BASELINE MEASUREMENTS OF NATURAL RADIOACTIVITY AT THE TEXAS A&M ENGINEERING EXTENSION SERVICE- DISASTER CITY

A Thesis

by

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MASTER OF SCIENCE

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ABSTRACT

"Disaster City" is a 52-acre mock city that serves as a training facility for emergency responders. Emergency responders from distant locations come to Disaster City (DC) for search and rescue training and exercises. The facility has also been used by Texas A&M's Nuclear Security Science & Policy Institute (NSSPI) for several radiological emergency training activities. Periodically, sealed radioactive sources are used at DC to train emergency responders and students to become more familiar with radiation dose rates and field detection equipment. One of the radiological emergency training exercises that is being considered currently is to prepare for potential short-lived radiological contamination using unsealed radioactive sources. Contamination control and monitoring are important elements of using unsealed radioactive sources in the environment. It is paramount, therefore, to document the present environmental conditions of the DC site in order to help scientists assess future effects caused by human activities. The measurement of naturally occurring radiation to establish baseline levels is a normal part of security and emergency preparedness. As a result, this research involved the conduction of a preliminary survey of gamma radiation background from terrestrial sources at the DC site to provide a baseline for the site prior to the startup of radiological contamination. This research involved a ground based radiation survey using a 4"x4"x16" thallium-doped sodium iodide (NaI (Tl)) ORTEC search system (ORTEC NaI-SS). In addition, soil samples, water samples and *in situ* measurements

were analyzed using a high-purity germanium (HPGe) detector. Aliquot water samples were counted using liquid scintillation counter (LSC). All data collected were reviewed to identify any radiological anomalies. The ORTEC NaI-SS measured count rates that ranged from 656 to 2321 s^{-1}. The highest average count rate of 1625±63.2 s^{-1} was observed in the "Rubble Pile 2 area." Second by second spectral data were summed in areas of where the count rates exceeded 1564 s^{-1} to attempt to identify the reason for the higher count rates. The analysis showed only increased levels of ^{40}K and ^{232}Th. Similarly, collected laboratory samples and *in-situ* HPGe spectra were reviewed. This review showed specific radionuclides in the ^{238}U chain, ^{232}Th chain, and ^{40}K. For the LSC analysis of water samples, the results indicate no detectable radioactivity. In summary, the results of this project indicated the presence of only natural background, and no man-made radiation sources were discovered.

DEDICATION

This thesis is dedicated to my beloved mother, the late Charlotte Akosua Anyomi. May your soul rest in peace.

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NOMENCLATURE

DC	Disaster City
TEEX	Texas A&M Engineering Extension Service
Cs	Cesium
NSSPI	Nuclear Security Science & Policy Institute
CEBAF	Continuous Electron Beam Accelerator Facility
JA	Johnston Atoll
DRI	Desert Research Institute
ERG	Environmental Restoration Group
NRC	Nuclear Regulatory Commission
GPS	Global Positioning System
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
NORM	Naturally Occurring Radioactive Material
DOE	Department Of Energy
NRC	Nuclear Regulatory Commission
EPA	Environmental Protection Agency
NSC	Nuclear Science Center
US EML	United States Environmental Measurements Laboratory
TAMU EHS	Texas A&M University Environmental Health and Safety
HPGe	High Purity Germanium
Ge	Germanium

FWHM	Full Width at Half Maximum
TSTA	Technical Skills Training Area

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Assistant Professor Craig Marianno [advisor] and John W. Poston, Sr. of the Department of Nuclear Engineering and Professor Cody Folden of the Department of Chemistry.

All other work conducted for the thesis was completed by the student independently.

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1. INTRODUCTION

The Texas A&M Engineering Extension Service (TEEX) is a state agency that offers training programs and technical assistance to public safety workers, both in Texas and from around the world. The agency sponsors the state's primary urban search and rescue force, and operates the Brayton Fire Training Field. "Disaster City" (DC), is a 52-acre (0.21 km^2: 0.081 sq mi) mock city located on the southern border of the Training Field. The site serves as a training facility for emergency responders. Emergency responders from all over the world come to DC for search and rescue training. The facility has also been used by Texas A&M's Nuclear Security Science & Policy Institute (NSSPI) for several radiological emergency training activities. Periodically, sealed radioactive sources have been used at DC to train emergency responders and students to become more familiar with the use of radiation detection equipment in the field. One of the radiological emergency training exercises that is being considered currently is to prepare for a potential short-lived radiological contamination exercise using unsealed sources.

An unsealed source is a form of radioactive material which is not encapsulated or contained. The use of unsealed sources carries the risk of contamination when not used in a controlled setting. The uncontrolled nature of contamination may lead potentially to the contamination of the environment. However, planning and preparation for such radiological contamination exercise can help minimize potential public health and environmental threats. In addition, it is essential to conduct and document baseline

measurements before the commencement of any contamination exercises. These measurements will provide a baseline for clean-up should it be necessary.

For this reason, a preliminary-survey of external gamma radiation levels throughout DC was conducted. The external survey used a 4"x4"x16" NaI (Tl) gamma radiation search mobile detector system. This research also included *in situ* measurements and analysis of soil and water samples using a HPGe detector. In addition, liquid scintillation was employed to analyze water samples from surrounding bodies of water.

The most common radionuclides in soil and ground water are from three natural decay series, ^{238}U, ^{232}Th and ^{40}K [1]. Naturally occurring radionuclides found in the environment may originate from a variety of sources [2]. In addition, naturally occurring radioactive material concentrations can be increased above the average natural background through human activities. Considering the environmental factors and uncertainties involved, the results from this research will provide a useful baseline for future exercises at DC. This research documented all radiological survey results and provides detailed information on present radiological conditions at DC.

The research objectives were: to characterize the radiation background of DC and provide a map showing the distribution of gross count rate of background radiation and to collect spectra for soil and water samples. A site map of DC is shown in Figure 1. The detection of man-made radionuclides other than naturally occurring radioactive materials was doubtful. However, if any man-made radionuclides were identified, the samples

would be retained and the Radiological Safety Division of Texas A&M University Environmental Health and Safety (TAMU EHS) would be informed immediately.

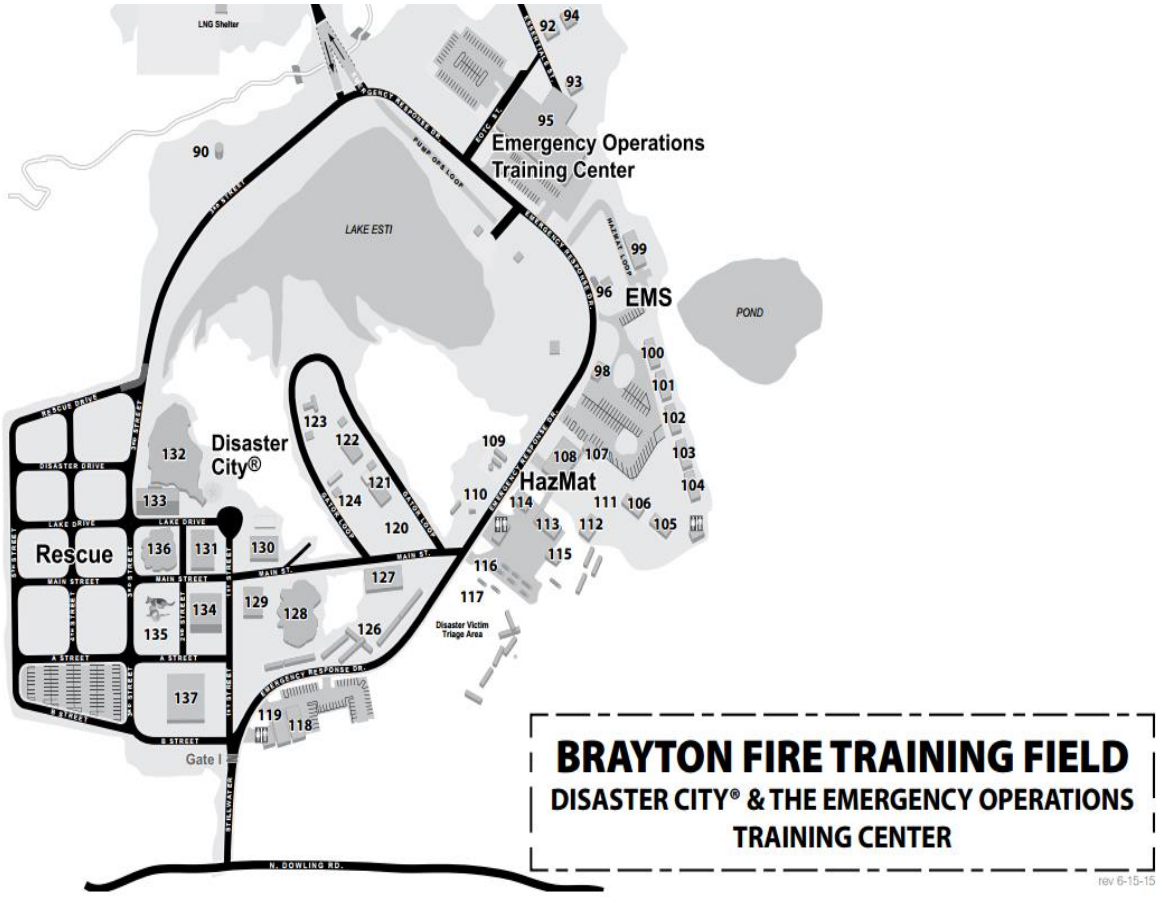

Figure 1. Map of sampling and measurement location.

2. LITERATURE REVIEW

There are many other examples of site surveys that have been performed to screen large areas for radioactive material. The following examples closely pertain to the project objectives at DC.

Wollenberg et al., [3] conducted a survey of the gamma radiation background from terrestrial sources at the Continuous Electron Beam Accelerator Facility (CEBAF) site in Newport News, VA, on November 12-16, 1990. The survey provided a gamma-radiation baseline for the site prior to the startup of the accelerator. The survey measurements were conducted using a portable gamma-ray spectrometer system (the Geometrics GR 410), incorporating a 3-inch diameter by 3-inch thick NaI(TI) detector, accompanied by the collection of soil samples. Wollenberg conducted the survey by placing the detection devices approximately 3-ft above the ground while traversing the site on foot. The soil samples were collected by troweling the top 2 to 3-cm of the soil from several points over a 20-ft diameter area into plastic bags.

Wilson-Nichols et al. [4] conducted a radiological survey in 1980 to determine the extent of surface transuranic contamination on Johnston Atoll (JA). The survey was also conducted to help evaluate the gamma radiation background. Survey measurements were made with different grid spacing depending on the specific areas being surveyed. For some areas, a 50-100-ft grid spacing was used in the survey measurements. A series of ground measurements were conducted through soil sampling. Each soil sample was composed of 12 subsamples, each 15-cm on a side and 3-cm deep within a given 50-ft

by 50-ft sampling location. Results of the survey were compiled into a long-term database by the Desert Research Institute (DRI) for future reference.

The Environmental Restoration Group (ERG) [5] conducted a baseline radiological study for the Dewey Burdock uranium *in-situ* recovery project site owned by Powertech (USA), Inc. The study was performed between August 2001 and August 2008 to obtain a radioactive material license from the U.S. Nuclear Regulatory Commission (NRC). The radiological field measurements consisted of the following activities: a). performing Global Positioning System (GPS)-based gamma-radiation surveys at 100 to 500-m transects spanning the site; b). collecting surface soil samples (0-15-cm) at 75 randomly selected and at 5 different locations.

The GPS-based gamma-radiation survey was conducted using an unshielded 2" x 2" NaI detector and a Trimble Pro XRS GPS receiver. In order to find greater variations in gamma-ray emission, the transect spacing was reduced in certain areas. The survey speed was maintained between 2 and 5-ft per second with x and y coordinates and gamma-ray count rates recorded every second. The NaI detector height was relatively constant at approximately 18-inches above the ground surface.

