-001	5.29069E-002
		768.36	4.89		
		806.17	1.23		
		934.05	3.16		
		1120.28	15.04		
		1155.19	1.69		
		1238.11	5.92		
		1280.96	1.47		
		1377.65	4.02		
		1385.31	0.78		
		1401.50	1.39		
		1407.98	2.48		
		1509.19	2.19		
		1661.28	1.15		
		1729.60	3.05		
		1764.51	15.92		
		1847.44	2.12		

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (pCi/gm)	Activity Uncertainty
BI-214	0.211	2118.54	1.21		
PB-214	0.728	74.81*	6.33	3.34160E-001	1.06201E-001
		77.11*	10.70	3.23619E-001	7.60523E-002
		87.20	3.70		
		89.80	1.03		
		241.92	7.47		
		295.22*	19.20	1.63809E-001	1.06211E-001
		351.99*	37.10	1.93795E-001	6.05893E-002
		785.95	1.09		
RA-226	0.973	185.99*	3.28	6.43924E-001	7.67944E-001
TH-234U	0.932	92.60*	5.57	5.12693E-001	3.28295E-001
		112.81	0.25		
AM-241	0.998	59.54*	36.30	8.33446E+000	5.02928E-001

* = Energy line found in the spectrum.
@ = Energy line not used for Weighted Mean Activity

Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.20
Errors quoted at 1.960 sigma

****
***** I N T E R F E R E N C E C O R R E C T E D R E P O R T *****
****

	Nuclide Name	Nuclide Id Confidence	Wt mean Activity (pCi/gm)	Wt mean Activity Uncertainty
	K-40	0.991	1.104323E+000	4.819607E-001
	CS-137	1.000	8.735176E-002	3.232206E-002
	TL-208	0.557	3.442301E-002	3.271951E-002
X	BI-211	0.252		
	PB-212	0.752	1.042128E-001	3.804937E-002
	BI-214	0.211	1.908408E-001	5.290695E-002
	PB-214	0.728	1.730178E-001	4.749950E-002
	RA-226	0.973	6.439245E-001	7.679444E-001
	TH-234U	0.932	5.126927E-001	3.282946E-001
X	U-235	0.509		
	AM-241	0.998	8.334462E+000	5.029277E-001

? = nuclide is part of an undetermined solution
X = nuclide rejected by the interference analysis
@ = nuclide contains energy lines not used in Weighted Mean Activity

Errors quoted at 1.960 sigma

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

Peak Locate Performed on: 6/10/2008 4:08:30 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 4096

	Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty	Peak Type	Tol. Nuclide
m	1	49.97	3.1279E-002	26.14	Tol.	TH-227

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

Errors quoted at 1.960 sigma

Appendix E

Nuclides to Report 6/10/2008 6:18:28 PM 4029A UP Page 1

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**************************************************************************
*****             BROOKS AFB, RADIOANALYTICAL BRANCH                 *****
*****             N U C L I D E S   T O   R E P O R T                *****
**************************************************************************
                 Filename:  G:\GAMMAN2K\CAMFILES\FILTER\FIL00199.CNF
           Detector Name:  HPGE1
         Sample Geometry:  PTFA
   Sample Identification:  4029A UP
    Nuclide Library Used:  G:\GENIE2K\CAMFILES\Stdlib.nlb

          Nuclide   Nuclide MDA     Uncertainty     Units
          Name      or Activity      or Units