The studies above were mainly used to provide guidance to meet the objectives of this study. Some specific survey techniques and data analysis methods were implemented on this project. For example, Wollenberg et al. conducted the ground-based measurements on foot as implemented in this study. In addition, the survey described here used techniques similar to the Environmental Restoration Group to conduct *in-situ* analysis. Ground measurements conducted by Wilson-Nichols et al.

provided insight into soil sampling and analysis. Using examples of past research helped shape the execution of this work.

3. RADIATION IN THE ENVIRONMENT

Human exposure to radiation is an inescapable part of life. Everyone is exposed to ionizing radiation in their daily life. Other than medical treatment, the majority of our daily exposure comes from primordial sources of radiation from radionuclides that remain from the creation of all matter billions of years ago [6]. Among the primordial sources are the ^{40}K (half-life 1.27 x 10^9 yr), and the ^{238}U (half-life 4.46 x 10^9 yr) and ^{232}Th (half-life 1.39 x 10^{10} yr) decay series as shown in Figure 2. These radionuclides are found in rock, soil, and water bodies, as well as other environmental media. All radionuclides present in the soil are somehow part of the food chain that leads to the human body. For example, these radionuclide can drain into water, plants absorb the water through the soil and are released into the air where they are consumed and inhaled by humans. Another exposure path can be found through building materials containing primordial radionuclides. The radiation emitted by primordial radionuclides contributes about 90% of the average exposure to natural background ionizing radiation in the United States and 76% of the average exposure when considering all other sources such as medical x-ray, nuclear medicine, consumer products, etc. [7].

The remaining 10% of the average exposure to natural background radiation in the United States comes from cosmic radiation. It is also interesting to note that natural background radiation levels vary from one location to another. These exposures depend on two things: altitude and the position of the earth. The atmosphere serves as a shield- that is why living at sea level results in lower background doses than living in Denver. But, position on earth is also important, that is, equator versus the poles. In addition,

under certain weather conditions, there may be short-term variations of natural radiation levels.

Radiation in the environment has been mapped and surveilled to better understand the variation of radiation intensity. In addition to natural radiation, man-made radionuclides from nuclear weapons fallout, nuclear power plants, and many radiological accidents have contributed to contamination of the environment, thus making studies in environmental radioactivity even more important.

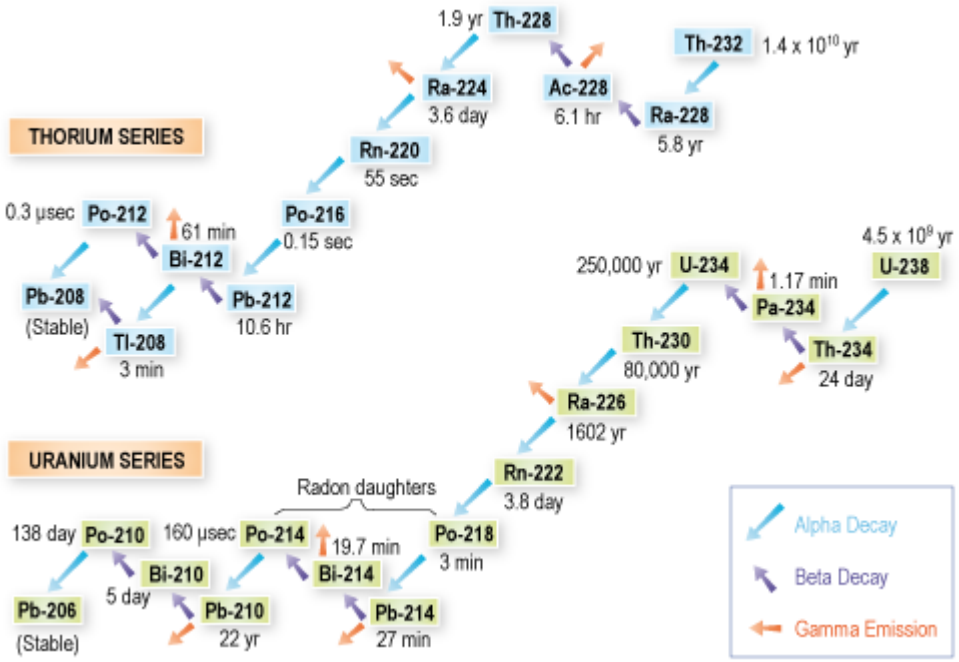

Figure 2. The radioactive decay in ^{232}Th and ^{238}U series [8]

3.1 Anthropogenic sources

Anthropogenic sources are man-made (artificial) radionuclides, which are produced as a result of human activities. Most artificial radionuclides are used to manufacture goods and produce energy. For example, ^{241}Am is used in smoke detectors. Humans also produce radionuclides for use in agriculture, research and medicine. There are many other examples of radionuclides in consumer products, and each contributes to some exposure to mankind.

Other artificial radionuclides that can impact environmental studies include fallout radiation from past atmospheric nuclear weapon tests. During the 1950s and 1960s, many radioactive elements were released into the atmosphere [9]. These radioactive contaminants have been transported through the atmosphere and deposited around the world. A few examples of atmospheric releases are: ^{137}Cs, ^{90}Sr, and ^{95}Zr [10]. In summary, all sources of natural and man-made radiation can contribute to background radiation.

3.2 Pathways of radionuclides in the environment

As mentioned above, natural or artificial radiation sources can contribute to some levels of radioactivity present in the environment. The three main migration pathways for radiological contaminants include air, ground water and soil. Mostly these migration pathways can be concentrated with NORM or artificially produced radionuclides. Other ways of releasing radionuclides in the environmental are through accidents and poor waste disposal. Contamination of food and water sources can occur from dust transported by wind from uranium mine sites and waste deposits [11].

The major routes of exposure pathways to humans are ingestion, inhalation, and direct exposure. Human receptors may be exposed through ingestion and inhalation of radiologically contaminated dust and soil particles in the environment. Also, direct gamma exposure may occur when receptors are near enough to radiological contamination to receive a dose. A good illustration of the many pathways that the public may be receive radiation exposure is shown in Figure 3.

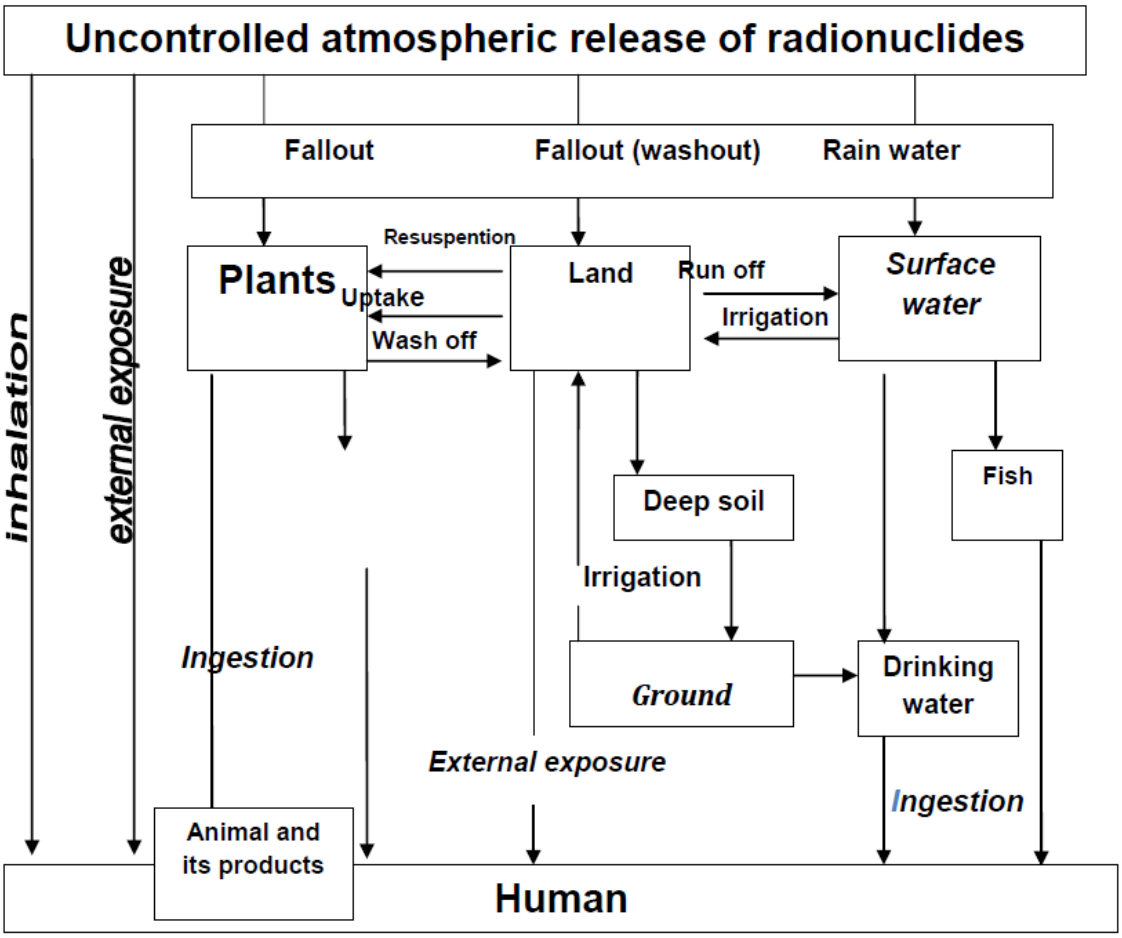

Figure 3. Radionuclides exposure to humans [12]

4. SURVEY METHODS

4.1 Detector functionality

To assure spectral data were accurate a rigorous detector response check regime was maintained. The detector spectrum was set at a 3 MeV scale in order to detect a series of nuclides that might be found naturally on the site and would be used during contamination exercises. There were a series of detector operational response checks conducted before and after every walkover survey. Prior to leaving for DC, the energy response of the instrument was checked using a single ^{137}Cs source (10 µCi). This was done to assure the functionality of the detector before transporting it to the site. Due to problems that might have occurred during transportation of the detector system, a second response check was performed at the site. By doing this, any change in detector response was noticed before a survey was conducted. After a 1-hr background acquisition, the detector was gain stabilized on natural potassium (^{40}K) at 1460.2 keV using the ORTEC system software. A rigorous-energy calibration was not performed since exact radionuclide identification was not the purpose of the survey. The purpose of the survey was to evaluate background levels present in DC. Therefore, a single energy response check provided the quality assurance that the detector system was functional.

In addition, the function of the survey instrument was checked at the end of each work day using the same radionuclide standard. At every scan interval (water break), a five-minute, energy-response measurement was performed using the same radionuclide standard. This check was performed periodically during the day to determine the functionality of the detector.

The ORTEC NaI-SS was conveniently packaged in a rugged plastic container and controlled by a computer system via a USB cable. The NaI-SS used a ORTEC digiBASE, which provided high voltage and a digital multi-channel analyzer (MCA) for the NaI(TI) detector. The detector system was controlled by NaISS-B32 system software version 2.5. The ORTEC MAESTRO-32 analysis software (included in the NaISS-B32 software suite) was used for spectra analysis. The NaISS-B32 system acquires and records second by second gross counts, gamma-ray spectra and GPS locations in an internal database. A GPS, integrated into the measuring system, records the exact position of the detected radiation.

In addition, the NaISS-B32 system software has a feature for setting regions of interest (ROI): a way to denote energy ranges in the spectrum for specific radionuclides. The NaISS-B32 system software operational manual was followed to set the ROIs for the survey [13]. The energy ranges of the ROIs selected for the survey were based on the naturally occurring radioactive materials such as ^{238}U, ^{232}Th, and ^{40}K. Due to the low gamma-ray energy of ^{238}U, the daughter radionuclide ^{234m}Pa with highest gamma-ray energy (1001 keV) was used. The following radionuclides were also included in the ROI: ^{99m}Tc, ^{56}Mn, and ^{18}F. These radionuclides were identified for potential use at DC. However, since rigorous calibration was not performed these ROIs were not trusted. To test the functionality of the energy ranges set in the ROI, the detector was tested with reference radionuclides of ^{60}Co and ^{137}Cs. These are industrial long-lived radionuclides which might be present in DC, and therefore, were tested and monitored during the survey

Although the concentration of radioactive materials in effluents of research reactors are much lower compared to power reactors, environmental monitoring is still essential. The DC site under study is approximately 2 miles north-east to the Texas A&M University Nuclear Science Center (NSC) that houses 1MW TRIGA research reactor. For this reason, other radionuclides of environmental concern were added to the ROIs for monitoring purposes. Some of these radionuclides that were included in the ROIs were: ^{137}Cs and ^{131}I.

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4.2 Gamma walkover survey

Ground-based survey and water sampling procedures of the DC site were performed with well-established methods in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) and Environmental Monitoring Laboratory (EML) manual respectively [14, 15]. The MARSSIM document is a multi-agency consensus document that was developed together by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOE), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear Regulatory Commission (NRC). The MARSSIM and EML document provided information on planning, conducting, sampling, and documenting building surface, vegetation, water, and surface soil radiological survey.

The walkover survey was conducted using a 4"x4"x16" ORTEC NaI- Search System (NaI-SS). The ORTEC NaI-SS was mounted on a four-wheel cart and pulled at a walking speed between 2 and 3-feet per second, in a “serpentine” pattern with a line spacing of approximately 10-20-ft, throughout the area as terrain and obstacles permitted. The detector was kept at approximately 18-inches above the ground and in the same orientation as shown in Figure 4. The goal was to record data for natural background radioactivity, to identify radionuclides that are present in the areas, and to map the distribution of background gamma radioactivity. The data collected coupled with mapping tools such as Quantum Geographical Information System (QGIS) was used to provide a visual representation of background radioactivity.

Figure 4. Walkover system configuration used for the DC survey.

The GPS-based gamma survey was conducted over 3 days between June 07, 2016 to July 22, 2016. For the survey purposes, the DC site was categorized into five (5) sections: Rubble Pile 1 Area, Rubble Pile 2 Area, Disaster Victim Triage Area, Technical Skills Training Area (TSTA), and Parking Lot Area as shown in Figure 5. For completeness, the roads in DC were covered in the survey. The surveys were transected at approximately 40-60-ft apart in all areas as permitted by terrain and obstacles. The second by second spectra and count rates were recorded. ROI count rates were also recorded. The count rate from the survey measurement was assigned a color code; blue (low count rates (656-1025 s^{-1})), yellow (mid-range count rate (1025-1564 s^{-1})), and red

(high count rate (1564-2321 s^{-1})) and plotted on a map of DC. The map of background radiation was developed using Quantum Geographic Information System (GIS) version 2.16. In addition, minimum, maximum, and mean of the data points were compared to one another.

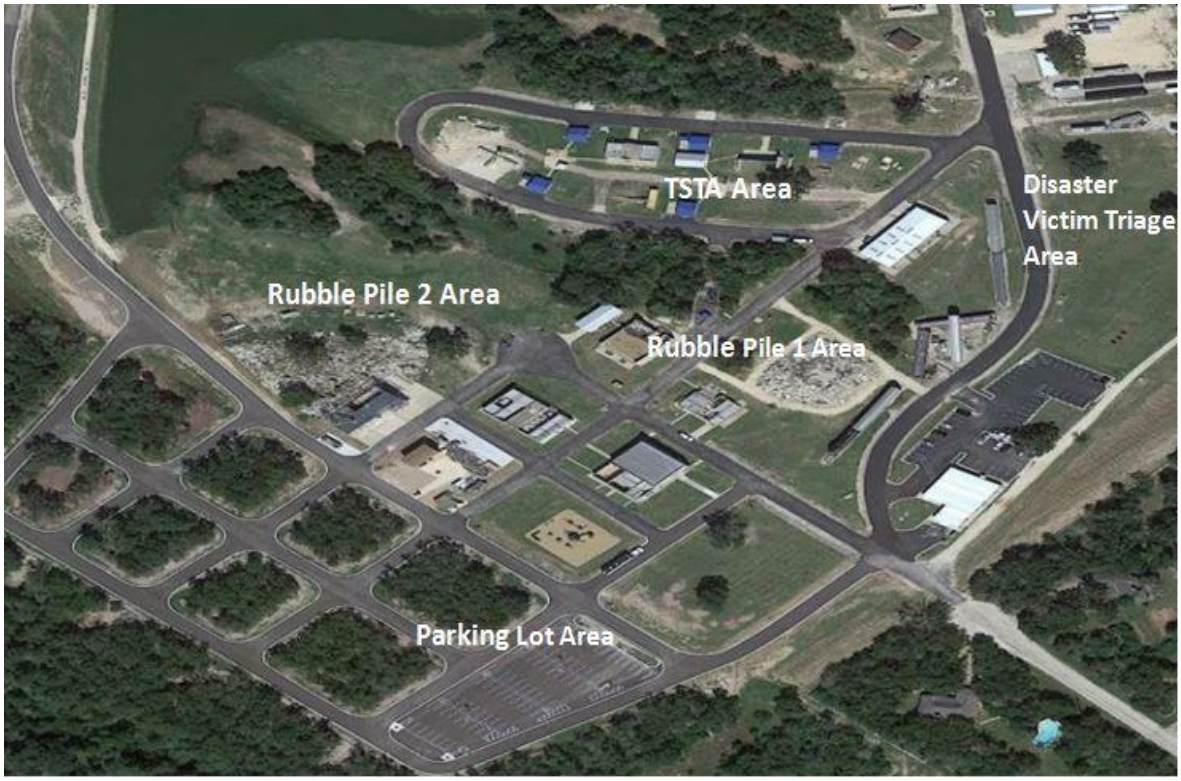

Figure 5. Map of DC with the survey areas displayed.

4.3 *In situ* measurements

In situ measurements were taken using a HPGe in areas not accessible by the cart. These areas include Rubble Pile 1 and 2 since they are most likely to be used during a contamination exercise. Measurements were collected on six different static locations on top of the rubble piles as shown in Figure 6. A portable tripod-mounted gamma spectroscopy system (HPGe) was used in these measurements. The detector was suspended at a height approximately 3-ft above the surface. The face of the HPGe detector was pointed at the ground to detect gamma rays from the pile as shown in Figure 7. Each measurement was counted 15-minutes.

Figure 6. *In situ* measurement locations.

Figure 7. Tripod-HPGe detector apparatus used for in-situ measurements on the rubble piles.

5. SOIL SAMPLING

Soil samples were collected based on a review of the walkover survey. Based on the ground-based map distribution of natural radioactivity, the location with the highest gamma-ray reading logged was selected for soil sampling. Additionally, samples were collected in areas to be impacted by future operations. During the sample collection, latitude and longitude were recorded to provide traceability.

In total, a set of twenty two samples were collected from DC with depths of 2-5-cm (surface soil). In all, nine samples were collected from Rubble Pile 1 area, three samples from Rubble Pile 2 area, three samples from DVTA, and three samples from the TSTA area (See Figure 5). The soil sample location identifiers and location are listed in Table 1. Visual location of soil samples and geographical location are shown in Figure 8 and listed in Table 1 respectively.

Table 1. Collected soil samples and geographical locations.

		Geographical Location	
Sample Location	**Sample Code**	**Latitude º**	**Longitude º**
Rubble Pile 1	Pile 1-SA1	30.575767	-96.350400
	Pile 1-SA2	30.575650	-96.350383
	Pile 1-SA3	30.575533	-96.350450
	Pile 1-SA4	30.575433	-96.350550
	Pile 1-SA5	30.575217	-96.350550
	Pile 1-SA6	30.575183	-96.350317
	Pile 1-SA7	30.575400	-96.350100
	Pile 1-SA8	30.575033	-96.350500
	Pile 1-SA9	30.575550	-96.350267
Rubble Pile 2	Pile 2-SA1	30.575667	-96.351617
	Pile 2-SA2	30.575800	-96.351967
	Pile 2-SA3	30.576100	-96.352533
Disaster Victim Triage Area	DVTA-SA1	30.576450	-96.349383
	DVTA-SA2	30.575983	-96.349217
	DVTA-SA3	30.575550	-96.349417
	DVTA-SA4	30.575817	-96.348617
	DVTA-SA5	30.575167	-96.349250
Technical Skills Training Area	TSTA-S1	30.575883	-96.349950
	TSTA-S2	30.576583	-96.351617
	TSTA-S3	30.576000	-96.351383
	TSTA-S4	30.576117	-96.350333
Training Center	TC_S1	30.574150	-96.350433

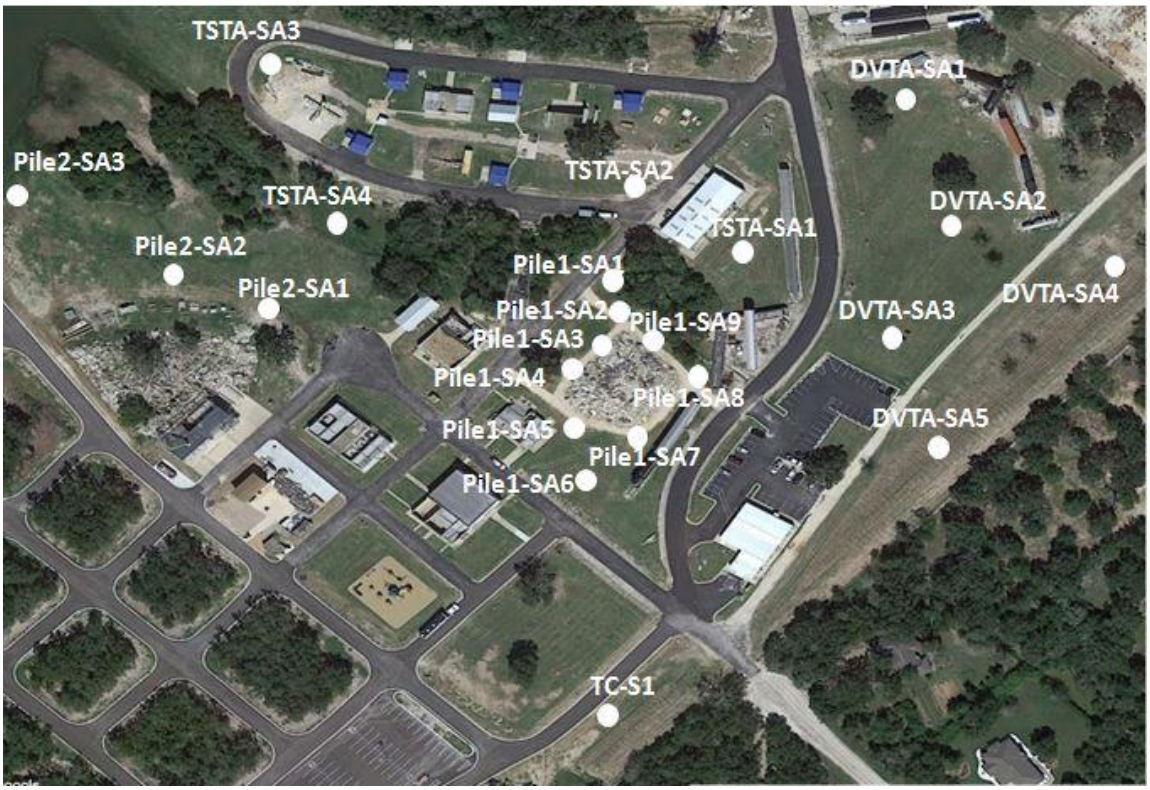

Figure 8. Soil sample locations in Disaster City.