       +  BE-7      < 6.9360E-001                (pCi/gm  )
       +  NA-22     < 1.1936E-001                (pCi/gm  )
*****  +  NA-24     < 2.6121E-003                (fCi/gm  ) ***** UC *****
       +  K-40      < 1.8812E+000                (pCi/gm  )
       +  CR-51     < 6.5181E-001                (pCi/gm  )
       +  MN-54     < 1.0273E-001                (pCi/gm  )
       +  CO-57     < 6.9680E-002                (pCi/gm  )
       +  CO-58     < 9.7310E-002                (pCi/gm  )
       +  FE-59     < 1.3126E-001                (pCi/gm  )
       +  CO-60     < 1.0657E-001                (pCi/gm  )
*****  +  NI-65     < 1.0000E-011                (fCi/gm  ) ***** UC *****
       +  ZN-65     < 2.7369E-001                (pCi/gm  )
       +  KR-85     < 3.5175E+001                (pCi/gm  )
*****  +  KR-85M    < 1.5159E-014                (fCi/gm  ) ***** UC *****
       +  SR-85     < 1.3742E-001                (pCi/gm  )
       +  Y-88      < 9.3485E-002                (pCi/gm  )
       +  NB-94     < 1.0441E-001                (pCi/gm  )
       +  NB-95     < 9.6804E-002                (pCi/gm  )
       +  ZR-95     < 1.7330E-001                (pCi/gm  )
*****  +  TC-99M    < 1.4001E-010                (fCi/gm  ) ***** UC *****
       +  RU-103    < 7.4778E-002                (pCi/gm  )
       +  RU-106    < 9.8356E-001                (pCi/gm  )
       +  CD-109    < 1.3534E+000                (pCi/gm  )
       +  SN-113    < 1.3971E-001                (pCi/gm  )
       +  SB-122    < 1.0822E-002                (pCi/gm  )
       +  SB-124    < 8.6875E-002                (pCi/gm  )
       +  SB-125    < 2.7578E-001                (pCi/gm  )
*****  +  I-130     < 1.6512E-004                (fCi/gm  ) ***** UC *****
       +  I-131     < 4.5135E-002                (pCi/gm  )
       +  BA-133    < 1.3879E-001                (pCi/gm  )
       +  CS-134    < 1.1751E-001                (pCi/gm  )
*****  +  I-135     < 8.5684E-009                (fCi/gm  ) ***** UC *****
       +  CS-136    < 5.8252E-002                (pCi/gm  )
       +  CS-137    < 1.4418E-001                (pCi/gm  )
*****  +  CS-138    < 1.0000E-011                (fCi/gm  ) ***** UC *****
       +  CE-139    < 8.8878E-002                (pCi/gm  )
       +  BA-140    < 2.6521E-001                (pCi/gm  )
*****  +  LA-140    < 2.4067E+000                (fCi/gm  ) ***** UC *****
       +  EU-152    < 2.0856E-001                (pCi/gm  )
       +  EU-154    < 1.5038E-001                (pCi/gm  )
       +  EU-155    < 1.5636E-001                (pCi/gm  )
*****  +  TL-201    < 9.1220E+000                (fCi/gm  ) ***** UC *****
       +  TL-202    < 5.3862E-002                (pCi/gm  )
```

Nuclides to Report 6/10/2008 6:18:28 PM 4029A UP Page 2

```
       +  HG-203    < 8.6175E-002                (pCi/gm  )
```

```
+  TL-208    < 1.3719E-001                (pCi/gm  )
+  PB-210    < 2.5524E+000                (pCi/gm  )
   BI-211      8.74E-001  +/-  3.6107E-001 (pCi/gm  )
+  PB-211    < 2.8809E+000                (pCi/gm  )
+  BI-212    < 7.7533E-001                (pCi/gm  )
   PB-212      1.80E-001  +/-  9.1484E-002 (pCi/gm  )
   BI-214      1.58E-001  +/-  9.2518E-002 (pCi/gm  )
+  PB-214    < 1.6114E-001                (pCi/gm  )
+  RA-224    < 2.7502E+000                (pCi/gm  )
+  RA-226    < 2.4668E+000                (pCi/gm  )
+  TH-227    < 9.0100E-001                (pCi/gm  )
+  AC-228T   < 4.7838E-001                (pCi/gm  )
+  PA-231    < 2.5995E+000                (pCi/gm  )
+  TH-231    < 6.0026E-001                (pCi/gm  )
+  PA-233    < 2.0763E-001                (pCi/gm  )
+  PA-234M   < 1.8232E+001                (pCi/gm  )
+  TH-234U   < 1.0717E+000                (pCi/gm  )
+  U-235     < 1.4967E-001                (pCi/gm  )
+  NP-237    < 4.1515E-001                (pCi/gm  )
   AM-241      8.90E+000  +/-  6.0228E-001 (pCi/gm  )
+  CM-245    < 2.3287E-001                (pCi/gm  )
+  CF-249    < 1.4295E-001                (pCi/gm  )