Sampling equipment was selected based on the type of soil and required sample depth. Soil samples were collected using a bulb planter (to provide uniform diameter) and hand trowel (to remove vegetation cover). The vegetation cover (e.g., rocks, plant roots, or concrete) was removed before sampling. To eliminate problems associated with different depth profile for samples, constant surface area and depth were maintained. After collection, the samples were carefully transferred into 0.5-L Marinelli beakers (approximate weight of 450-g) for radionuclide analysis using an HPGe high-resolution gamma-spectrometer in Figure 9. When performing sample analyses, errors in the measured quantities because of inappropriate sampling and sample preparation methods can occur. Considering these concerns, every procedure employed in this research was

consistent with United States Environmental Measurements Laboratory (US EML) approved procedures [16].

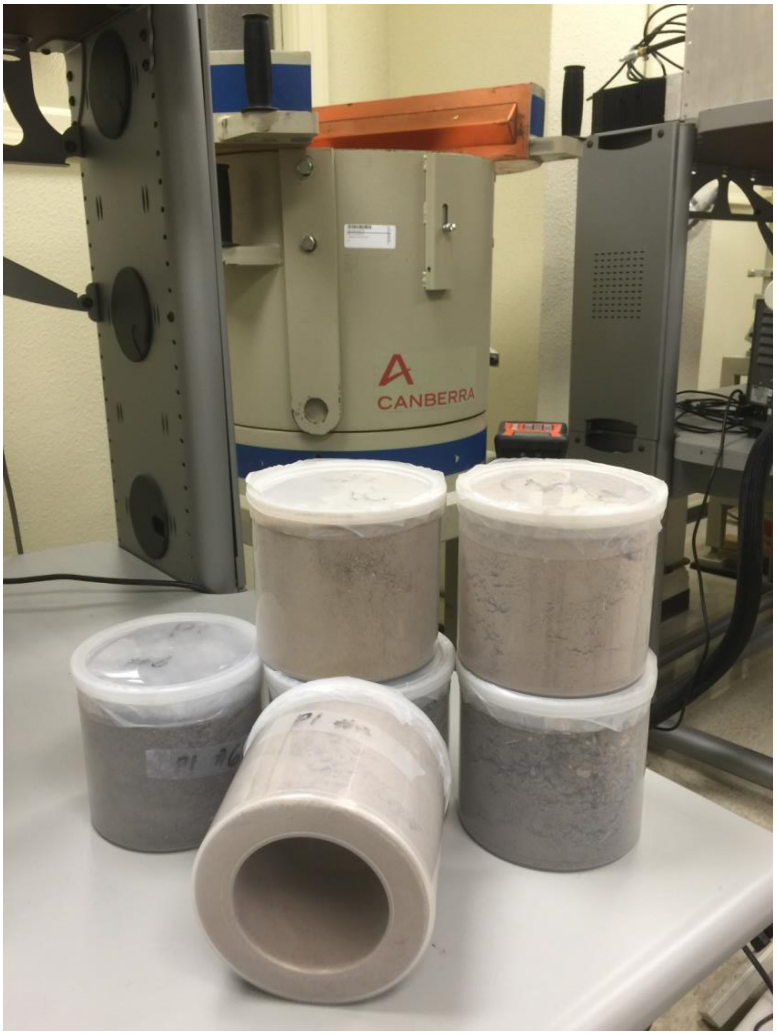

Figure 9. Soils samples sealed into 0.5-L Marinelli Beakers.

5.1 Gamma spectroscopy of soil and water samples

The advantage of gamma-ray spectrometry is the ability to measure gamma emitters directly in samples without performing chemical separations. To record spectra of soil samples, an HPGe detector was used. HPGe detectors are used in gamma-ray spectroscopy analysis because of their excellent energy resolution. Each sample was measured with a 55% relative efficiency HPGe and a multichannel analyzer with 8192 channels (Appendix A).

Prior to the analysis, the HPGe detector was energy calibrated. In addition, a 24-hour background measurement was performed in the shielded detector. The detector was surrounded by a cylindrical shield consisting of lead with thickness of about 5-cm, which provided shielding for background gamma radiation present at the laboratory. A counting time of twenty-four hours was allocated for each sample to record a spectrum. For each samples, a background-subtracted spectrum was evaluated using ORTEC's GammaVision 32 software program.

6. WATER SAMPLING

Water is important in environmental studies because of its ability to transport pollutants. NORM is a common part of natural waters, in particular alpha-radiation-emitting uranium, radium, and their progeny, including radon [17]. In addition, when contamination is identified in soil samples, there is a greater chance of contaminants migrating to ponds and lakes in the vicinity of DC. Therefore, when assessing the groundwater condition at a site, serious consideration should be given to water migration paths [18]. This is mainly possible after a heavy rain via groundwater flow since these provide avenues for quick contaminant migration. For this reason, the environmental division of TAMU EHS accepted an invitation for a site visit to DC to help identify groundwater flow directions. The visit was very helpful in identifying suitable water sampling locations. Lake Esti is the closest body of water to the proposed locations for the future contamination exercises. In the event of a heavy rain, Lake Esti has the potential to overflow and could drain into White Creek. At the same time, Lake Esti was constructed to hold a large volume of water and has not overflowed in past years. Therefore, White Creek was not a major concern and was eliminated as a sample location.

Water samples were collected at Lake Esti and a pond in the vicinity of DC as shown in Figure 10. The water samples approximately 12-40-cm deep were collected in 2-L polypropylene bottles. Dose rate measurements were performed on each one gallon of water sample collected using a Victoreen (Fluke 451 Ion Chamber Survey Meter). The collected water samples were left for twenty-four hours in polypropylene bottles to

allow settling of any suspended solid materials. Aliquot samples were transferred into 0.5-L Marinelli beakers for radionuclide analysis via gamma-ray spectrometry. The remaining samples were used in LSC analysis for better counting efficiency for alpha and beta emitters.

Figure 10. Water sampling locations in Disaster City.

6.1 Liquid Scintillation analysis of water samples

LSC is the most common and practical method for measuring low-energy beta emitters. The samples are combined into a "cocktail," which combines the nuclides with a liquid scintillator to optimize the counting efficiency of alpha and beta particles. In the cocktail, there is an emulsifier (solvent) and flour (solute). The incident radiation is deposited in the solvent molecule, which transfers energy to the fluor molecules [19]. Part of the kinetic energy of the ionizing particle is transferred to the cocktail and converted into light, which is detected by the LSC system.

In total, a set of ten water samples were collected from bodies of water in DC. Seven water samples were collected from Lake Esti while three water samples were collected from the pond (Figure 10 and Table 2). The LSC analysis of water samples were conducted using a Tri-Carb 3110 TR Liquid Scintillation Analyzer system located at the TAMU EHS Radiological Safety Office as shown in Figure 11. The detector assembly is surrounded by a minimum of 5-cm of lead. The instrument was calibrated before any samples were counted. The calibration was performed using the Self-Normalization and Calibration (SNC) standard containing ^{14}C, ^{3}H, and a background source. The calibration standards have varying efficiencies for the two radionuclides; the efficiency with the ^{14}C standard was 95% and that of ^{3}H was 60%. For the purpose of screening and being conservative, the counting efficiency of the LSC system was assumed to be 33%. The efficiency was assumed in order to help overestimate count rate. The LSC system has the capability of setting three separate measuring regions for alpha and beta counts. Counting was conducted to analyze the following energy regions:

channel A (1.9 to 18.6 keV), B (1.9 to 157.0 keV), and C (1.9 to 2000 keV). These regions represent the energy range of alpha, beta and gamma, respectively.

Table 2. Collected water samples and geographical locations.

		Geographical Location	
Sample Location	**Sample Code**	**Latitude º**	**Longitude º**
Lake Esti	LE1	30.576100	-96.352600
	LE2	30.576700	-96.352300
	LE3	30.577000	-96.351900
	LE4	30.577600	-96.350800
	LE5	30.578100	-96.351800
	LE6	30.577700	-96.352700
	LE7	30.577200	-96.352700
Pond	P1	30.578800	-96.349800
	P2	30.579200	-96.349800
	P3	30.579400	-96.349300

For the purpose of recording background count rate, the TAMU Radiological Safety Office procedures for counting "carboy liquid waste" samples were employed. For the carboy waste measurements, a 1-mL to 5-mL sample-cocktail ratio was used. The ratio was modified to accommodate the low-level environmental water samples. Higher sample volume allows for better counting results. Therefore, 3-mL water sample aliquots were transferred into a vial containing 15-mL of cocktail and agitated for 1-min. Background count rates were determined by measuring control water samples (triple purified distilled water) and cocktail in the same proportions and conditions as DC samples. After sample preparation, the samples were left in the LSC counter for 2-3 hours to obtain dark effect. This step reduces the chemiluminescence influenced by both the water sample and the concentration of cocktail added. Chemiluminescence results in the emission of light as a result of a chemical reaction between the water sample and the cocktail. This process could cause a false reading (high CPM). One way of overcoming chemiluminescence counting problems is to leave the samples in the dark before counting. Subsequently, after dark adapting the samples were counted for 60-minutes.

If samples with counts double the background were discovered, these samples were to be set aside for further measurement using alpha/beta discrimination.

Figure 11. TriCarb 3110 TR Liquid Scintillation System.

7. RESULTS AND DISCUSSION

7.1 Measurement results of mobile radiological survey

The walkthrough scanning of DC was conducted over three separate days. In total, the actual survey took just over 1-hour. The reason the survey was spread out over several days was to work around DC scheduling and system checks. In all 4659 second-by-second and spectral measurements were recorded. The 4659 gamma readings are plotted as a color scheme on the map of DC to show the location at which they were taken as shown in Figure 12.

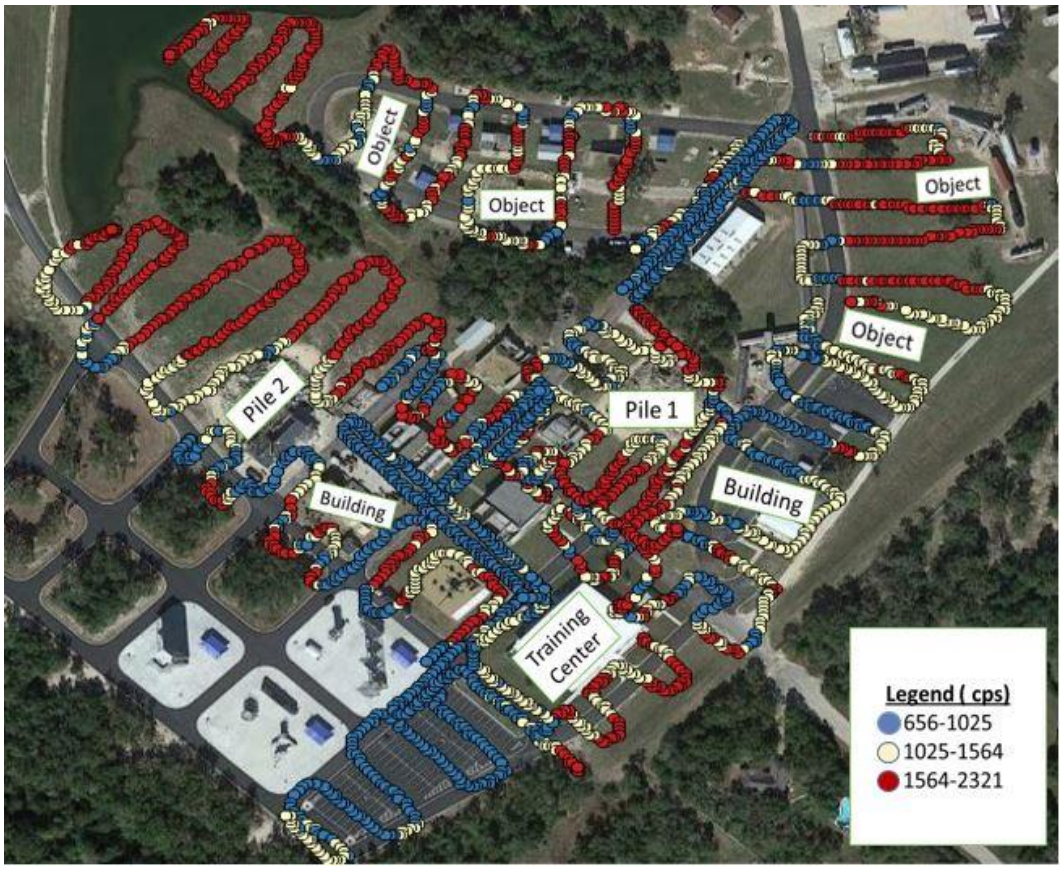

Figure 12. Visual distribution of total counts per second of gamma-rays in Disaster City.

The results indicated that the natural background gamma radiation count rates on the site ranged from 656 to 2321 s^{-1} using a 4"x4"x16" thallium-doped NaI detector. The count distributions were grouped into three categories: with 656 to 1025 s^{-1} being the blue, 1025 to 1564 s^{-1} being the yellow and 1564 to 2321 s^{-1} as red. These regions were chosen to represent equal interval of the data. Figure 13 shows the histogram of the combined count rate recorded in the detector at various surveyed zones at DC.

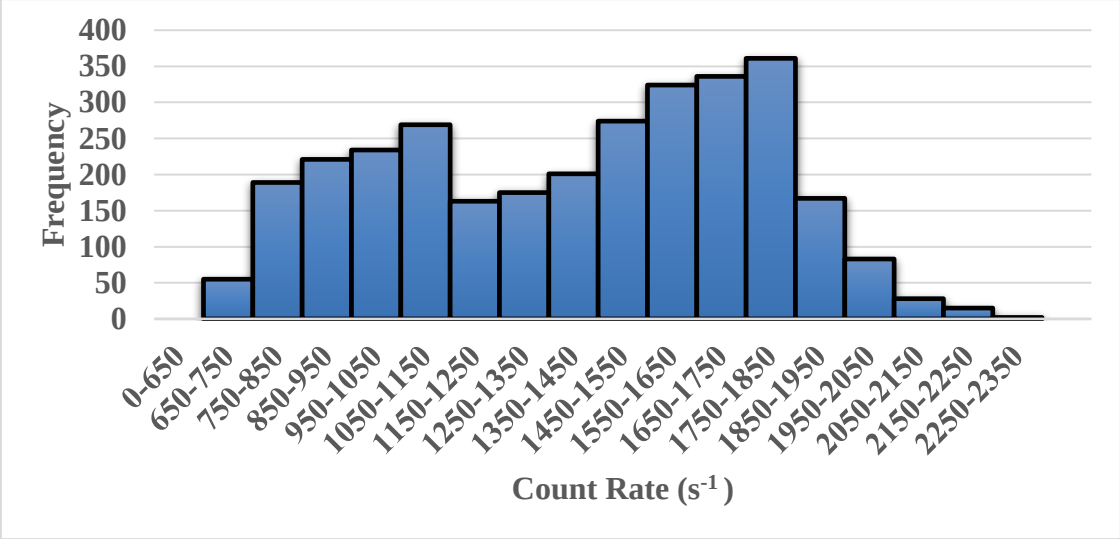

Figure 13. Histogram of the count rates recorded in various survey zones at Disaster City.

The graph shows that the combined count rates do not demonstrate a normal (bell-shape) distribution. Collectively, the most frequently recorded count rates were between the ranges of 1650-1750 s^{-1} and 1750-1850 s^{-1}. In addition, the data set was summarized into a histogram for individual areas surveyed as shown in Figures 14 through 19. Each histogram has a bi-modal distribution that is different for each areas

surveyed. The variability appears to be due to the natural background radiation variation. The average, minimum, and maximum spectrum count rate registered for different surveyed areas are shown in Table 3.

From the ground survey, it was shown that some areas have higher average count rates. For areas around the rubble piles, increased background is probably due to the increased concrete and building materials present. For the open grassland, the temperature (heat) creating moisture from the soil can contribute to higher count rate [20]. In addition, the detector walk-over was conducted on open grassland with no shielding covering the grassland. This can cause a higher count rate of natural background radiation.

In situ measurements were completed and spectra were analyzed. Figure 20 shows a typical gamma-ray spectrum collected for *in situ* measurements. The *in situ* measurements showed the same photopeak structure as that of the soil samples. Radionuclides in the NORM group (^{238}U chain, ^{232}Th chain, and ^{40}K) were identified.

Table 3. Total count rate registered for different survey areas in Disaster City.

	Count Rate (s^{-1})					
	TSTA	Parking Lot	DVTA	Rubble Pile 1	Rubble Pile 2	Roads
Average	556.6±51	943±33.6	1308±44.3	1461±50.3	1625±63.2	931±29.8
Maximum	2244	1196	1989	2025	2321	1317
Minimum	909	778	656	831	927	711
Data Points	695	572	1241	481	810	860

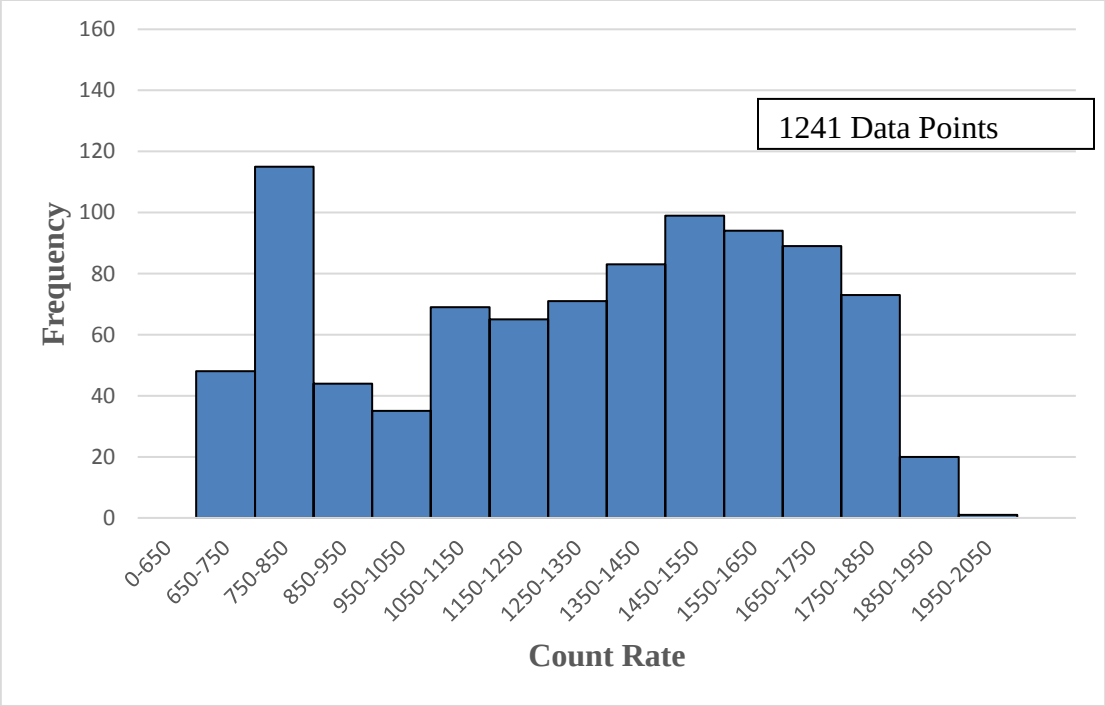

Figure 14. Histogram of total count rate recorded in Disaster Victim Traige Area.

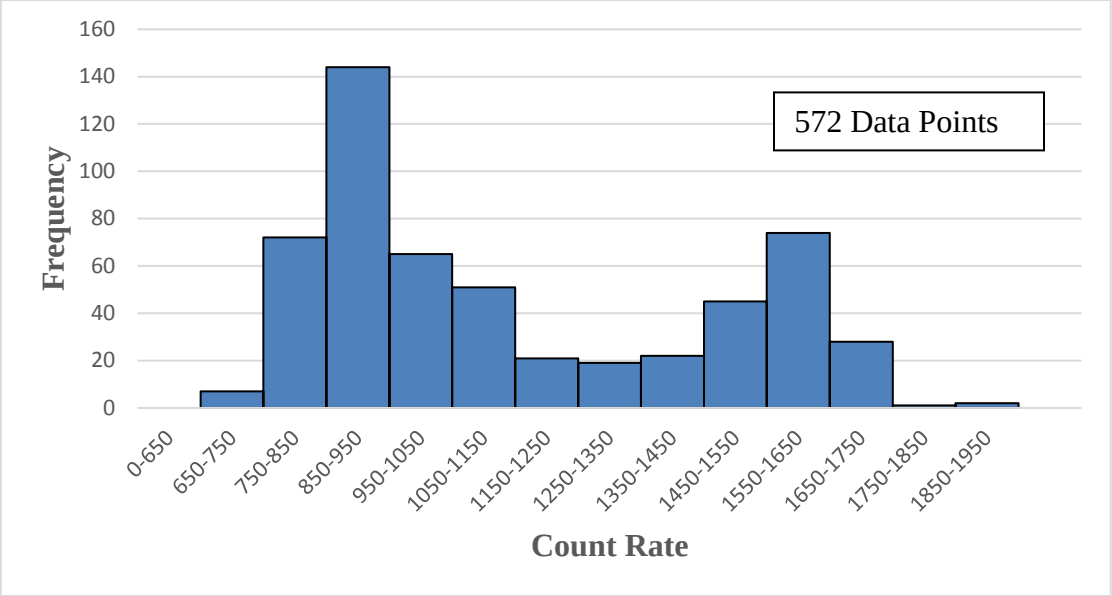

Figure 15. Histogram of total count rate recorded in Parking Lot area.

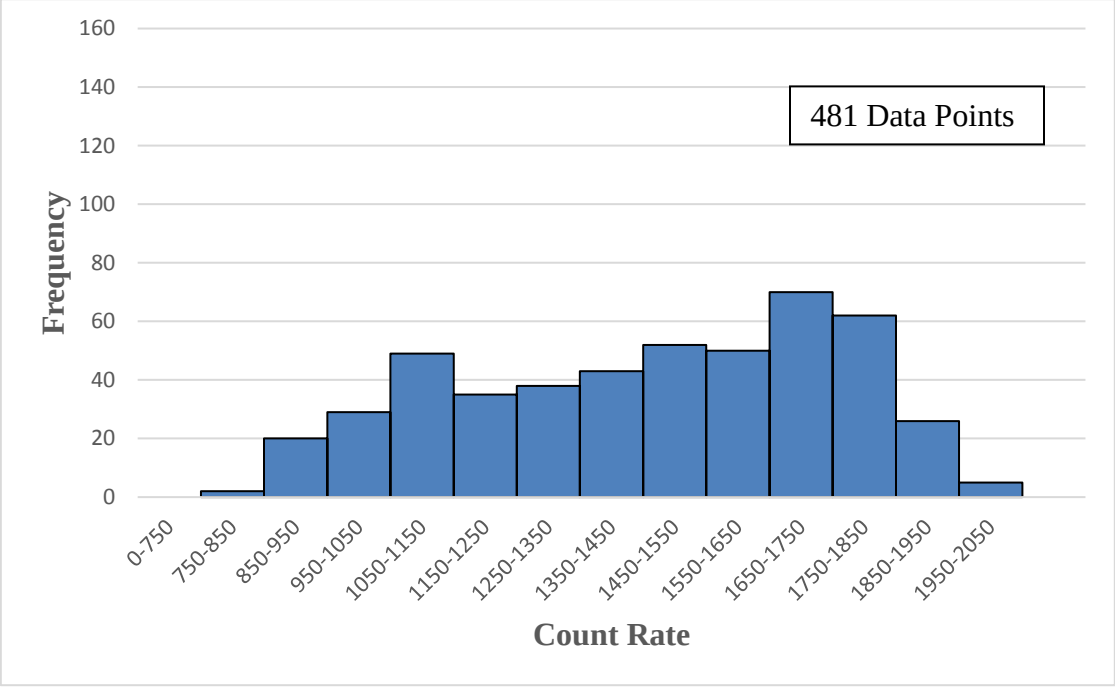

Figure 16. Histogram of total count rate recorded in Rubble Pile 1.