If the nuclide is not Identified an MDA is Reported, When Identified and the
uncertainty is greater than the calculated nuclide weighted mean activity
the MDA is reported.  All other circumstances the nuclide weighted
mean +/- the weight uncertainty is reported
*************************************************************************
*****              BROOKS AFB, RADIOANALYTICAL BRANCH               *****
*****        G A M M A   S P E C T R U M    A N A L Y S I S         *****
*****              Sample Counted on Detector: HPGE1                *****
*************************************************************************


Filename: G:\GAMMAN2K\CAMFILES\FILTER\FIL00199.CNF

Report Generated On             : 6/10/2008   6:18:28 PM

Sample Title                    :
Sample Identification           : 4029A UP
Sample Type                     : Filter
Sample Geometry                 : PTFA

Peak Locate Threshold           :  3.00
Peak Locate Range (in channels) :     1 -  4096
Peak Area Range (in channels)   :     1 -  4096
Identification Energy Tolerance :    1.000 keV

Sample Size                     :  6.240E+001 gm

Sample Taken On                 : 6/20/2008   1:00:00 PM
Acquisition Started             : 6/10/2008   5:36:44 PM

Live Time                       :     2500.0 seconds
Real Time                       :     2500.4 seconds

Dead Time                       :   0.01 %


              Energy Calibration Used Done On       : 6/20/2008
              Efficiency Calibration Used Done On   : 6/20/2008
              Efficiency ID                         : PTFA

Peak Locate Analysis Report  6/10/2008   6:18:28 PM 4029A UP        Page  4

*************************************************************************
*****              BROOKS AFB, RADIOANALYTICAL BRANCH               *****
*****             P E A K   L O C A T E   R E P O R T               *****
*************************************************************************
```

Detector Name: HPGE1
Sample Identification: 4029A UP
Peak Locate Performed on: 6/10/2008 6:18:26 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 4096
Peak Search Sensitivity: 3.00

Peak No.	Centroid Channel	Centroid Uncertainty	Energy (keV)	Peak Significance
1	119.12	0.1272	59.66	31.29
2	154.19	0.4017	77.19	3.67
3	476.83	0.3439	238.49	4.10
4	703.44	0.3398	351.78	3.23
5	1022.15	0.3645	511.12	3.19
6	1218.27	0.3348	609.17	3.83

? = Adjacent peak noted

Errors quoted at 1.960 sigma

****
***** BROOKS AFB, RADIOANALYTICAL BRANCH *****
***** 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 Identification: 4029A UP
Nuclide Library Used: G:\GENIE2K\CAMFILES\Stdlib.nlb

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

Nuclide Name	Energy (keV)	Yield (%)	Activity (pCi/gm)	WtMean Act (pCi/gm)	WtMean ERR (pCi/gm)
AL-26	511.00*	191.26	3.134E-002	3.134E-002	3.951E-002
	1129.65	2.40			
	1808.61	99.73			
	2938.18	0.27			
BI-211	72.87	1.20			
	351.10*	12.20	8.745E-001		
	404.80	4.10			
	426.90	1.90			
	831.80	3.30			
PB-212	74.81	9.60			
	77.11*	17.50	1.967E-001		
	87.20	6.30			
	89.80	1.75			
	115.18	0.58			
	238.63*	43.10	1.716E-001		
	300.09	3.27			
BI-214	609.32*	46.09	1.577E-001	1.577E-001	9.252E-002
	768.36	4.89			
	806.17	1.23			
	934.05	3.16			
	1120.28	15.04			
	1155.19	1.69			
	1238.11	5.92			
	1280.96	1.47			
	1377.65	4.02			
	1385.31	0.78			
	1401.50	1.39			
	1407.98	2.48			
	1509.19	2.19			
	1661.28	1.15			
	1729.60	3.05			
	1764.51	15.92			
	1847.44	2.12			

	2118.54	1.21			
AM-241	59.54*	36.30	8.901E+000	8.901E+000	6.023E-001

* = Energy line found in the spectrum.
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.20
Errors quoted at 1.960 sigma

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

Peak Locate Performed on: 6/10/2008 6:18:26 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 4096

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 1.960 sigma

****
***** 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:
Nuclide Library Used: G:\GENIE2K\CAMFILES\Stdlib.nlb

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

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (pCi/gm)	Activity Uncertainty
AL-26	0.650	511.00*	191.26	3.13384E-002	3.95132E-002
		1129.65	2.40		
		1808.61	99.73		
		2938.18	0.27		
BI-211	0.246	72.87	1.20		
		351.10*	12.20	8.74468E-001	3.61065E-001
		404.80	4.10		
		426.90	1.90		
		831.80	3.30		
PB-212	0.525	74.81	9.60		
		77.11*	17.50	1.96712E-001	1.56305E-001
		87.20	6.30		
		89.80	1.75		
		115.18	0.58		
		238.63*	43.10	1.71560E-001	1.12829E-001
		300.09	3.27		
BI-214	0.213	609.32*	46.09	1.57716E-001	9.25182E-002
		768.36	4.89		
		806.17	1.23		
		934.05	3.16		
		1120.28	15.04		
		1155.19	1.69		
		1238.11	5.92		
		1280.96	1.47		
		1377.65	4.02		
		1385.31	0.78		
		1401.50	1.39		