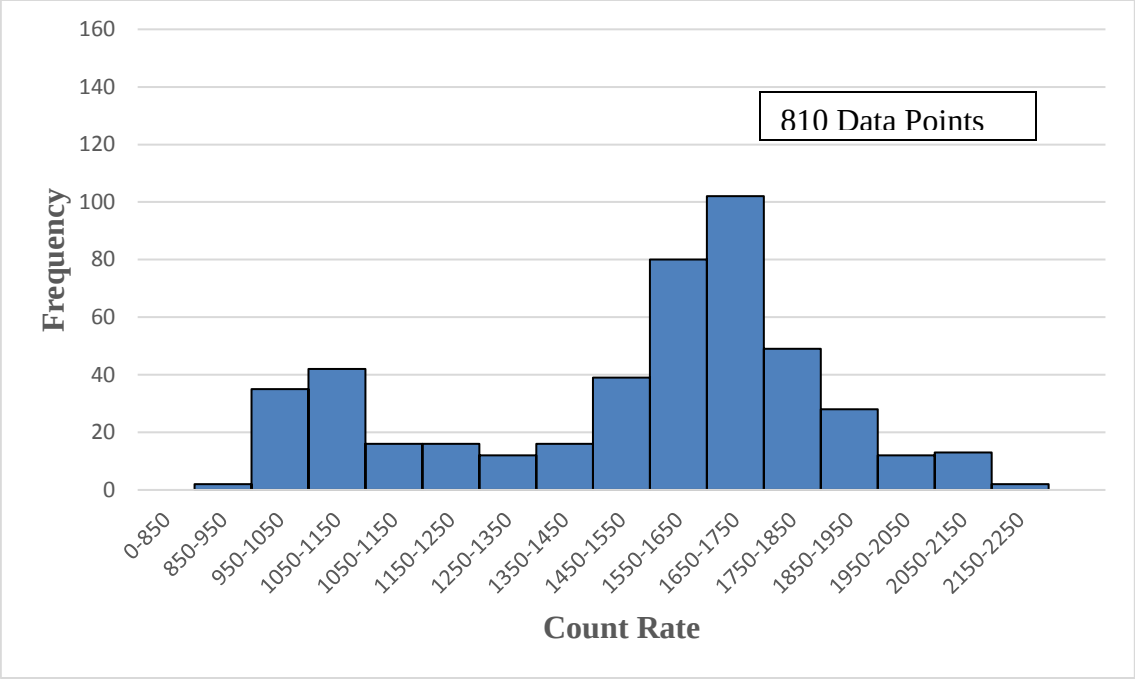

Figure 17. Histogram of total count rate recorded in Rubble Pile 2.

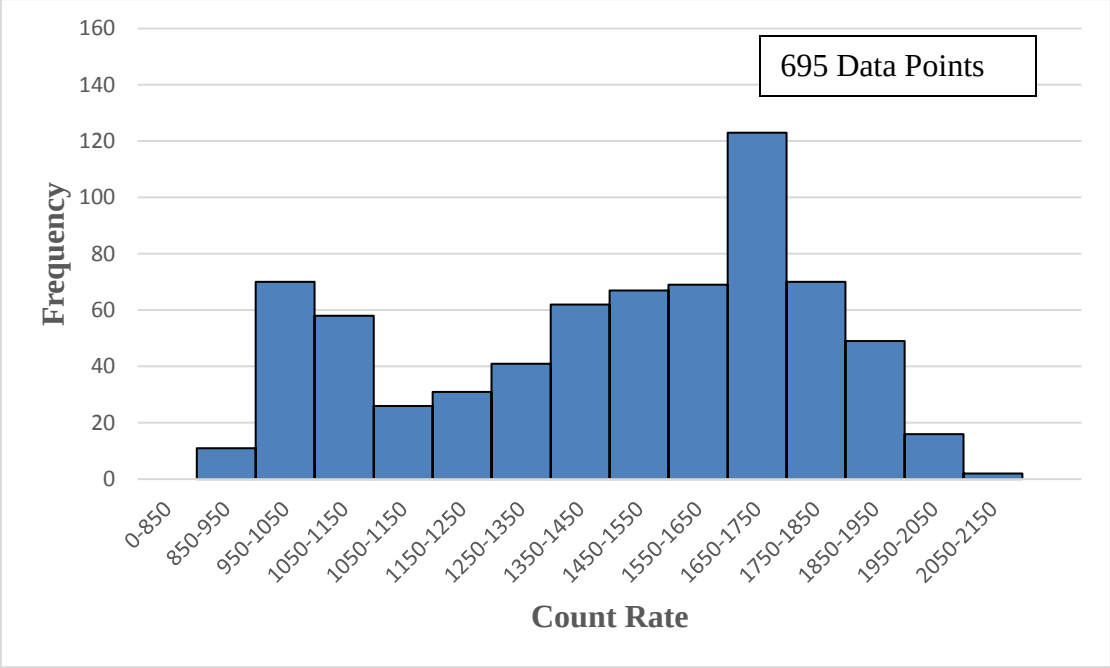

Figure 18. Histogram of total count rate recorded in TSTA area.

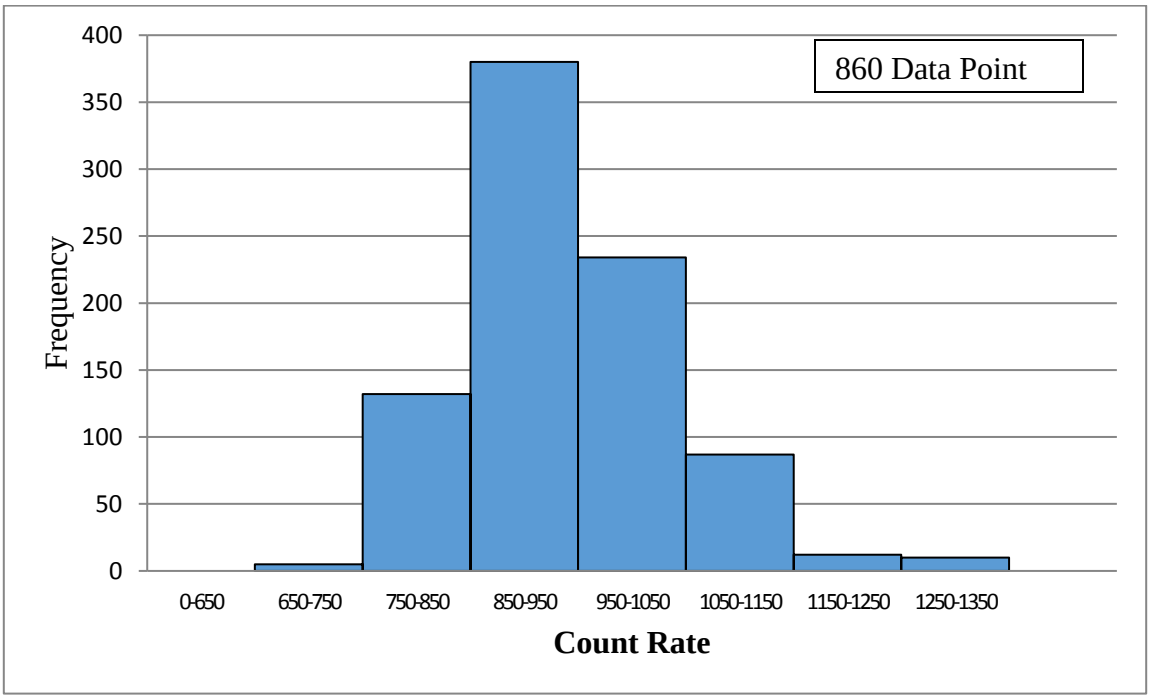

Figure 19. Histogram of total count rate recorded on the Roads.

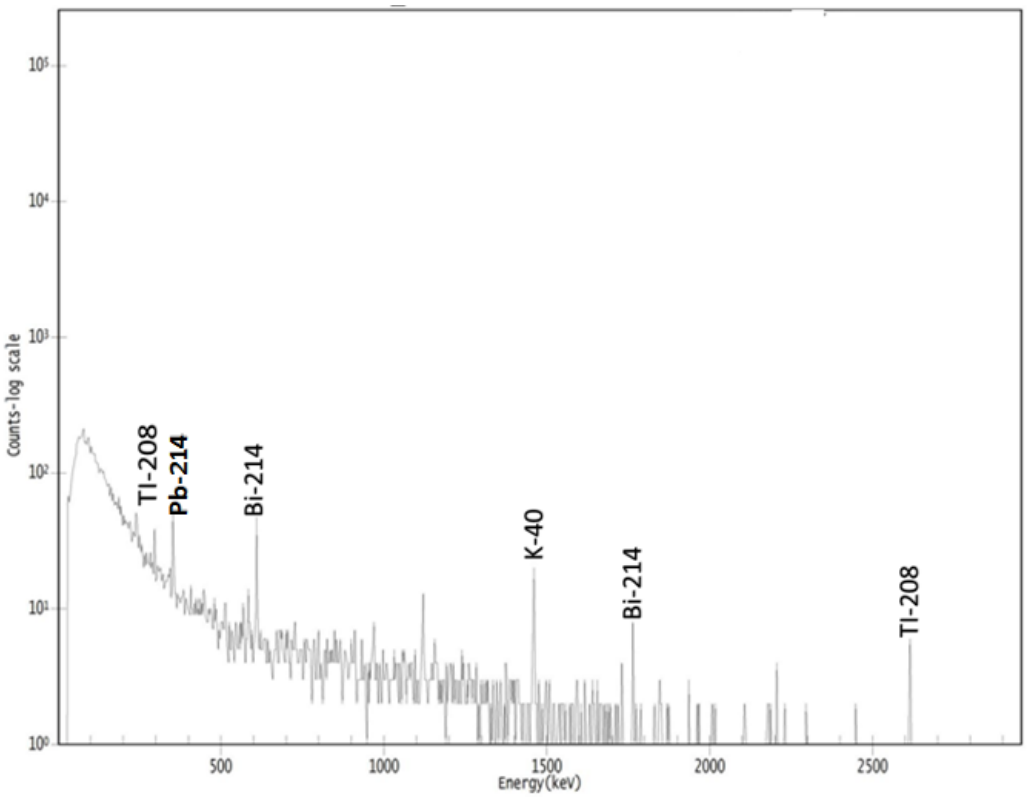

Figure 20. Typical gamma-ray spectrum for *in situ* measurements.

In addition, 10-sec selected spectra were summed for survey locations where "high" and "low" background count rates were observed. This was done to compare the spectra and to identify the reasons for elevated count rates in some areas such as Rubble Pile 2. Figure 21 and Figure 22 illustrate 10 seconds, each, of summed spectra from Rubble Pile 2 area (count rates between 1634 s^{-1} and 2321 s^{-1}) and the Parking Lot area (background) . The ten high count rate areas were all compared to the background areas and shows similar results. The spectra were over-laid for comparison as shown in Figure 23. Gamma analysis software GammaVision-6.0 was used.

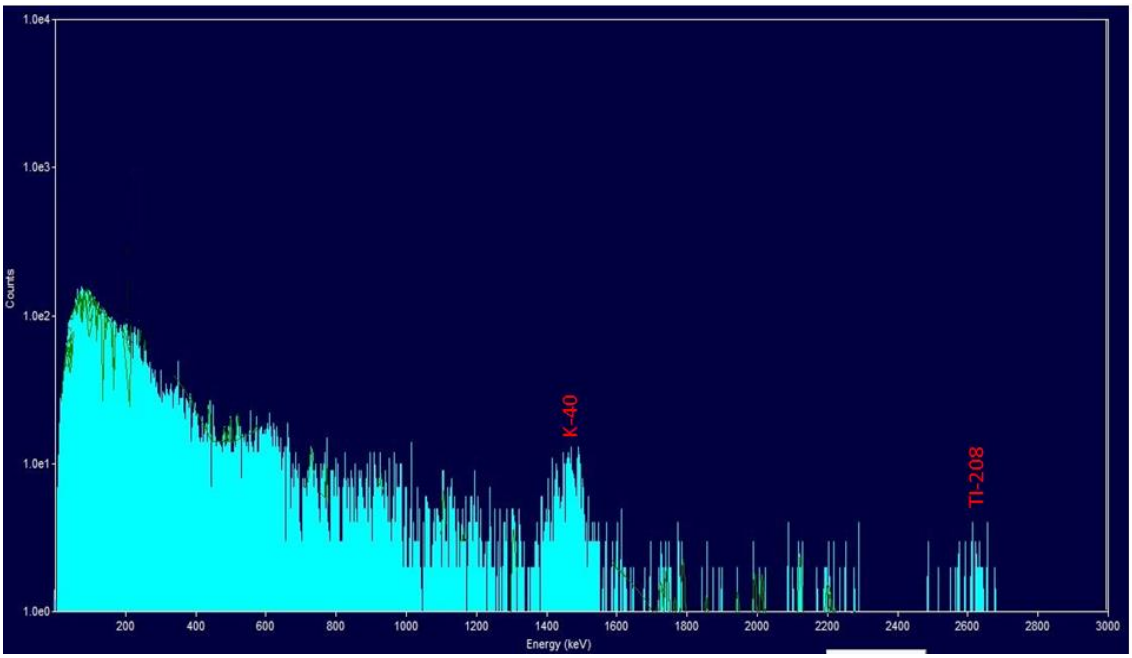

Figure 21. A 10-sec summed spectra of high background count rates in Rubble Pile 2.

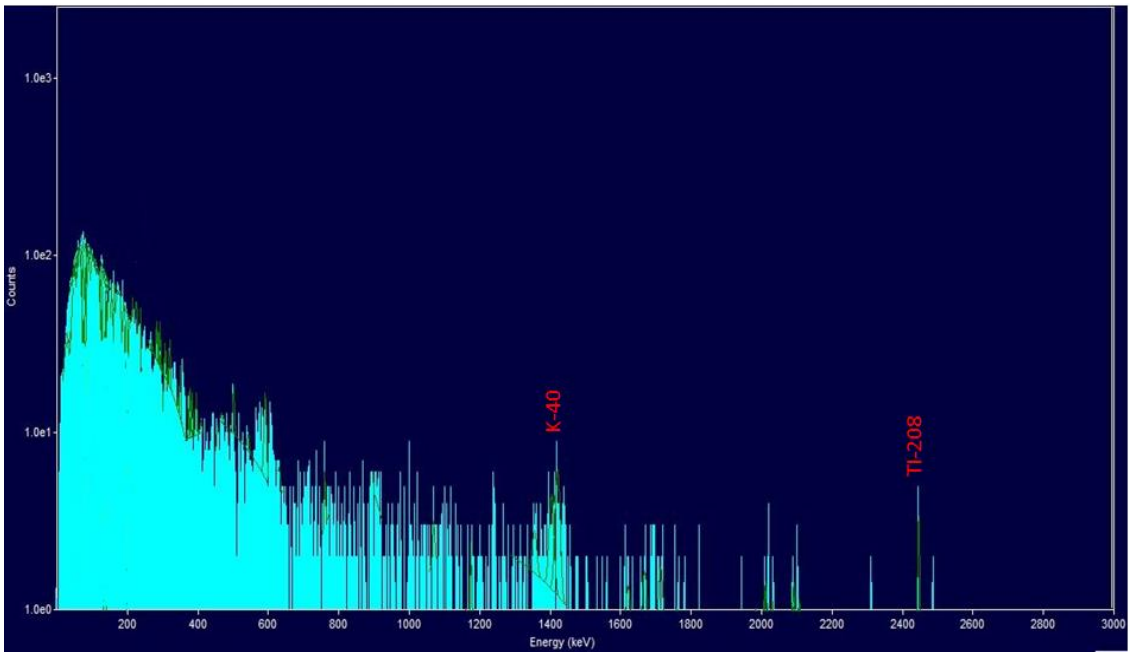

Figure 22. A 10-sec summed spectra of low background count rates in Parking Lot.

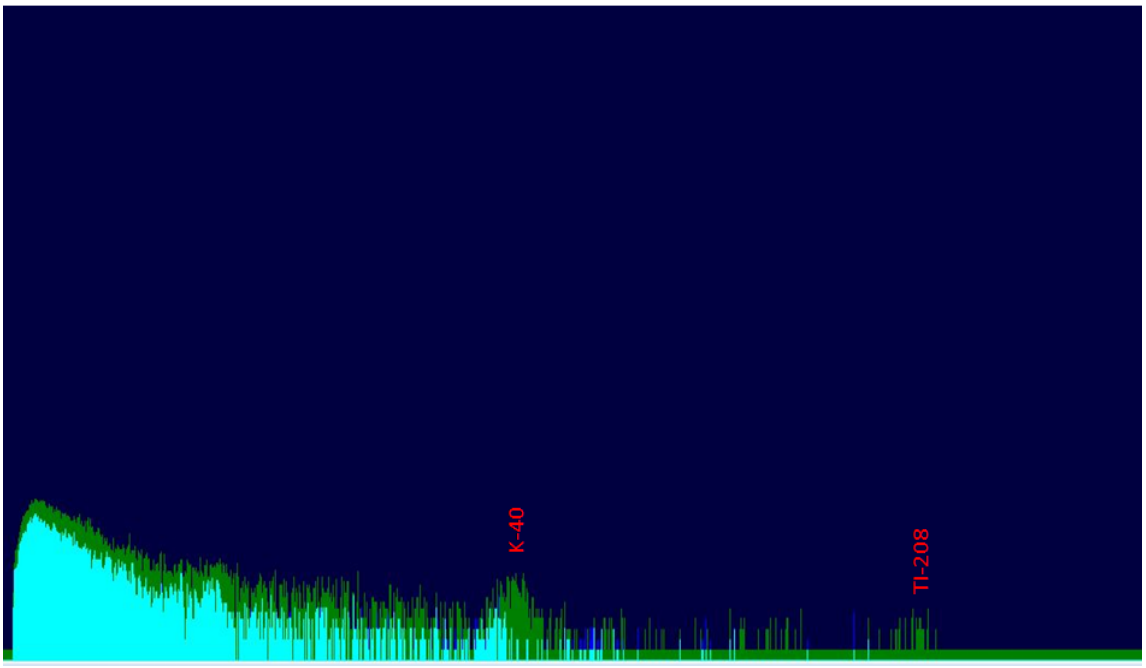

Figure 23. Comparison of spectra in Figure 19 and 20. The cyan color represents selected summed spectra from low background count rate area. The green represent selected spectra from high background count rate area.

From the second-by-second spectra comparison of areas surveyed, it was observed that the increase in count rate was due to elevated counts obtained from ^{40}K (1460.2 keV) and ^{232}Th (through the intensity of 2614 keV gamma-line). The Compton region (that is the lower energy end of the spectrum) was also observed to be higher than the lower background areas. This is due to the higher energy photons from ^{40}K and ^{232}Th Compton Scattering, which adds to the counts in this region.

7.2 Radioactivity in soil samples

The soil samples were collected based upon a review of data collected from the field survey. These areas showed the highest count rates during the walk-over survey. Samples were taken in the proximity of areas where the count rates were above 1634 s^{-1}. This count rate was chosen based on the survey results, 73.3% of the data points were below this count rate. In addition, samples were collected in areas that may be impacted by future contamination exercises. A set of 22 samples were analyzed via gamma spectroscopy. As anticipated, various radionuclides in the NORM group (^{238}U chain, ^{232}Th chain, and ^{40}K) were identified. During the spectra review, special attention was given to radionuclides whose photopeaks may not be easily resolved: ^{238}U (49.55 keV) and ^{226}Ra (186.2 keV). These radionuclides have low-gamma-energy lines and are a concern for regulation purposes during environmental analysis. The presence of uranium and radium was verified by identifying daughter photopeaks. In general, ^{214}Bi (609 keV), which is in secular equilibrium with ^{226}Ra can be used as a surrogate for determining the presence of ^{226}Ra. Likewise, ^{234m}Pa (1001 keV) can be used to determine the presence of ^{238}U. ^{232}Th can be identified with the daughter (^{208}TI) through the intensity of 2614 keV gamma-line. These assumptions were used because of the secular equilibrium status of the parent and daughter radionuclides. Spectra were collected for soil samples and all similar NORM photopeaks and their associated radionuclides were identified. A typical spectrum for soil samples collected in DC is shown in Figure 24.

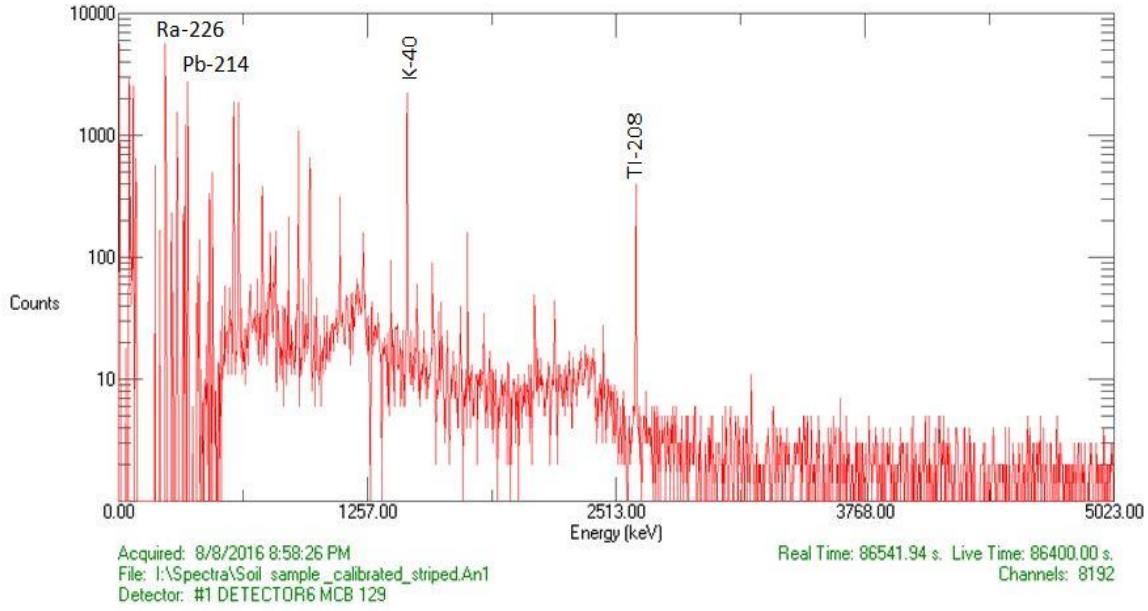

Figure 24. Typical background-subtracted gamma-ray spectrum for measurements of soil samples.