```
                    1407.98      2.48
                    1509.19      2.19
                    1661.28      1.15
                    1729.60      3.05
                    1764.51     15.92
                    1847.44      2.12
                    2118.54      1.21
   AM-241    0.998     59.54*    36.30   8.90099E+000  6.02284E-001

       * = Energy line found in the spectrum.
       @ = Energy line not used for Weighted Mean Activity
       Energy Tolerance :    1.000 keV
       Nuclide confidence index threshold =   0.20
       Errors quoted at  1.960 sigma
```



```
**************************************************************************
*****   I N T E R F E R E N C E   C O R R E C T E D   R E P O R T   *****
**************************************************************************


                Nuclide       Wt mean         Wt mean
       Nuclide     Id          Activity        Activity
       Name     Confidence    (pCi/gm  )      Uncertainty

       AL-26      0.650      3.133836E-002   3.951322E-002
       BI-211     0.246      8.744680E-001   3.610654E-001
       PB-212     0.525      1.801764E-001   9.148411E-002
       BI-214     0.213      1.577157E-001   9.251825E-002
    X  PB-214     0.248
       AM-241     0.998      8.900993E+000   6.022837E-001

       ? = nuclide is part of an undetermined solution
       X = nuclide rejected by the interference analysis
       @ = nuclide contains energy lines not used in Weighted Mean Activity

       Errors quoted at  1.960 sigma


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

                Peak Locate Performed on:  6/10/2008   6:18:26 PM
                Peak Locate From Channel:      1
                Peak Locate To Channel:     4096

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

       All peaks were identified.
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	5c. PROGRAM ELEMENT NUMBER
AUTHOR(S)	5d. PROJECT NUMBER
Chaparro, Orlando M., Captain, USMC	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

In 1960 at the McGuire Air Force Base, New Egypt, New Jersey a helium tank ruptured causing a fire to ignite a nearby nuclear tipped Boeing Michigan Aeronautical Research Center (BOMARC) missile. During the fire the weapons grade plutonium (Pu-239, Pu-240, and Pu-241) ignited and was released into the surrounding area, due to both firefighting efforts, where high pressure water was used to put out the fire, as well as smoke that deposited plutonium as oxidized particles in the surrounding area (Cicotte, 2007). This study investigates the heterogeneity of the distributed plutonium contamination in the McGuire Air Force Base BOMARC missile site soil based upon direct measurements of Am-241, a decay product of Pu-241. The heterogeneity of soil samples taken from the BOMARC missile site was quantified using a conjugate counting method with gamma spectroscopy analysis. Plutonium was shown to be heterogeneously distributed in the BOMARC missile site soil. The physical properties of the heterogeneously distributed plutonium contamination evaluated in this research likely consist of individual particles of plutonium metal alloys. The fate of these particles in the environment as they continuously are exposed to weathering and other physical factors is unknown.

15. SUBJECT TERMS
Plutonium, Heterogeneity, BOMARC

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
REPORT	ABSTRACT	c. THIS PAGE			David A. Smith, Lt Col, USAF (ENV)
U	**U**	**U**	**UU**	63	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 785-3636, ext 7404; e-mail: David.A.Smith@afit.edu

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