Based on the measured soil samples, specific radionuclides in the ^{238}U chain, ^{232}Th chain, and ^{40}K were identified in the spectra. The spectra showed a low level single photopeak of ^{137}Cs in the soil samples. The ^{137}Cs detected in the soil samples are not related to the operations at DC. This is not unexpected; long lived decay and activation products from nuclear weapon tests and/or nuclear facilities (mainly ^{137}Cs) add to the normal background radiation in the environment [21]. Today, approximately 30 years since latest deposition, low level of ^{137}Cs can still be measured in soils in the environment [22]. Soil samples from different regions of DC showed similar photopeak structures. The spectra of soil samples and reports were saved to provide a baseline. In the future, any changes or contaminant in soil samples other than NORM can be easily identified.

7.3 Radioactivity in water samples

Aliquot water samples were put into a standard geometry (0.5-L Marinelli beaker) for gamma-ray counting. The pH values of the water samples were measured on-site. The pH of the groundwater varied from 7.1 to 7.8. To record spectra of water samples, a HPGe detector was used. All gamma spectra were analyzed and stored in the appropriate software-compatible device for future reference. A typical background subtracted spectrum collected from the Lake Esti and the Pond is shown in Figure 25.

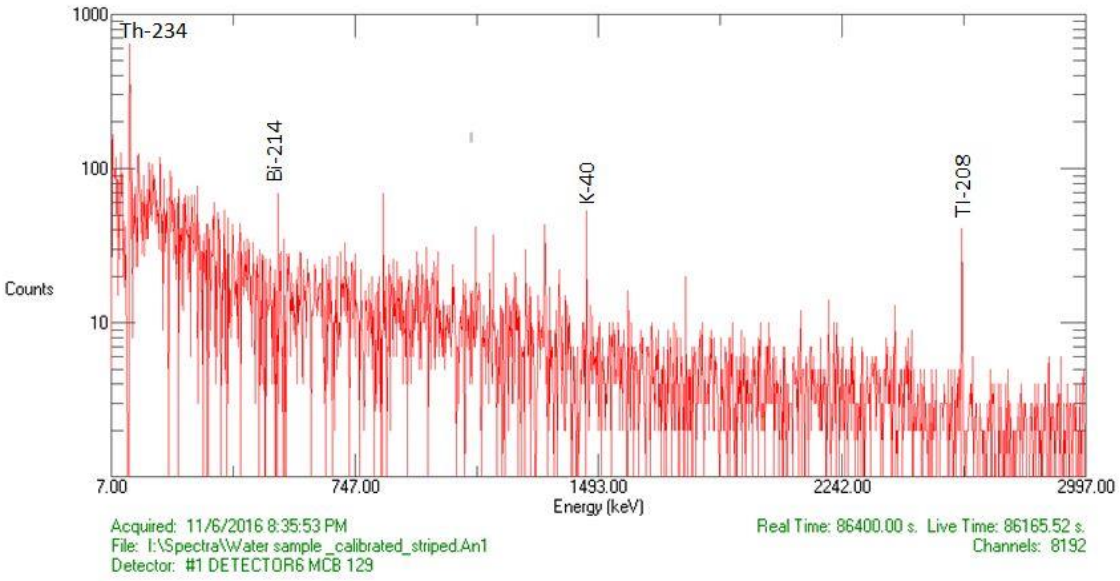

Figure 25. Typical background-subtracted gamma-rays spectrum for measurements of water samples.

As expected, radionuclides in the NORM group (^{238}U chain, ^{232}Th chain, and ^{40}K) were identified and measured. The photopeaks were identified directly with their gamma-rays energies and via their daughter radionuclides. ^{40}K was identified by using its own gamma-ray photopeak at 1460.2 keV. Recorded counts in the HPGe water spectra were two times lower than those observed in soil samples. The background counts in the water mainly came from natural sources through the sediments. The higher counts in soil samples originate mainly from the uranium and thorium decay series and radioactive potassium. Dose rate measurements were in the range between 3-8-µR h^{-1}. In the future, any changes or contaminants in water samples other than NORM can be easily identified via gamma spectroscopy.

7.3.1 Liquid Scintillation counting analysis

The LSC results from Lake Esti water samples are shown in Table 4. The first column represents the water sample identification number. Due to the wide energy range in region C, the results in that column presented the total gross counts in the samples. The results showed an average background count rate of approximately 20 cpm. The results obtained were approximately equal to or less than the controlled background sample count rate.

Table 4. Results for total radioactivity in Lake Esti water samples (See Figure 10).

Lake Esti - 60-minutes Count					Surveyed by	IYT
16-Nov-2016					Survey Date	11/4/2016
PerkinElmer	Tri-Carb 3110 TR	User #	31		Input by	IYT
Average Background	19.8	Efficiency	33%		Input Date	11/8/2016
Minimum Detectable Activity (MDA) in DPM			65.7		Date Counted	11/7/2016
Minimum Detectable Activity (MDA) in CPM			21.67		Samples	7+3

Sample #	CPM A	CPM B	CPM C	
LE1	8.33± 2.9	13.67±3.6	20.00±4.5	**Sample Gross Counts**
LE2	8.33±2.9	13.67±3.6	19.67±4.4	
LE3	8.33±2.9	13.67±3.6	20.00±4.5	
LE4	8.67±4.0	14.00±3.7	19.67±4.4	
LE5	8.33±2.9	13.67±3.6	20.00±4.5	
LE6	8.33±2.9	13.67±3.6	19.67±4.4	
LE7	8.33±2.9	13.67±3.6	20.00±4.5	
BKG 1	8.67±4.0	14.00±3.7	19.67±4.4	**Background**
BKG 2	8.33±2.9	13.67±3.6	20.00±4.5	
BKG 3	8.33±2.9	13.67±3.6	19.67±4.4	

The results obtained from the Pond are shown in Table 5. It was observed that the count rates obtained with triple-distilled water compared with the collected samples did not differ significantly. Both Lake Esti and the Pond showed results approximately equal to the background measurements. The results indicate no detectable radioactivity in the water samples.

Table 5. Results for total radioactivity in pond water samples

Pond - 60-minutes Count					Surveyed by	IYT
16-Nov-2016					Survey Date	11/4/2016
PerkinElmer	Tri-Carb 3110 TR	User #	31		Input by	IYT
Average Background	19.8	Efficiency	33%		Input Date	11/8/2016
Minimum Detectable Activity (MDA) in DPM			65.7		Date Counted	11/7/2016
Minimum Detectable Activity (MDA) in CPM			21.67		Samples	3+3

Sample #	CPM A	CPM B	CPM C	
P1	8.33±2.9	14.00±3.7	19.67±4.4	**Sample Gross Count**
P2	8.00±2.8	13.67±3.6	19.67±4.4	
P3	8.33±2.9	14.00±3.7	19.67±4.4	
BKG 1	8.00±2.8	13.67±3.6	20.00±4.5	**Background**
BKG 2	8.33±2.9	14.00±3.7	19.67±4.4	
BKG 3	8.00±2.8	13.67±3.6	19.67±4.4	

8. SUMMARY AND CONCLUSION

To expand the training capabilities at the Disaster City complex, NSSPI researchers are investigating the use of loose contamination in and around the facility structures. However, prior to using loose contamination, it is important to know the existing radiation environment. This research conducted a baseline survey for the purpose of determining the natural radiation levels currently present within Disaster City. A ground-based radiation survey was conducted a using 4"x4"x16" thallium-doped sodium iodide (NaI(Tl)) gamma radiation search mobile detector system. Other environmental media such as water, soil and *in situ* measurements were analyzed by using a HPGe detector. Also, water samples were counted by a liquid scintillation counter.

The results from the walk-over survey with the 4"x4"x16" thallium-doped sodium iodide (NaI(Tl)) recorded the highest average count rate of 1625±63.2 s^{-1} at the Rubble Pile 2 location. A comparison between the water and soil samples showed spectra typical of NORM in the environment. Also, similar spectral signatures are found in the *in situ* measurements on the rubble piles. In addition, the LSC analysis of water samples indicated no detectable radioactivity is present in Lake Esti and the pond.

In conclusion, this research was able to provide a baseline measurement of background radiation throughout DC. Spectra of soil and water samples were collected and saved for future reference. With reference to these baseline results, any future changes in the environment radiation levels, mainly those arising from radiological training activities at the Disaster City, can be ascertained. However, considering that

environmental conditions may change over a period of time, DC should be monitored periodically. Particularly, at the start of the contamination exercise, possible impacted areas should be re-surveyed. Soil and water samples should be re-collected for gamma-ray spectroscopy analysis. This will provide more current results that will be used to compare with the study already done by this thesis.

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APPENDIX A

HPGE DETECTOR SPECIFICATION SHEET

QUALITY ASSURANCE DATA SHEET

GEM Series HPGe (High-Purity Germanium) Coaxial Detector System

Model and Serial Numbers

Detector Model No.	GEM55P4-83-SMP		
Cryostat Configuration	CFG-X-COOL-III-115	Ship Date	8-May-15
Dewar Model	No Dewar	Serial No.	54-TP42654A
Preamplifier Model	A257P	When calling Customer Service, always	
Preamplifier Serial No.	15306346	reference the Detector Serial No.	
H. V. Filter Model	138EMI	Sales Order No.	50005551
H. V. Filter Serial No.	13346957		
SMART-1-P Serial No.	13331311		

Cryogenic Information

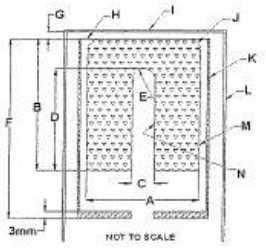
Dewar Capacity	0	Static Holding Time	
Detector Cool-Down Time			

High Voltage Bias

Recommended Operating Bias: POSITIVE 3000 Volts

Performance Specifications*

	Warranted	Measured	DSP Rise Time
Resolution (FWHM) at 1.33 MeV, ^{60}Co	1.90 keV	1.79 keV	12 µs
Peak-to-Compton Ratio, ^{60}Co	67:1	79:1	12 µs
Relative Efficiency at 1.33 MeV, ^{60}Co	55 %	55.5 %	12 µs
Peak Shape (FWTM/FWHM), ^{60}Co	1.9	1.9	12 µs
*Peak Shape (FWFM/FWHM), ^{60}Co	2.8	2.5	12 µs
* FWFM/FWHM is typical not warranted			
Resolution (FWHM) at 122 KeV, ^{57}Co	1100 eV	816 eV	12 µs



E: NOMINAL 5-mm RADIUS

F: 105-mm CUP LENGTH

G: 4-mm SPACE

H: 0.03-mm/0.03-mm Al/Mylar

I: 1-mm Al

J: NOMINAL 8-mm RADIUS

K: 0.8-mm Al

L: 1-mm Al

M: 0.7-mm Ge/Li DEAD LAYER

N: 0.3-micron Ge/B DEAD LAYER

A= 65.7 mm — Crystal Diameter

E= 74 mm — Crystal Length

C= 11 mm — Hole Diameter

D= 62 mm — Hole Depth

OTHER Caspsule: NOCA # 11095
Cryo: X-COOL-III-115 # 131104ER

Data Certified By: DJ Wilson DATE 12-7-15

Form no. 0308BK vers. 1

APPENDIX B

WEATHER CONDITIONS DURING THE WALK-OVER SURVEYS

Date of Site Visit	Wind	Humidity	Temp. (ºF)	Pressure	Visibility	UV Index	Precipitation (mm)
	W 6mph	73%	91	30.00 inHg	10.2 mi	1	0
6/07/2016							
	S 8mph	82%	76	29.00 inHg	10.0 mi	1	0
6/11/2016							
	SW 7mph	77%	82	30.10 inHg	10.0 mi	1	0
7/22/2016							